VEGETATION DYNAMICS AND SOIL CHARACTERISTICS OF ABANDONED CULTIVATED FIELDS

by

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Tjaart Myburgh

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January 2013

DEDICATED TO MY PARENTS

To my parents, Gert Jacobus en Anna Martha Myburgh, for all the love, guidance and opportunities you gave me in life. Thank you for the interest, encouragement and support throughout my life. I love you.

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Abstract

Up to the 1980's marginal soils were successfully ploughed for crop production, but unfortunately those soils soon proved to be marginal. Due to high input costs, the Department of Agriculture soon implemented the "soil conversion scheme" to promote the conversion of those ploughed marginal soils to permanent pastures. It was especially the low maize prices that triggered the conversion scheme in the 1980's. Regardless the implementation of the soil conversion scheme, many farmers unfortunately just abandoned some of these marginal fields which resulted in many hectares of unproductive previously cultivated fields, being referred to as abandoned fields. The aim of this study was to investigate a few abandoned fields at a single location in the semi-arid central Free State in an attempt to gather information on the dynamics of such disturbed ecosystems and identify their restoration potential.

The study investigated the interaction between plant and soil variables to quantify the impact of different soil physical and chemical characteristics on vegetation dynamics (species composition and density). The species richness, as well as the influence of different soil characteristics were determined to identify which might have the biggest influence on the recovery potential of the disturbed area. The soil seed bank was also investigated to quantify the survival potential of climax grass species on abandoned fields, and why these species do not establish voluntarily on these disturbed areas. The main aim of the study was to quantify the influence of soil characteristics on the vegetation dynamics of abandoned fields.

The results clearly showed that marginal soils, withdrawn from cash-crop cultivation, are among the most seriously degraded areas with low soil fertility (N and C content). It is creating a more favourable habitat for pioneer grass species. This study sheds more light on the poor natural rehabilitation rate of abandoned fields in the semi-arid Free State Province of South Africa. It was proven that the establishment of climax vegetation might be largely influenced by phosphorus (P), cation exchange capacity (CEC), nitrogen (N), carbon (C), soil compaction and the composition of the soil seed bank.

It was note worthy that some of the abandoned fields still showed very slow progress in natural restoration after 20 years. The areas that showed least recovery needed to be cultivated and established with a cultivated pasture like *Digitaria eriantha* sub*. eriantha.* On the other hand, other areas recovered to such an extent that oversowing or the placement of *Themeda triandra* sheafs might improve restoration. The best recovered areas can only be upgraded in productivity by scientific management strategies which include long resting periods.

Drastic human interference is an absolute necessity to speed up the process of plant succession (rehabilitation). Future investigation might include long-term trials to monitor the reaction of vegetation and soil characteristics to the introduction of organic matter as well as the seed of climax grass species.

Opsomming

Marginale gronde was tot en met die 1980's ekonomies suksesvol omgeploeg vir kontantgewasproduksie, maar was kort voor lank as onekonomies (marginaal) beskou. Hoë insetkostes het veroorsaak dat die Departement van Landbou 'n grondomskakelingskema geïmplementeer het om die omgeploegde marginale gronde weer terug te skakel na natuurlike weiding. Dit was veral die lae mieliepryse wat die omskakeling teweeg gebring het. Ongeag die implementering van die grondomskakelingskema het sekere boere steeds geen restourasie aksies op van die marginale gronde toegepas nie. Die gevolg hiervan was dat baie hektare voorheen bewerkte lande onproduktief agtergelaat is sonder om aangeplante weidings daarop te vestig. Hierdie studie het ten doel gehad om hierdie onproduktiewe oulande, wat geleë is in die sentrale Vrystaat, te bestudeer ten einde die dinamika van versteurde ekosisteme te verstaan en dan die restorasie potensiaal daarvan te identifiseer.

'n Studie oor die interaksies tussen plant en grond veranderlikes is onderneem om sodoende die impak van die grond se fisiese en chemiese karaktereienskappe te kwantifiseer. Die plantegroei dinamika, naamlik spesie samestelling en digtheid is ook gekwantifiseer. Die spesie samestelling, asook die invloed van grondeienskappe is bepaal om sodoende die komponente te identifiseer wat die grootste invloed op die herstelpotensiaal van die versteurde area sou hê. Die saadbank is ook bestudeer om sodoende te bepaal of daar wel klimaksgrassade teenwoordig is in die oulande, asook waarom die oulande nie natuurlik herstel nie. Die hoofdoel met die studie was om die invloed van grondeienskappe op die plantegroei dinamika van die oulande te kwantifiseer.

Die resultate wys duidelik dat marginale gronde, wat onttrek is van kontantgewasverbouing, ernstige gedegradeerde areas is, met 'n lae grond vrugbaarheid (C en N inhoud). Dit skep 'n meer gunstige habitat vir pionier grasspesies. Die studie het ook meer lig gewerp op die swak natuurlike restourasie tempo van oulande in die semi-ariede Vrystaat Provinsie van Suid Afrika. Dit is bewys dat die vestiging van klimaksgrasse grootliks beïnvloed word deur fosfor (P), katioon uitruilbare kapasiteit (KUK), stikstof (N), koolstof (C), grond kompaksie en die samestelling van die grondsaadbank.

Dit was merkwaardig dat die oulande stadige vordering getoon het na 'n tydperk van 20 jaar van bewerkingsonttrekking. Daar word aanbeveel dat die swakste herstelde areas gerestoureer word met die vestiging van 'n aangeplante weiding soos *Digitaria eriantha* sub. *eriantha.* Aan die anderkant kan areas wat reeds gevorderde herstel toon met *Themeda triandra* gerwe wat daarop gepak word aangevul word om restourasie te versnel. Die beste

reeds herstelde areas kan met ‘n wetenskaplik gefundeerde veldbestuurspraktyk opgradeer word wat lang rus periodes insluit.

‘n Drastiese ingryping deur die mens is van kardinale belang om die proses van plant suksessie te versnel. Toekomstige ondersoeke moet langtermyn proewe insluit ten einde die plantegroei en die grondeienskappe se reaksies op die aanvulling van organiese materiaal en saad van klimaksgrasspesies te ondersoek.

Chapter 1

Introduction

The fact that 80% of the agricultural land allows only animal farming implies that livestock production is primarily natural resource dependent (Fynn 2012; Snyman 2012). The only way that the vegetation resource base can be used for food production is through herbivores (Snyman 2012). Therefore, good understanding of the dynamics and interaction between rangeland, pastures, climate and livestock is essential for sustainable livestock farming. Livestock production, be it from an ideal rangeland condition (healthy) or a poor condition (degraded) has the same common basis, net fodder production. The better the condition of the rangeland, the higher and more sustainable livestock production will be (Snyman 1998). However, it is well documented that the productivity of all rangelands unfortunately has been compromised by serious erosion (40-50% of potential) due to *inter alia* desertification, overgrazing, bush encroachment and the loss of palatable plant species (Van der Westhuizen *et al.* 1999). Should this deterioration be allowed to continue, sustainable livestock production will be jeopardized.

The underlying cause of the present low turnover, inefficiency and vulnerability of the livestock sector is primarily inadequate feeding, both quantitatively and qualitatively. Therefore, any significant technological development and professional research that will improve plant production of the natural vegetation or planted pastures will have a positive impact on present and future livestock production and food security.

In the 1970's the total number of livestock in South Africa were 7.9 million animals. These numbers increased to 12.4 million in 1987, which required more intensive rangeland production systems than previously accepted (DAFF 2012). Rangeland condition and availability may therefore influence livestock production (Snyman 1998). Less than 15% of the surface area of South Africa is suitable for crop production with the other 80% mainly utilized for extensive livestock production (Van Niekerk 1989). In 1970 the total area under cultivation in South Africa was 4.8 million hectares and declined to 2.9 million hectares in 2011 (DAFF 2012). Up to the 1980's marginal soils were ploughed for crop production, but unfortunately these soils soon proved to be uneconomical (Snyman 2012). Due to high input costs, the Department of Agriculture soon implemented the "soil conversion scheme" to promote the conversion of these ploughed marginal soils to permanent pastures (DAWA 1987). It was especially the low maize prices that triggered the conversion scheme in the 1980's. Regardless of the implementation of the soil conversion scheme, many farmers unfortunately just abandoned some of these marginal fields. This led to many hectares of unproductive previously cultivated fields, also referred to as abandoned fields (DAWA 1987).

Over time, it was noticed that these abandoned fields were naturally revegetated by mostly pioneer grass species and could remain unproductive for up to 40 (or more) years (Milton 1994). In semi-arid areas, like the central parts of the Free State Province, abandoned fields recover slowly and are unlikely to return to pre-disturbance conditions (Snyman 2012). There are many examples where the species richness, composition and profusion of cultivated rangelands remained for many years subsidiary in comparison to uncultivated rangeland (Scott & Morgan. 2012). The conclusion of most researchers was that abandoned fields in arid and semi-arid regions were very sensitive to recovery and might never return to pre-disturbance conditions (Snyman 2012). Therefore, it was decided to investigate a few such fields at a single location in the central Free State to try and gain some knowledge on the dynamics of such disturbed ecosystems.

This previously disturbed rangeland can affect the sustainability of intensive food production for a growing population and can contribute on a small scale to the alleviation of a major, worldwide problem. Human population increases exponentially, and with better knowledge of the environment and its limitations we might ensure a more sustainable resource. Furthermore there is a clear correlation between the development level of civilization and the population size (Dolgonosov & Naidenov 2006). In South Africa the human population grew from 19.211 million in 1970 to 50.587 million in 2011 (DAFF 2012). The human impact on the environment in most cases led to a total loss of grazing capacity due to overgrazing (Briske et al. 2008b).

Abandoned fields, in many instances have deteriorated to the point that desirable species are either not present, or recovery is slow or will not occur without revegetation (Masters & Sheley 2001). Different methods of tillage on rangelands result in different percentages of organic matter loss and therefore a decrease in soil quality (Brady 1973). Poor soil quality can only be restored by changing the micro climate of the specific area, and these improvements might take years (Brady 1973). Degradation of soil quality may also result in a micro climate change (Snyman & Du Preez 2005). If soil formation is changed (parent material, climate, biota, topography and time), the system can take years to recover or rehabilitate to its original form (Brady & Weil 2008). Textural classes of soil do not change over time. In contrast, erosion, tillage, irrigation and factors like wind can remove the top layer and bring the more clayey parts to the surface. The horizons within the deeper soil can be exposed resulting in a different plant life (Brady & Weil 2008).

With soil disturbance, the soil-water capacity can change and may have an influence on plant regrowth (Snyman 1998; Russel et al. 2001; Palmer & Yunusa 2011). Herbage production and water-use efficiency decrease with plant deterioration when soil conditions decline. When soil is exposed, water infiltration, runoff, surface compaction and germination may change (Snyman & Du Preez 2005). Plant cover plays an important role in protecting the soil and reducing evaporation from bare uncultivated soil surfaces, which can be 69% in some cases, giving a clear indication of water loss (Snyman 2000a). Rangeland degradation plays a major negative role in the establishment of a micro-climate (Snyman 2000b). Soil micro-organism activity also takes part in changing the structure of soil and opens the pores for water to infiltrate, and also binds nitrate for plant uptake (Du Preez & Snyman 1993).

This study investigated the interaction between plant and soil variables, to quantify the impact of different soils' physical and chemical characteristics on vegetation dynamics (species composition and density). The species richness, as well as the influence of different soil characteristics, were determined to identify which might have the biggest influence on the recovery potential of the disturbed area. The soil seed bank was also investigated to identify the potential of climax grass species on abandoned fields, and why these species do not establish voluntarily on these disturbed areas. The main aim of the study was to quantify the influence of soil characteristics on the vegetation dynamics of abandoned fields. The most important environmental factors influencing vegetation recovery were therefore quantified, as well as the potential of rangeland recovery in semi-arid areas. The following detailed research questions were investigated:

- How do the vegetation dynamics of abandoned fields differ from that of undisturbed natural rangeland?
- How do the soil dynamics of abandoned fields differ from that of undisturbed natural rangeland?
- Do the soil chemical and physical characteristics of abandoned fields have an influence on plant species composition? and
- Are there any climax grass species available in the soil seedbank for rangeland restoration?

Chapter 2

Literature review

South Africa is very poorly endowed with high potential agricultural land, and most of these soils have already been ploughed. Due to the high input costs of cash crop cultivation, it is essential that marginal land is converted to pastures (Snyman 2013). The nineteen eighties decade were characterised by deep-rooted structural problems, which lead to tension in the agricultural industry, not only in South Africa but in various other countries (Dickinson *et al.* 2004). Locally, problems with farming debt, cash flow and low profitability were amongst the symptoms of a struggling agricultural industry (Snyman 2013). It was thus necessary for a change in the agricultural sector. “While change has come up to a point, further changes can be expected during the next decade” (Dickinson *et al.* 2004). The status quo was upset by the changes, uncertainty and tension, but on the other hand, the situation offered opportunities for development and progress to the whole industry and also individuals (Dickinson *et al.* 2004).

“As a consequence of South Africa’s inability to compete profitably on the world grain market, a limited internal demand for maize and the change to a market oriented pricing policy, it was estimated that about one million hectares of maize had to be substituted by other cash crops. Furthermore incentives have been made available in the form of the Land Conversion Scheme (1987) so that more perennial cultivated pastures should be established for the eventual inclusion of the stock factor” (Dickinson *et al.* 2004).

For both field enhancement and field usage, knowledge of the relocation of new fodder plants is needed. Except for the group of fodder plants which spread through above- or underground stolons, most field grasses depend on seeds for their survival, distribution and expansion (Snyman 2013). Knowledge of the whole dynamics of field restoration is essential for sustainable animal production.

2.1 Soil conversion scheme

In the 1980’s maize prices were below the export realizations and thus not profitable on marginal soils. These high maize prices in South Africa made it possible for farmers to expand their farming practices to low and also unreliable rainfall areas. Although marginal soils in some areas of South Africa were not suitable for cultivation, large areas were still ploughed for cash crop production. South Africa was in the situation where maize surpluses were exported at a loss, which caused great financial problems for farmers. With this as background, many areas were therefore a risk for the economical sustainability of the environment (DAWA 1987).

The only solution for the above mentioned problem was to convert marginal cultivated soils, which were not profitable for cash crops, to permanent pastures. Utilization of more cultivated pastures will take financial pressure off the cash crop farmer and the government. The practical implication could be less maize to sell at a loss (DAWA 1987).

Cultivated pastures first became known after the Second World War. The value of cultivated pastures as a source of fodder for the livestock industry began to play a larger role from 1933 (Dannhauser 1991). The interest developed as farmers became aware of management and the additional role of cultivated pasture. In the past, field in good condition was ploughed that should never have been. As mentioned, these marginal lands were often not economically suitable for crop production and luckily it was later realized to be less risky under planted pastures. The aim of the Soil Conversion Scheme of 1987 was to help farmers convert this marginal land into cultivated perennial pasture crops. During the past years it became clear that cultivated pastures are not always economical. Therefore, the planning of the establishment of pastures on lower potential soil is a great need throughout South Africa (Dannhauser 1991).

2.2 Vegetation dynamics

2.2.1 Rangeland sustainability

Climax grasses are sensitive when the environment is wrongly influenced by human activity which can lead to permanent loss of grazing potential. The loss of *Themeda triandra* for example, through poor management is often the first indication that grassland degradation is occurring (Snyman *et al.* 2013). According to Ndawula-Senzimba (1972), *T. triandra* was eliminated after only one year of cutting and grazing of every two weeks. With cutting every eight weeks 30% more yield was collected, when compared to a four week cutting period. Dominant - and indicator species can be used to determine rangeland condition, and these quantitative aspects control grazing capacity (Van der Westhuizen *et al.* 1999).

In Kenya there were clear indications of an increase in some vegetation species, while others decreased with long-term impact of ploughing on rangeland. Species like *Pennisetum mezianum* increased significantly while *Sporobolus ioclados* decreased (Berliner & Kioko 1999). Uneven use of herbaceous forage plants by livestock may result in an unbalanced ecosystem contributing to unfavourable impacts on soil nutrients, vegetation structure, production and composition (Snyman 1998), resulting in an unsustainable ecosystem (Nsinamwa *et al.* 2005). Trampling can also contribute to degradation of vegetation and soil (Beukes & Ellis 2003). It was concluded that soil from degraded areas had been altered almost permanently and resting alone might not achieve the desired vegetation recovery. Basal cover had the greatest influence on runoff from rangeland, while a slope (3%) had no significant influence (Snyman *et al.* 1985). According to Snyman *et al.* (1980) runoff was 171% higher from pioneer than climax rangeland.

Re-establishment of species on bare soils after abandonment was quantified by Du Plessis & Van Wyk (1969), who found over-sowing of bare areas, which included soil disturbances and covering with tree branches, the most efficacious. Plots without sowing practises contributed to 70% less germination of seed in the soil seed bank (Du Plessis & Van Wyk 1969). Sowing of *Eragrostis curvula* in combination with a tillage practice may be used to cover bare patches where rangeland has been damaged (Van Rensburg 1971). Agriculturally improved rangelands, which dominate modern intensive agricultural landscapes, are usually poor in natural vegetation due to the original diversity of plants having been destroyed by cultivation (O'Connor & Bredenkamp 1997). According to O'Connor & Bredenkamp (1997), *T. triandra* and *E. lehmanniana* decreased, whereas *A. congesta* and *T. koelerioides* increased with more intensive grazing during the summer in semi-arid regions.

Ejrnaes *et al.* (2008) addressed the question of how long it would take to re-establish a productive rangeland after degradation. The most limiting factor was a lack of appropriate seeds to establish a species rich rangeland. It was found that fertilization contributed largely to vegetation dynamics, and thus by contributing to vigorous growth (Ejrnaes *et al.* 2008). According to Ruprecht (2006), abandoned fields might take a few decades to develop into semi-natural rangeland. Ejrnaes *et al.* (2008) also concluded that secondary succession in intensively farmed landscapes, which are isolated from semi-natural vegetation, may take a different course of development and never fully convert to natural grassland. There is a contrast between the relative contributions of perennial species to vegetation composition compared to that of pioneer species (Van Rooyen *et al.* 2010). For a period following cultivation, perennial species increase with time, while annual species decline with time (Van Rooyen *et al.* 2010).

2.2.2 Fertilization

The impact of different soil chemical elements on plant life was investigated by numerous researchers (Janse van Rensburg *et al.* 1990; Snyman 2002). The species density which increased with fertilization were *Cynodon dactylon, Eragrostis paspaloides, Panicum* *coloratum* and *Digitaria eriantha,* while *Eragrostis muticus, Themeda triandra, Cymbopogon pospischilii* and *Heteropogon contortus* decreased. Fertilization results in a lowered ecological status of the ecosystem, but an increase in the production and palatability of the grassland. Most researchers also found a decrease in basal cover with fertilization of grassland (Janse van Rensburg *et al.* 1990; Snyman 2002).

After applying N and P to rangeland, there was a decrease in soil pH, Ca, Mg and K over the long-term (Donaldson *et al.* 1984). These higher levels of N and P also increased the compaction of the soil surface layer (Snyman 2002). A combination of N and P had a much higher contribution to rangeland productivity (Snyman 2002). In semi-arid grassland *Themeda triandra* was intolerant of high concentrations of N (Fynn & Naiken 2009). According to Du Pisani *et al.* (1986b), *Panicum maximum* produced best in a neutral to slightly alkaline soil medium while fertilization increased the organic matter digestibility and dry matter production of the plant. *Themeda triandra* produced nearly double the biomass of taller grass species in low-nutrient treatments, with the opposite found in high-nutrient treatments (Ghebrehiwot *et al.* 2006).

Most researchers are of the opinion that nitrogen increases the protein content of plants, which stimulates growth (Visser 1966; Dickinson *et al.* 2004). On the other hand, a high availability of nitrogen to rangeland will eventually negatively influence the ecosystem by encouraging less drought resistant plants (Visser 1966). The most limiting factor of growth in drier ecosystems however is water requirements (Snyman & Van Rensburg 1986). The soil dries out more rapidly and the consequent desiccation may cause hydrolysis of proteins. Under these conditions of drought degradation, an evolution in ammonia follows, which is toxic to plants (Visser 1966).

An important constraint on animal production from pastures is insufficient intake of digestible nutrients in relation to animal requirements. These, at times, can be aggravated by deficiencies of specific nutrients in the herbage (De Waal 1990). According to Dube & Gwarazimba (2000) heavy selective grazing by animals reduces the nutrient levels in plants and lowers the availability of high valued species which eventually lowers the grazing capacity.

According to Du Pisani *et al.* (1986a) high dry matter production from grassland was obtained in a neutral soil medium, but not with alkaline and acid soil mediums. Although fertilization habitually increased dry matter production, this was not necessarily beneficial, because plants could grow out of their water and nutrient supply (Snyman 2002). These aspects can relate to abandoned fields, because of fertilizing over years leading to changes in the chemical characteristics in the soil. The whole ecosystem can be changed by these aspects from a lively micro-climate to a dead soil with very little to no pores, living organisms and organic matter. Soil in such conditions may never rehabilitate but by directly influencing the micro-climate of the bare soil, these areas may develop life on a small-scale, which in fact is the beginning of rehabilitation (Altieri 1999).

After only four years of applying N-fertilizer, the botanical composition of the grassland changed from climax grasses to sub-climax vegetation (Snyman 2002). Louw (1966), Vorster & Mostert (1968) and Opperman *et al.* (1974) also found that in late succession all species were sensitive to increased nitrogen in the soil. The sensitivity of climax grasses as opposed to sub-climax grasses to increased nitrogen availability, could be due to the differential effect of nitrogen on the photosynthetic activity, CO_2 compensation point and photorespiratory activity of enzymes of these species (Wolfson *et al.* 1982; Wolfson & Tainton 1999). They also concluded that andropogonoid grasses were more sensitive to soil nitrogen levels than eragrostoid grasses to soil N levels. Moderate concentrations of soil N stimulated both andropogonoid and eragrostoid grasses, but the growth of andropogonoid grasses was retarded by high levels of N, while stimulating that of the eragrostoids (Tainton *et al.* 2000). Stimulation of shoot growth of andropogonoid grasses through fertilization increased soil water usage by the plant, and therefore a more rapid drying of the soil profile. Xerophytic eragrostoids were favoured more, relative to the mesophytic andropogonoids (Visser 1966; Donaldson *et al.* 1984). Feed producing species were classified according to agro-bioclimatic zones to identify which species were better or less well adapted to the enviroment (Le Houérou *et al.* 1993). *Elionurus muticus* showed the greatest decrease in frequency (62%) due to N fertilization (Snyman 2002). Phosphorus fertilization only, had an insignificant influence on species composition and basal cover over four years on grassland (Snyman 2002). The more fertilizer applied the more sensitive to drought the climax grasses became (Snyman 2002). One of the reasons could be the limitation of plant available water.

2.2.3 Climate limitations

Van den Berg (1983) investigated the relationship between the long-term grazing capacity and the long-term average rainfall of the dry areas of South Africa. There was a positive relationship between average rainfall and grazing capacity. According to De Jager *et al.* (1980) it was evident that effective planning for sustainability should depend on knowledge of the climate/plant/soil interaction. The most limiting environmental factor on vegetation production was water (Snyman 1998; 2012).

Fields abandoned for several years are exposed to intense climatic conditions. The partly exposed areas suffer from extremely high soil temperatures and will only start to recover when the micro-climate changes (Du Preez & Snyman 1993; Seitlheko *et al.* 1993). These areas tend to stagnate after a while until rehabilitation starts. After the ecosystem decreases to a lower equilibrium it slowly starts to recover (Kosmos *et al.* 2000). The micro-climate of these areas are almost the same to that of heavily grazed areas and according to Seitlheko *et al.* (1993), these areas have a low infiltration rate and a low saturated hydraulic conductivity and water stable aggregates. Soil compaction also plays a big role due to water loss, while studies show (Seitlheko *et al.* 1993) an increase in bulk density values in degraded areas. Heavily grazed areas also had lower mean porosity values, and lower organic carbon percentages. According to Peddie *et al.* (1995) a single season's rest will be sufficient to restore the vigour of severely grazed *Themeda triandra* rangeland, with a positive effect on exposed areas. By contrast a lower basal cover with severe grazing and therefore rangeland degradation (Snyman 1998) significantly increases soil temperatures both daily and seasonally (Du Preez & Snyman 1993), while the soil-water content also decreases (Snyman 2003a).

Rangeland in a good condition responds more efficiently to rainfall than rangeland in a poor condition (Snyman 1998). In terms of aboveground phytomass production, basal cover decreases linearly with deterioration in rangeland condition (Snyman & Fouché 1993). Rangeland in a poor condition may take longer to rehabilitate in dry circumstances, if grazed after a shortage of rain (Snyman 1998). Increaser I grass species will survive a drought, but Decreaser species may struggle if not managed well (Danckwerts & Stuart-Hill 1988). With The farmer is creating his own droughts when rangeland is in a poor condition namely man made droughts (Snyman 1998; 2013).

2.2.4 Soil seed bank studies

Soil seed bank is essential to the composition of different plant communities and thus in their conservation (López-Mariño *et al.* 2000). The composition of the seed bank depends on the production and composition of the present and previous communities, as well as on the longevity of the seeds of each species under local conditions (Bekker *et al.* 1997; Snyman 2013). Soil seed banks play a role in the rehabilitation of degraded vegetation communities after disturbance (De Villiers *et al.* 2003; Solomon *et al.* 2006; Kassahum *et al.* 2009; Snyman 2013). Removal of vegetation has a significant impact on the number of seeds produced by a plant and released as seed rain (Snyman 2013). The existence of seeds in disturbed habitats is determined by the association between the original plant assemblages, the amount of propagule production and the capability to build up seed reserves in the soil (Kinucan & Smeins 1992; Chang *et al.* 2001). In rangeland management an ecosystem can deviate from a reference state (rangeland in a good condition) in which the ecosystem is in equilibrium and may be at risk of a degraded state if the rangeland condition lowers into an alternative stable state from which it is unable to recover without active intervention (Dreber & Esler 2011; Snyman 2013).

The role played by seedling recruitment in undisturbed rangelands is not always clear (Snyman 2013). Rangelands have a large, persistent seed bank, often with a species composition that does not bear a resemblance to the aboveground vegetation (Kassahum *et al.* 2009) and it is well documented that these seeds can dictate the successional trends that occur following large-scale disturbances (Edwards & Crawley 1999; Snyman 2013). The understanding of the function and dynamics of seed banks is necessary to determine the role of the seed bank in ecosystem functioning and to improve the integrated management of ecosystems (Luzuriaga *et al.* 2007; Snyman 2009; Dreber 2011).

Different grass species depend on different forms of soil disturbances before germination, and it is important whether various types of disturbances have equivalent effects on the soil seed bank (Bekker *et al.* 1997; Page *et al.* 2006; Ma *et al.* 2010). The effects of disturbance whether intense and/or frequent, must also be given careful consideration (Jutila & Grace 2002).

Snyman (2013) quantified the effect of plant and soil disturbances on seed density, species richness and seed longevity of the soil seed bank. The study was conducted over a five year period, in the central Free State on a Valsrivier semi-arid rangeland with a 530 mm annual rainfall per year, and included fire, tillage and blocked seed rain. This study area of Snyman (2013) was more or less the same as the study conducted at Verkeerdevlei. Before physical impact on the plant and soil, the seed bank was dominated by perennial species. With tillage the Decreaser and Increaser species decreased in the seed bank, whereas a contradictory effect occurred in the field. The emergence of weeds was increased by tillage (Snyman 2013). The shocking fact was that after only three years of seed removal of *Themeda triandra,* no further seeds appeared in the soil seed bank (Snyman 2013). This is of great concern, because the chances for grassland recovery are very poor after reaching a threshold value. A study conducted by Céspedes *et al.* (2012) showed that water availability is the main controlling factor of germination. The seed dynamics of *Themeda triandra,* will play a limiting role in the restoration of grasslands in degraded areas (Everson *et al.* 2009). These mentioned aspects could contribute to the loss of grazing capacity.

Some seeds need the perfect temperature for germination, while other can germinate over a range of temperatures (Snyman 2013). Soil provides an ideal medium for germination through regulation of soil temperature. The soil surface absorbs most of the heat which provides a cooler micro-climate for germination to take place below the surface (Brady & Weil 2008). Therefore soil is forming a micro environment with its own biodiversity. The ecosystem function improves with biodiversity (Wardle *et al.* 1997). These views are based on experiments in which species richness contributed to a micro-climate rehabilitation program over all species diversity (Wardle *et al.* 1997). Indirectly human impact on soil physical and chemical characteristics may negatively influence germination success of some plant species. All shrub populations have a low rate of turnover when rangeland is disturbed (Milton 1993).

Soil has six key roles, firstly, soil provides a medium for plant roots and nutrient elements and by changing/altering its structure, plant cover may change. Secondly, texture will control water-use efficiency and does not change with tillage, and thereby has less impact on species composition, unless the textural classes are mixed. Thirdly, a role in recycling of organic matter and fourthly, as a habitat for living organisms. Fifthly, soil has a major influence on the atmosphere by taking up and releasing carbon dioxide, oxygen, methane, and other gasses. Lastly, soil plays an important role as an engineering medium (Brady & Weil 2008).

The grassland biome is one of the most transformed biomes in South Africa, with cultivation and other human impacts having the most effect on pristine grassland (Van Oudtshoorn *et al.* 2011). Conversion of rangeland to cropland destroys natural vegetation seed banks (Van Oudtshoorn *et al.* 2011). When croplands are abandoned, the secondary succession leads to low diversity, with *Hyparrhenia hirta* dominated plant communities (Van Oudtshoorn *et al.* 2011). With plough and rip techniques the largest effect was on the establishment of local non-sown species (Van Oudtshoorn *et al.* 2011). The re-establishment of old crop fields is slow and they may never fully recover (Van Oudtshoorn *et al.* 2011). Snyman (2003b) conducted a study in the central Free State on a Valsrivier semi-arid rangeland with a 530 mm annual rainfall per year to test the establishment of seed in a degraded soil seed bank. Rangeland in a poor condition showed a significantly higher seed density in the seed bank and more seedling establishment than grassland in a good condition. The poor condition rangeland had no climax seed germination, while very few seeds in the good rangeland survived to the end of the season. A decrease in species richness, both in the seed bank and seedling establishment in the field, was verified on the degradation gradient (Snyman 2003c).

The soil seed bank plays an important role in the composition of different plant communities and thus in their conservation (Shaukat & Siddiqui 2004). External factors include temperature, water, oxygen and sometimes light or darkness (Bewley & Blade 1982).

Individual plant species require different variables for successful seed germination and sometimes never germinate because of disturbed areas (Bewley & Blade 1982). Often this depends on the individual seed variety and is closely linked to the ecological conditions of a plant's natural habitat. The composition of the seed bank depends on the production and composition of the present and previous communities (Harrington *et al.* 1984; Fenner 1985). For some seeds, their future germination response is affected by environmental conditions during seed formation; most often these responses are types of seed dormancy (Bewley & Blade 1982).

Longevity of seeds of different species under local conditions also contributes to the composition of the seed bank (Bekker *et al.* 1997; Snyman 2013). The role that soil seed banks play in the restoration of degraded vegetation communities after disturbance is very important (De Villiers *et al.* 2003; Solomon *et al.* 2006). In rangeland certain practices may decrease the ecosystem equilibrium functioning to the extent where an ecosystem can deviate from a reference state and being at risk to cross a threshold into an alternative stable state from which it is unable to revert without active intervention (Briske *et al.* 2008; Dreber & Esler 2011).

2.3 Soil dynamics

Plant life depends on soil and the different functions of soil. Soil supports the plant's root system and has numerous functions namely,

- Physical support,
- Air,
- Water,
- Temperature moderation,
- Protection from toxins and
- Nutrient elements.

Soil mass provides physical support through anchoring the root system. There are a few meteorology aspects like wind and snow that have a major influence on the stability of the plant in the soil (Brady & Weil 2008). The soil contains micro- and macro organisms and influences the uptake of minerals for proper growth. Ventilation that allows CO_2 to escape and fresh O_2 to enter the root zone, is also an important function of soil. Pores in the soil absorb rainwater or irrigation and hold it in the soil for plants to use. Plants constantly use water and sunlight and it is therefore essential for survival. Some soil types are deep and hold more water for longer periods of time. These soils may have a non-infiltratable horizon (Brady & Weil 2008).

The solid phase of soil forms the soil matrix and consists of particles that vary in chemical composition as well as in size, shape, and orientation. Soil structure of the soil matrix determines the geometric characteristics of the pore spaces (Hillel 1998). The soil matrix stabilizes the organic matter in soil and is a function of the chemical nature of the soil mineral fraction. Cations in soil are capable of adsorbing organic materials (Baldock & Skjemstad 2000). The liquid and gaseous phases vary in composition according to time and space. The proportions of the three phases are not fixed and can change along a degradation gradient (Hillel 1998).

Soil organisms also play a big role in soil properties. Living organisms are part of the soil and influencing soil properties such as hydrology, ventilation and gaseous composition, all of which are essential for primary production and the decomposition of organic residues and waste materials (Brussaard 1997).

An average soil loss of 6 t ha^{-1} and 80,6% runoff may occur from rangeland (Snyman & Van Rensburg 1986). Natural rangeland tends to stay in balance when managed correctly to allow good infiltration of rainwater. Compaction on bare soil has the worst effect on regrowth while organic matter, runoff and infiltration deteriorate as well with rangeland degradation (Snyman & Van Rensburg 1986; Du Preez & Snyman 1993).

2.3.1 Soil as a plant growth medium

Due to soil disturbance the soil-water capacity can influence plant life. Herbage production and water-use efficiency decline with the deterioration of rangeland. With the exposure of bare soil, water infiltration, runoff, surface compaction and germination may change. Evaporation from bare, uncultivated soil surfaces can be 69% in some cases (Snyman 1998). Rainfall plays an important role in the establishment of a micro-climate (Snyman 2000a). If soil compaction occurs during cultivation of abandoned fields, infiltration may be less effective (Tanner *et al.* 1986).

2.3.2 Micro organisms

Organism life in soil helps with the distribution of elements and organic material. Influencing the soil through human activity, changes the ecosystem in the soil which can take years to rehabilitate (Snyman 2013). According to Van der Merwe & Van Rooyen (2011) the difference between abandoned croplands and natural rangeland can be apparent even after

33 years. The abandoned fields do recover, but at a slower rate in comparison to overgrazed natural rangeland. Chamaephyte and therophyte species are the least abundant on previously cultivated fields and hemicryptophyte, phanerophyte, liana and parasite species were the most abundant however, liana and parasite species were also seldom found in natural rangeland (Van der Merwe & Van Rooyen 2011). Soil micro-organism activity plays an important role in the structure of the soil, by opening the pores for water to infiltrate and play a big role in nitrate binding (Van der Merwe & Van Rooyen 2011).

2.3.3 Organic matter

Organic matter is the result of residue breakdown through organisms. These activities oxidize organic compounds in the residues with the release of carbon (C) into the atmosphere as carbon dioxide (CO_2) and methane (CH_4) (Van der Linde 2007). Organic matter is very important for microbes to survive and to live in a micro-climate that supports them. The effect of carbon and nitrogen on three different rangeland conditions were analysed by Du Preez & Snyman (1993) to investigate the effect on degradation. Both variables declined as the rangeland condition degraded. The largest differences were in the top soil layer and the least occurred in the deeper soil layers. The loss of organic matter in the soil might have a great negative influence on the phytomass production, soil erosion and soil climate. This degraded soil may restrain rangeland recovery (Du Preez & Snyman 1993). The degree of degradation plays a major role in the recovery time, but may be too severe to recover without human intervention.

Nitrogen has an essential role to play in plant development and growth. It is a component of proteins and related amino acids, which are critical for plant tissue building blocks, cell nuclei and also protoplasm in which hereditary control is vested (Brady 1984). Dissolved organic nitrogen plays a big role in the pool of soluble nitrogen in many soils. The low molecular weight component of dissolved organic nitrogen represents an important source of nitrogen for micro-organisms. The weight factor can also contribute to nitrogen uptake being utilized directly by some plants. A study was conducted to determine which of the pathways in the decomposition and subsequent ammonification and nitrification of organic nitrogen, represented a significant block in soil N supply in three agricultural grassland soils. Results show that the conversion of insoluble organic nitrogen to low molecular weight dissolved organic nitrogen, represents a major constraint to nitrogen supply. There are two distinct dissolved organic nitrogen pools in soil, which include free amino acids and proteins. The microbial community turned it over very rapidly, so it does not accumulate in soil. The second pool is a high molecular weight pool rich in humic substances. This second pool turns over slowly and represents the major dissolved organic nitrogen loss to freshwaters

(Jones *et al.* 2004). Nitrogen supplies plants with their deep green colour and plant death will occur with low nitrogen supply. Nitrogen also contributes to carbohydrate utilization within plants and stimulates root growth and development. Some nutrients also need nitrogen for uptake and thus nitrogen plays an essential role in plant growth (Brady 1984).

There are three forms of nitrogen: (a) organic nitrogen mainly in soil humus, (b) ammonium nitrogen fixed by clay minerals, and (c) soluble inorganic ammonium and nitrate compounds. Organic matter is associated with nitrogen in surface soils (Brady 1984). The direct uptake of dissolved organic nitrogen by plants is a factor in ecosystem functioning and vegetation succession. This uptake of dissolved organic nitrogen happens particularly in nitrogen limiting environments. Based upon experimental evidence, dissolved organic nitrogen uptake from the soil may not contribute largely to nitrogen gaining by plants. This uptake is primarily involved in the recapture of dissolved organic nitrogen previously lost during root exudation (Jones *et al.* 2005).

The nitrogen cycle is essential (Figure 2.1) for plant life and undergoes many transformations. Mineralization (Figure 2.1) is when the chemical compounds in organic matter decompose or are oxidized into plant-accessible forms. Mineralization is the opposite of immobilization. Nitrification (Figure 2.1) is the biological oxidation of ammonia with oxygen into nitrite followed by the oxidation of these nitrites into nitrates.

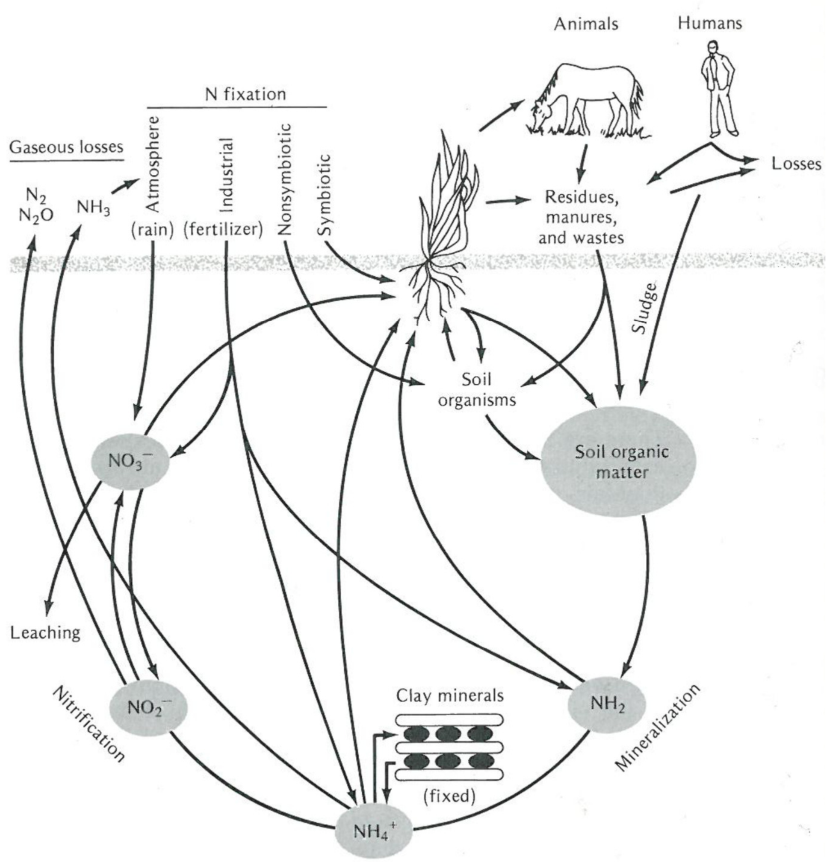

Figure 2.1 The nitrogen cycle (Brady 1984).

Degradation of ammonia into nitrite is usually the rate limiting step of nitrification and nitrification is an important step in the nitrogen cycle in soil (Brady 1984). Organic matter decomposition is closely associated with the nutrient cycle. Here the micro-organisms are essential and the rate at which the processes operate is determined by small grazers such as protozoa and nematodes. Larger animals improve the process in 'hot spots' such as the gut and excrements. Specific groups of soil bacteria are involved in autotrophic transformations which mean they do not depend on organic matter as a food source (Brussaard 1997).

Carbon plays a role in all life processes and the transformations of this element, termed the carbon cycle (Figure 2.2) is a biocycle that makes life possible. Photosynthesis process assimilated carbon dioxide and converts it into numerous organic compounds. Thus, plants use carbon dioxide and set oxygen free. The cycle converts carbon from man to waste followed by digestion by micro-organisms to release nutrients (Figure 2.2) (Brady 1984). When decomposition of organic matter occurs, defined simply as mineralization of carbon, 90% of the decomposition is carried out by micro-organisms such as bacteria and fungi. It is facilitated by soil fauna such as mites, millipedes, earthworms and termites that tear up the residues and scatter microbial propagules. Waste management and the purification of polluted soil are carried out by the soil decomposer community (Brussaard 1997).

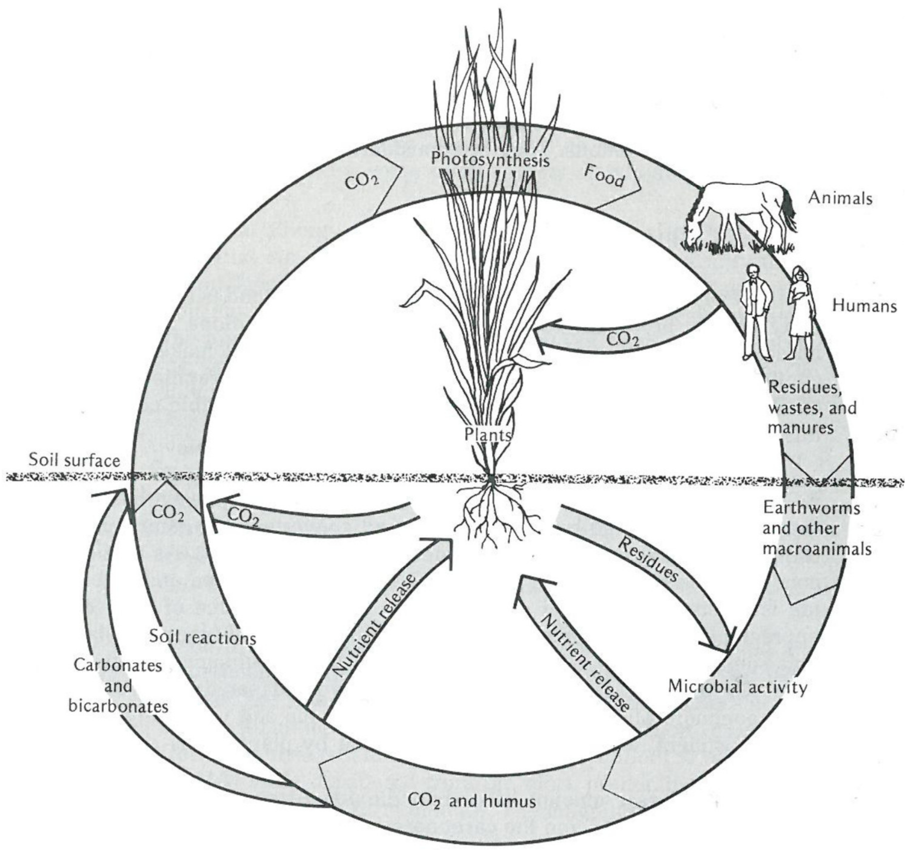

Figure 2.2 The carbon cycle (Brady 1984).

Water drop penetration time is a commonly used measurement to calculate water infiltration. When water enters soil spontaneously, the soil is unsaturated and the pores are big enough for water consumption, but if a water drop does not enter the soil spontaneously, the soil–water contact angle is greater than 90 ° and the soil is considered to be water repellent (Letey *et al.* 2000). The pressure by which water enters the soil pore spaces and become soil-water is known as infiltration. The difference between field capacity and the permanent wilting point is called the available water-holding capacity and there is a relationship between the soil-water capacity and the available water-holding capacity. Soil types differ in textural percentages and therefore differ in holding capacity of water. Soils with a high clay percentage have a tight hold on their water and therefore less water is available, than the case with well-granulated silk loam, since the clay have a high wilting coefficient. Organic material has an important influence on available water-holding capacity. Soil with 5% organic material has a higher available water-holding capacity than that of a well-drained mineral soil containing 3% organic matter. Organic matter also has an influence on infiltration, because the higher the organic matter, the better the infiltration (Brady & Weil 2008).

2.3.4 Bulk density

Bulk density, which is defined as the mass of unit volume of dry soil, includes both solids and pores. Fine textured soils such as silt, loams, clays and clay loams generally have lower bulk densities than sandy soils. This is because the solid particles of the fine-textured soils tend to be organized in porous granules, especially if adequate organic matter is present. Bulk density is higher, deeper in the profile due to lower organic matter (Brady & Weil 2008). Ahmed *et al.* (1987) tested the influences of continuous rotationally delayed and short-duration rotation grazing systems on soil compaction and water infiltration. Bulk density and water infiltration were also measured to evaluate the effects of grazing systems at moderate and heavy stocking rates (Ahmed *et al.* 1987). Grazing systems or stocking rates did not affect the bulk density. Trampling did affect the infiltration negatively, because the infiltration rate was significantly lower under the heavy stocking rate at the end of the grazing season. The bulk density and infiltration were never permanently affected in all of these trails.

Tillage loosens the soil surface temporarily, but over time increases the soil bulk density because it depletes soil organic matter and weakens soil structure (Brady & Weil 2008). Certain tillage implements, like a mouldboard plough and disk harrow, compact the soil below their working depth even as they lift the soil above it. Repeated work can form plough pans or traffic pans. Chisel-type ploughs can be used in subsoiling to break up dense subsoil layers. In wet conditions, compaction is more severe because of transition deeper with a greater expansion of weight (Brady & Weil 2008). Soil-water content and bulk density both affect soil strength (Brady & Weil 2008). The higher the bulk density, the higher the soil strength and it also applies when finer-textured soils dry out and harden. A higher bulk density prevents root penetration when the soil is moist. Roots can thereby penetrate more easily in a moist sandy soil than in a moist clay soil (Brady & Weil 2008). Soil structure is a key factor in supporting plant and animal life. The structure also has a big influence on environmental quality with particular emphasis on soil carbon impounding and water quality. The stability of aggregate is used as an indicator of soil structure (Six *et al.* 2000). The rearrangement of particles, flocculation and cementation is a result of aggregation (Duiker *et al.* 2003).

Degradation of soil may result in a total micro-climate collapse. If soil formation is changed which include parent material, climate, biota, topography and time, the system can take years to recover and rehabilitate to its original form (Brady & Weil 2008). Textural classes in soil do not change over time but erosion, tillage, irrigation and factors like wind can remove the top layer or turn the more clay parts to the surface. The horizons within the deeper soil can be exposed and a difference in plant life can occur (Brady & Weil 2008).

2.3.5 Soil chemical characteristics

Soil properties show that with an exception of ammonium, all soil variables can significantly differ among age-classes. Nitrate, phosphorous, potassium and sulphur contents were high in recently disturbed areas, with a drop over time to the extent that these properties were non-significant (Scott & Morgan 2012). According to Berliner & Kioko (1999) the decline in soil fertility does not reflect the significant changes in relative proportions of Decreaser grass species.

Toxins in soil may result from human activity, produced by plant roots, by micro-organisms or by natural chemical reactions. Ventilation of gasses, deposing or absorbing of toxins or suppressing toxin-producing organisms, can protect the plants. Minerals are essential not only for the plant but also the animal. These elements play an important role in the vigour of plants (Brady & Weil 2008). The primary productivity of the ecosystem eventually enters the decomposition subsystem as plant litter and as any other soil factor it is important for “afterlife effects” (Wardle *et al.* 1997).

2.3.5.1 Soil pH

The soil pH is a measure of the acidity or basicity in soils. It ranges from 0 to 14, with 7 being neutral, below 7 is acidic and above 7 is basic. Soil pH controls many chemical processes that take place and specifically affects plant nutrient availability by controlling the chemical forms of the nutrient (Van der Linde 2007). Soil pH affects: (a) the availability of nutrients, (b) the composition and diversity of the microbial community; (c) the equilibrium of the solid phase and (d) the plant response to soil type. These aspects can influence the types of plant life that occurs (Brady 1984). In acidic soils high levels of aluminium becomes soluble and is present in the form of aluminium or aluminium hydroxyl cations. When adsorbed, it causes permanent changes to soil colloides (Brady 1984). Enzyme activity is also affected due to the pH sensitivity of amino acid functional groups that influences conformational and chemical changes of amino acids essential for binding and catalysis. By influencing the concentration of inhibitors or activators in the soil solution and the effective concentration of the substrate, the activation of enzymes are also affected (Dick & Cheng 2000).

2.3.5.2 Phosphorus (P)

Phosphorus is a component of two compounds involved in energy transformation in plants, adenosine diphosphate (ADP) and adenosine triphosphate (ATP). These groups drive most biochemical processes requiring energy (Figure 2.3). This involves the uptake of some nutrients and their transport within the plant and also the synthesis of different molecules (Brady 1984). The most significant effects of phosphorus on plants are (Brady 1984):

- Cell division and fat and albumin formation,
- Flowering, fruiting and seed formation,
- Crop maturation,
- Root development,
- Straw strength and
- Improving of crop quality.

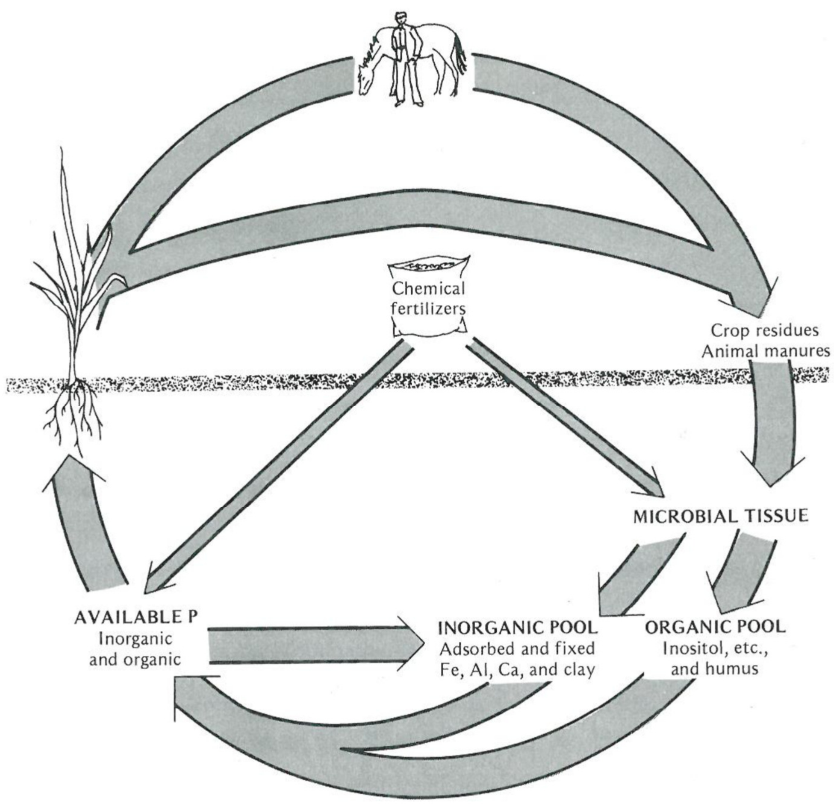

Figure 2.3 The phosphorus cycle in and above the soil surface (Brady 1984)

2.3.5.3 Potassium (K)

Improvement of the potassium nutritional status of plants can greatly decrease the reactive oxygen species production by reducing activity of NAD(P)H oxidases and maintaining photosynthetic electron transport (Cakmak 2005). Potassium is the activator of many enzymes responsible for processes such as energy metabolism, starch synthesis, nitrate reduction and sugar degradation. This element is very mobile and easily crosses membranes. Potassium's high concentration helps with the opening and closing of stomata in the leaves, and the uptake of water by root cells. It is essential for photosynthesis and helps with the development of chlorophyll (Brady 1984). Figure 2.4 shows a good indication of potassium which is held in a non-exchangeable, but slowly available form.

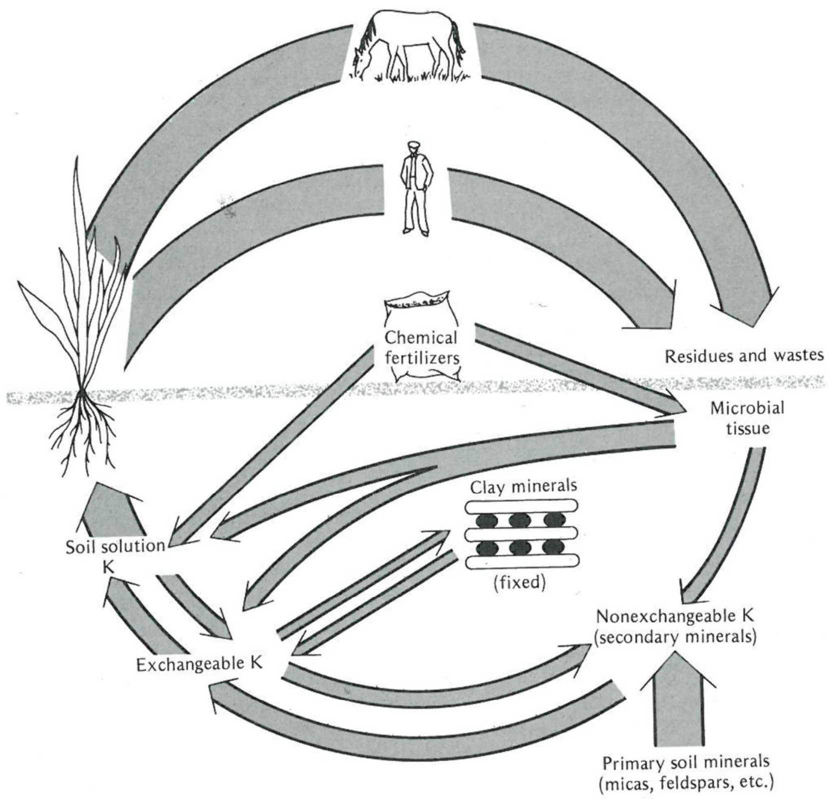

Figure 2.4 The major components of the potassium cycle (Brady 1984).

2.3.5.4 Sodium (Na)

Sodium plays an important role in the growth of plants using the C_4 pathway of carbon fixation and can also be important in plants with Crassulacean acid metabolism. Sodium increases production of dry matter, reduces water loss and hardly affects photosynthesis (Jennings 2008).

2.3.5.5 Calcium (Ca)

Calcium is a plant nutrient that is required for structural roles in the cell wall and membranes. It is taken up by the plant roots and excessive Ca restricts plant communities on calcareous soils (White & Broadley 2003).

2.3.5.6 Magnesium (Mg)

Magnesium plays an essential role in plants. The plant will not complete its life cycle if the element is removed and is thus a necessary component of an essential metabolite. Magnesium appears in soil as non-exchangeable, exchangeable and water soluble. Magnesium availability is reduced by competition from hydrogen, aluminium, and manganese at acidic pH values. Parent material, duration and intensity of weathering, and the capacity of soil to retain and supply magnesium affects the magnesium availability to plants (Sigal & Sigal 1990).

2.3.5.7 Cation exchangeable capacity (CEC)

Cation exchange replaces nutrient cations from the exchange complex by hydrogen ions from the root hairs, and micro-organisms. They gather in the soil solution where they can be assimilated by the adsorptive surfaces of roots and soil organisms. These cations can be removed by drainage. The exchangeability of the cations in the soil can differ along the capacity of the soil to expedite or retard the release of nutrients to plants (Brady 1984).

Chapter 3

Study area

The study was conducted from March 2011 to September 2012 on three abandoned fields with an average size of 50 ha each. A portion of adjacent natural rangeland, with a similar size, was used as a control to compare the abandoned fields with.

3.1 Description of study area

3.1.1 Location

The study was conducted on the farm Avonddal in the Verkeerdevlei district. The farm is located about 80 km north-east of the city of Bloemfontein in the semi-arid region of South Africa (28°55'36.69" S; 26°37'31.97" E, altitude 1 450 m).

3.1.2 Vegetation type

The study area is situated in the Grassland biome (Low & Rebelo 1996). This biome covers the largest part of the higher lying regions (Highveld) of central South Africa. It includes the central plateau and escarpment (extending from the Eastern Cape to Limpopo) and the mountainous regions of Kwazulu-Natal (Van Rooyen 2010). In 1988, Acocks described the extensive range of the grassland biome as due to human intervention that caused degradation of forests that used to occur in some areas of this biome (considering the climatic climax of the biome). Ellery *et al.* (1991), on the other hand, stated that these climatic climaxes (frost and lightning-induced fire), together with the disturbance caused by grazing, maintained the current structure and texture of grassland and prevented the establishment of trees.

The study area at Verkeerdevlei is situated in the Central Free State rangeland (Vegetation type Gh 6) and consists of plains supporting short grassland with *Themeda triandra* dominating in the natural condition (Mucina & Rutherford 2006). With degradation, *Eragrostis curvula* and *Eragrostis chloromelas* become dominant. The grassland contains an exceptionally high density of plant species, including a variety of rare and endemic species, growing in a variety of soil types, ranging from clays to poorly structured sands. Rangeland consists mostly of a single grass layer whereas woody species are limited to specialized habitats (riverbanks and gorges). Although most of the grass species are naturally adapted to defoliation through grazing, frequent and/or excessive grazing can cause severe damage to the structure and species composition of a vegetation habitat (Mucina & Rutherford 2006). According to Acocks (1988) the area at Verkeerdevlei is a transitional *Cymbopogon-Themeda* veld which is dominated by *Themeda triandra* in most areas. When the area is in a pristine condition *T. triandra* dominates entirely with a few other occurrences, particularly dicotyledonous forbs (Low & Rebelo 1996). Poor condition of the rangeland also contributes to the invasion of pioneer species such as *Aristida congesta, Cynodon dactylon, E. obtusa, A. canescens, Microchloa caffra* and *Tragus berteronianus* (Low & Rebelo 1996). *Aristida junciformis* occurs especially in areas where vegetation has been degraded due to overgrazing by livestock (Van Rooyen 2010). The vegetation associated with this biome has great potential for animal production, but the translocation of nutrients to the roots during winter months can be a limiting factor.

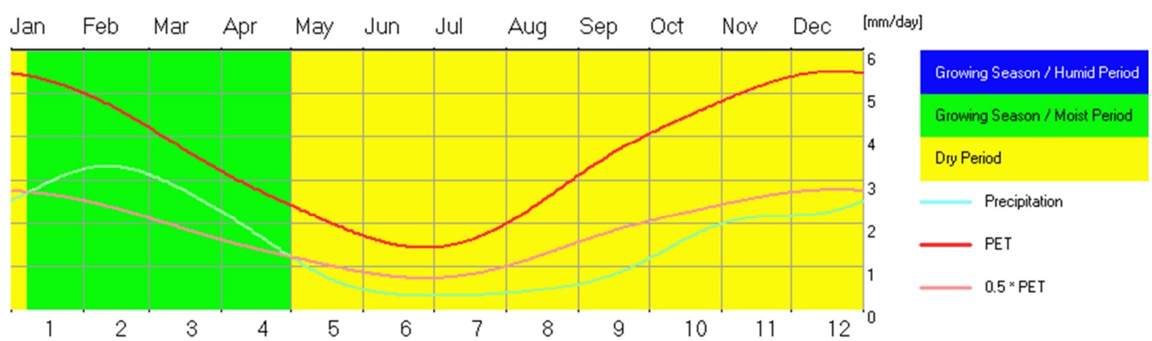

Figure 3.1 The predicted growing season of the study area (Avonddal farm in the Verkeerdevlei district) (New LocClim 2006).

The area is in a semi-arid region with a low humid period. This is also the moist period when germination takes place. The dry period is very long, and stretches from the end of April to the beginning of January (Figure 3.1). Plants have a short growing period, only from January to the end of April (Figure 3.1). Precipitation (PET) is given (Figure 3.1) at three different levels predicted for the area of Verkeerdevlei.

3.1.3 Topography, geology and soil

In the Grassland biome, deep red (Hutton) and yellow (Clovelly) soils predominate (Low & Rebelo 1996). According to Mucina & Rutherford (2006) sedimentary mudstones and sandstone, mainly of the Adelaide Subgroup (Beaufort, Karoo Supergroup) as well as the Ecca Group (Karoo Supergroup) are found in the northern parts which give rise to vertic, melanic and red soils (Arcadia, Bonheim, Kroonstad, Valsrivier and Rensburg). The soil type at Verkeerdevlei is the Swartland form with an orthic A, pedocutanic B and saprolite horizon (Table 3.1). There is a slope from south to north, which contributes to a horizon depth variation given in Table 3.1.

Calcareous accumulation above and within the saprolite is abundant. The soil layers (100-200 mm) above the saprolite have a high percentage calcium and are too shallow for diagnoses. In both the profiles wet signs were present.

The highest point of the abandoned fields is approximately 1 431 m above sea level with the lowest point in the rangeland at 1 422 m above sea level. This implies a 9 m decline from the highest to the lowest point in the study area. There is thus a smooth downhill slope from south (highest) to north (lowest).

At the study site two soil profile pits were made, one in abandoned field three (AF3) and one in the natural rangeland. Both soil profiles were the Swartland soil type (Table 3.1). The Swartland soil type is typical of freely to relatively poorly drained soil conditions in a dry, warm climate. The soil showed little variation in soil texture fractions. The clay content in the B horizon was very high (65.10%) with a low percentage very fine sand (1.24%). The A horizon had a higher percentage sand than that of the B horizon, with a much lower clay percentage (Table 3.1). No analyses were done on the Saprolite because of strong sub-angular structure.

Table 3.1 Comprehensive description of the soil type at study area

Swartland Form			
Master Horizon	**Orthic A**	**Pedocutanic B**	**Saprolite**
Depth	250/250 mm	900/600 mm	900+/600-1100 mm
Color	Red/Brown	Brown	
Wet signs	None	None	
Structure	Sub-angular block, moderate developed	Sub-angular block, strong developed	Sub-angular block, strong developed
Spots	None	Few with dull grey spots	Numerous with medium grey spots
Rocks	None	None	None
Mother material			
Concresis		Few slightly hard, moderate calcareous	Abundant, slightly hard and calcareous
Horizon crossing	Significant	Significant	Gradual
Silt (%)	7.42	4.9	
Fine silt (%)	29.1	29.04	
Clay (%)	29.66	65.1	
Very fine sand (%)	2.05	1.24	
Fine sand (%)	2.49	1.3	
Medium sand (%)	18.41	8.99	
Coarse sand (%)	22.42	10.85	
Gravel (%)	0.59	0.37	None

3.2 Climate

3.2.1 Frost

The most likely index temperature for the calculation of frost is 0℃. According to Kotzé (1980) there is a 10% probability that frost (Figure 3.2) will occur most likely on 20 April, with a 168 day period following up to 5 October. Frost occurs from the end of April to the beginning of October.

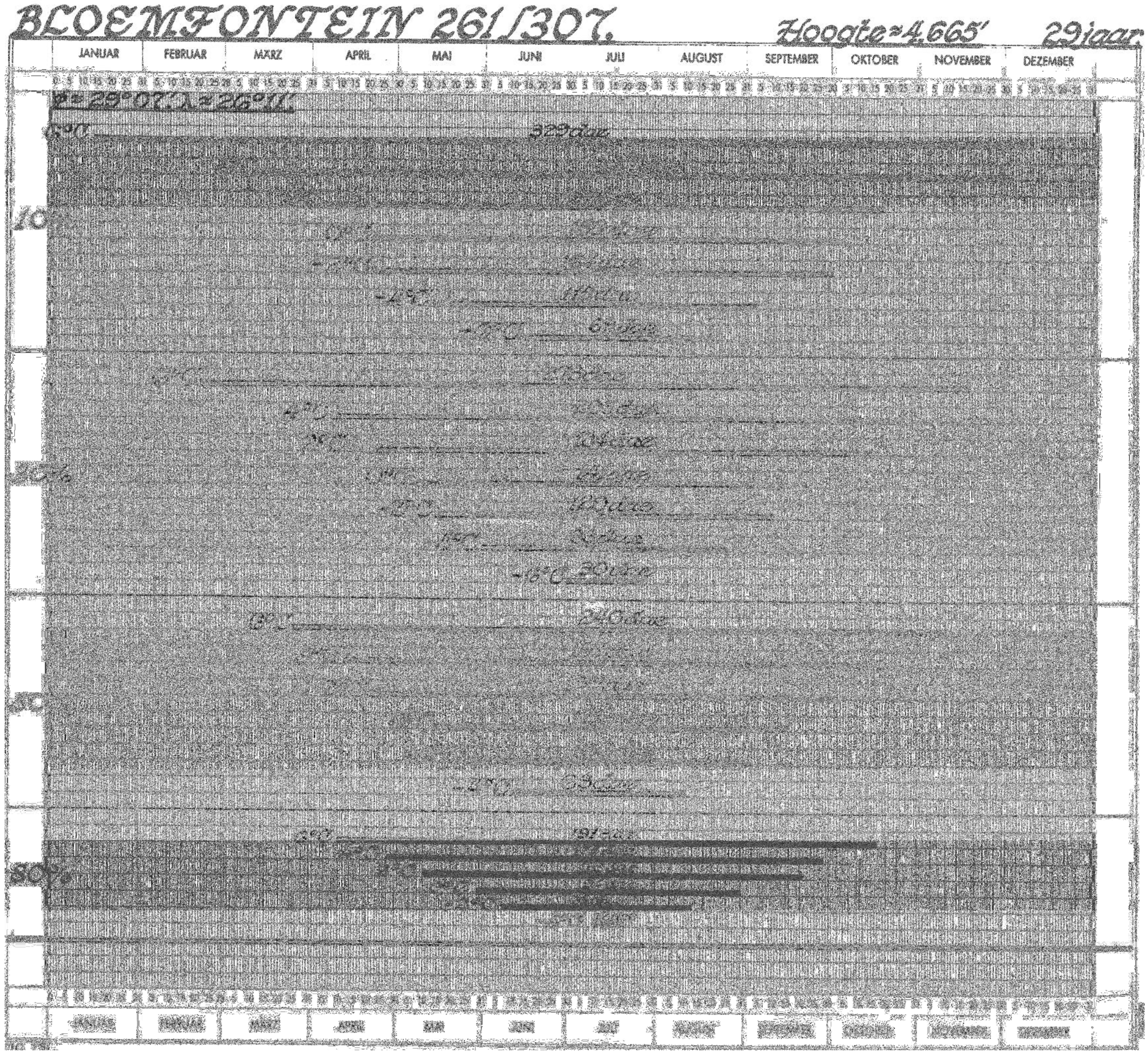

Figure 3.2 Likely acts of frost in the Bloemfontein area (Kotzé 1980).

There is a 30% probability of frost from 4 May to 22 September and a 50% probability from 14 May to 16 September. The period of frost shortens with an increase of frost probability and with an 80% probability the days shorten to 94 days from 27 May to 28 August (Kotzé 1980).

3.2.2 Wind

Figure 3.3 shows the general direction of wind in a year. The dominant wind direction is from the north, while the lowest appearance is from the south-east and east-south-east. The general direction of wind is mostly from the north-west and differs from a 0.5 m s^{-1} wind to a

10.7 m s^{-1} wind.

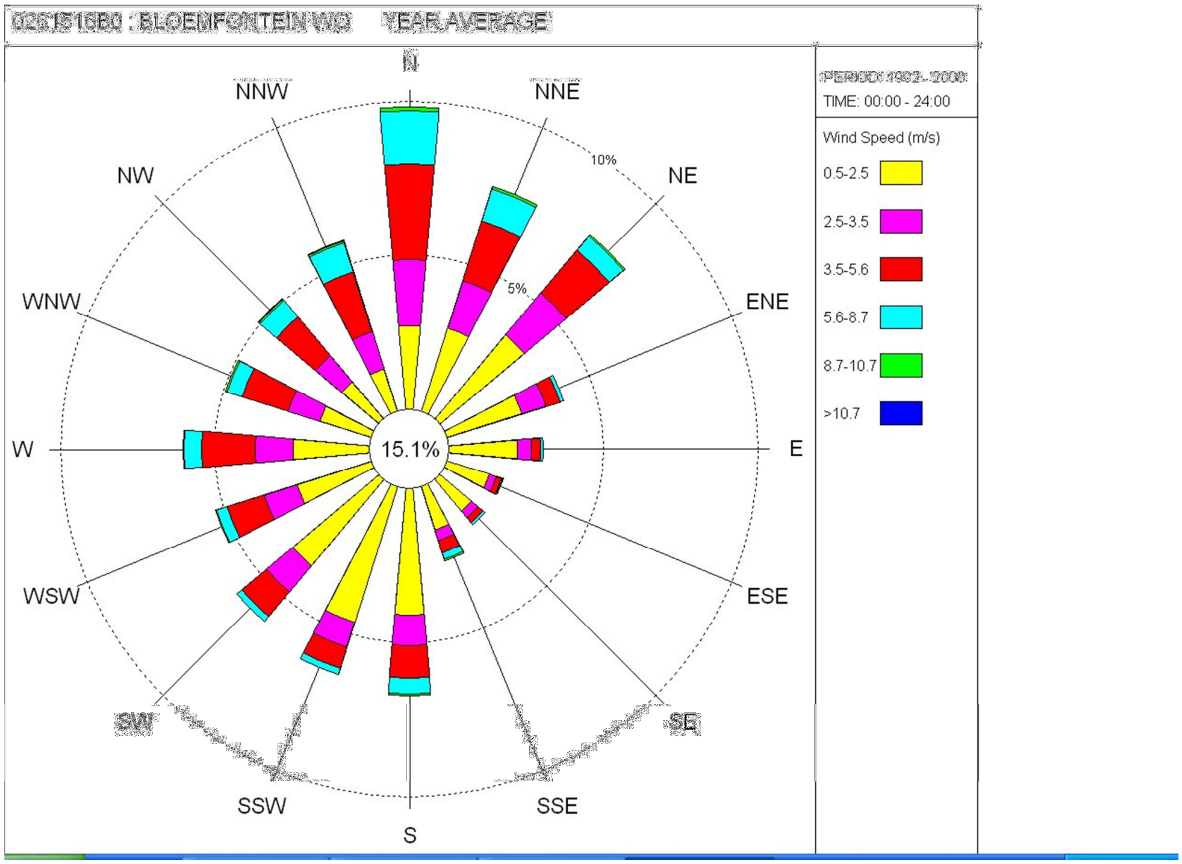

Figure 3.3 Annual average wind speed and direction over 16 years (SAWS 2012).

There is also a 15.1% chance of calm weather with no or slight wind. This percentage indicates wind changeability and fluctuation. The study area (abandoned fields) was situated to the SSE of the natural rangeland, which is downwind. This might influence the distribution of wind-driven seed towards the abandoned fields.

3.2.3 Precipitation and potential evapotranspiration

The highest precipitation occurs in January and February with a drop to less than 10 mm in July (Figure 3.4). The precipitation increases in September and decreases again at the end of February. The high estimate is higher than the best estimation and indicates exceptional years. The standard error is high which indicates unpredictability (Figure 3.4). Rain falls almost exclusively during summer (October to April), with a long-term annual mean of 525 mm and a mean of 66 rainy days per year (New LocClim 2006). The rainfall is unreliable and highly variable. The runoff is estimated at 39 mm $year^{-1}$ with a net primary production potential of 959 g (DM m^{-2} $year^{-1)}$ (New LocClim 2006).

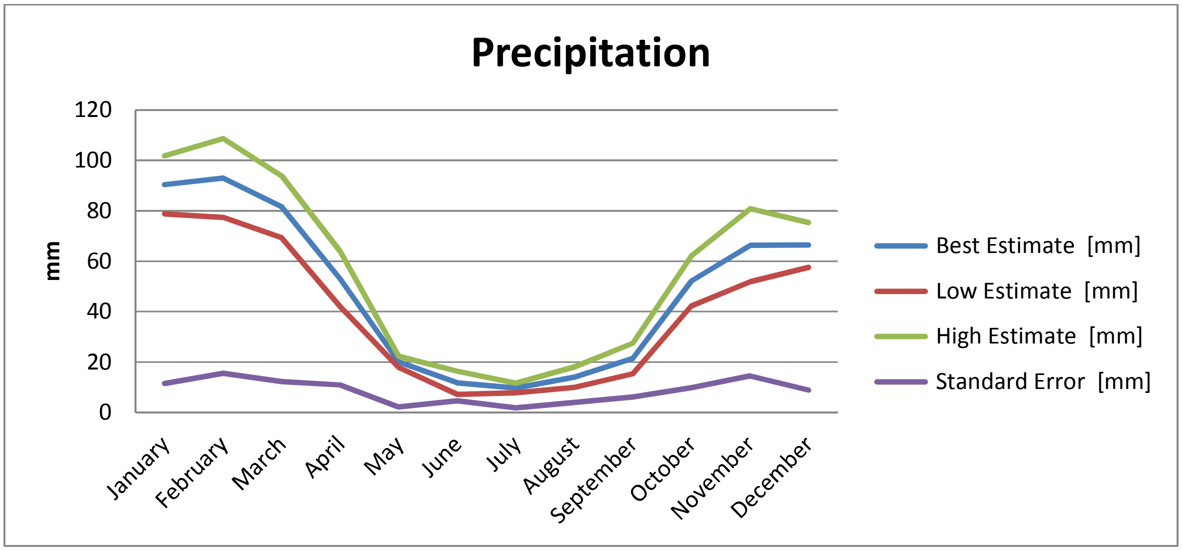

Figure 3.4 Mean monthly precipitation at Verkeerdevlei (New LocClim 2006).

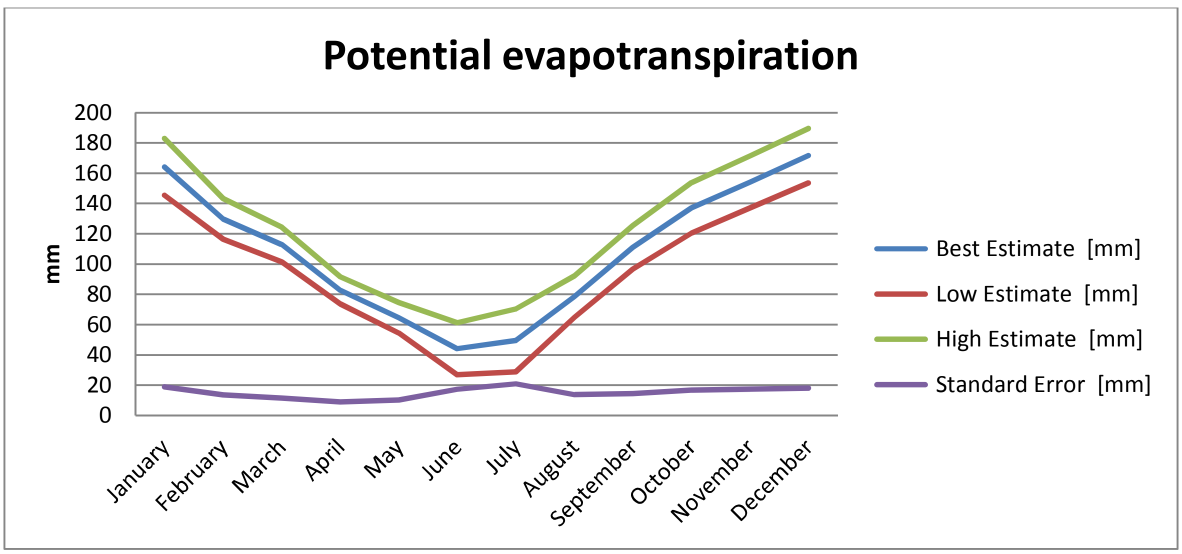

Figure 3.5 Potential evapotranspiration at Verkeerdevlei (New LocClim 2006).

The highest potential evapotranspiration coincides with the moist period. The results of New LocClim (2006) indicate a fluctuating condition resulting in a high standard error (Figure 3.5).

3.2.4 Vapour

Vapour follows the same tendency than the moist seasons (Figure 3.1). The standard error is larger because of the unpredictability of vapour (Figure 3.6). The best estimation of vapour pressure various from six to 15 hectopascal (hPa).

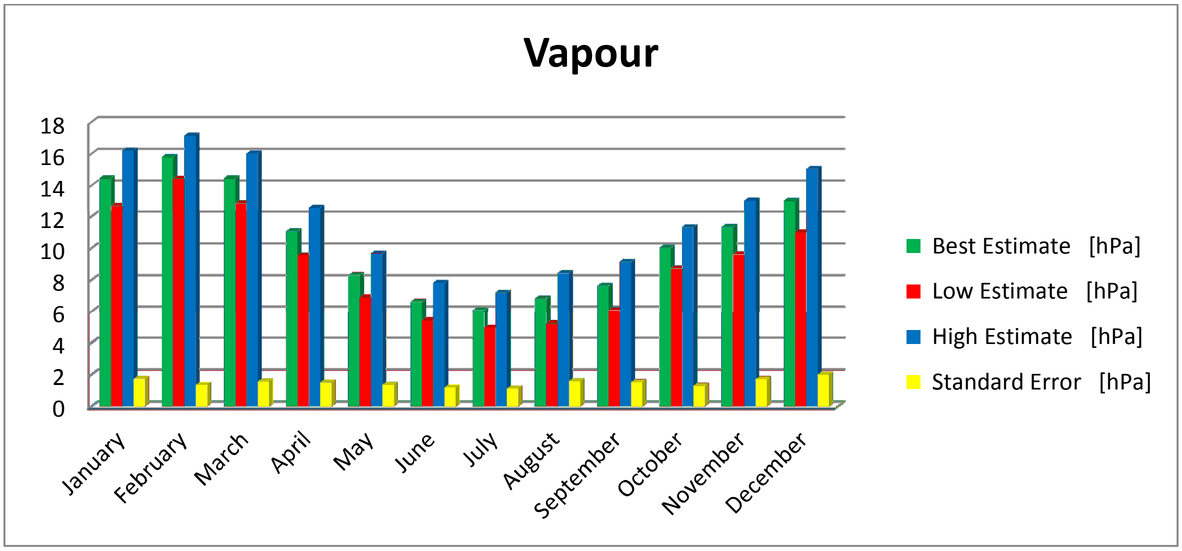

Figure 3.6 Vapour predictions at Verkeerdevlei (New LocClim 2006)

3.2.5 Temperature

The difference between low and high temperature estimations is small (Figure 3.7). The standard error is low because of a low fluctuation in annual estimations. The mean maximum temperatures (29-year average) range from 31.2℃ in January to 17.5℃ in July, while the mean minimum varies from 15.3℃ to -1.3℃ (WB 42 2002).

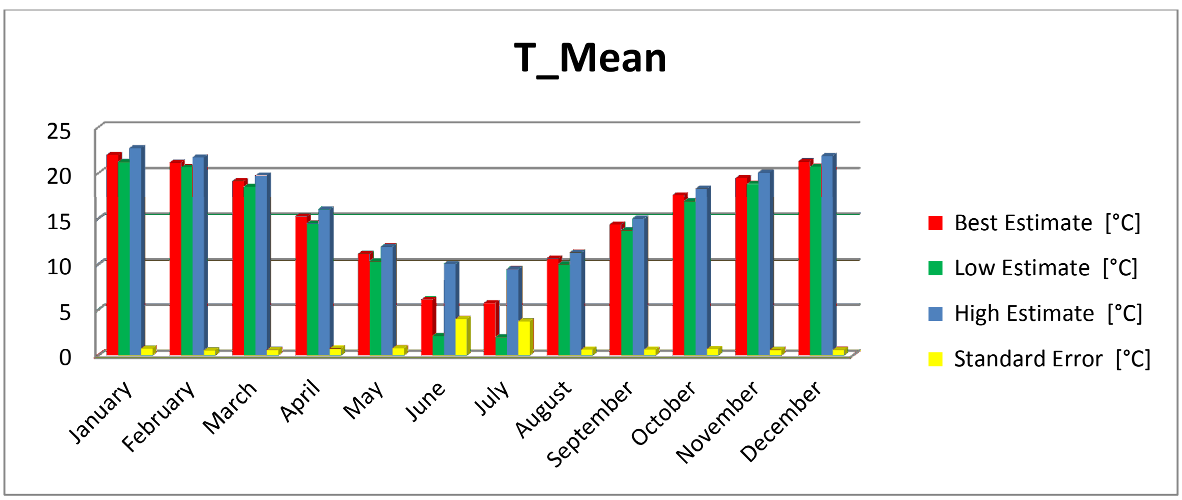

Figure 3.7 The mean temperatures in Verkeerdevlei (New LocClim 2006).

The temperature in the moist season is high and low in the dry season. Verkeerdevlei is a summer rainfall area, which is well explained by the high temperature in that season. According to Mucina & Rutherford (2006) the annual rainfall is 560 mm with much of the rainfall being of convectional origin and peaking in December to January.

Chapter 4

Vegetation dynamics

4.1 Materials and methods

4.1.1 Trial layout

The chosen area for the trial consisted of three abandoned fields (AF1, AF2 and AF3) and one paddock of natural rangeland (NR). These four study sites were all adjacent to each other and all had the same size of approximately 50 ha each (Figure 4.1).

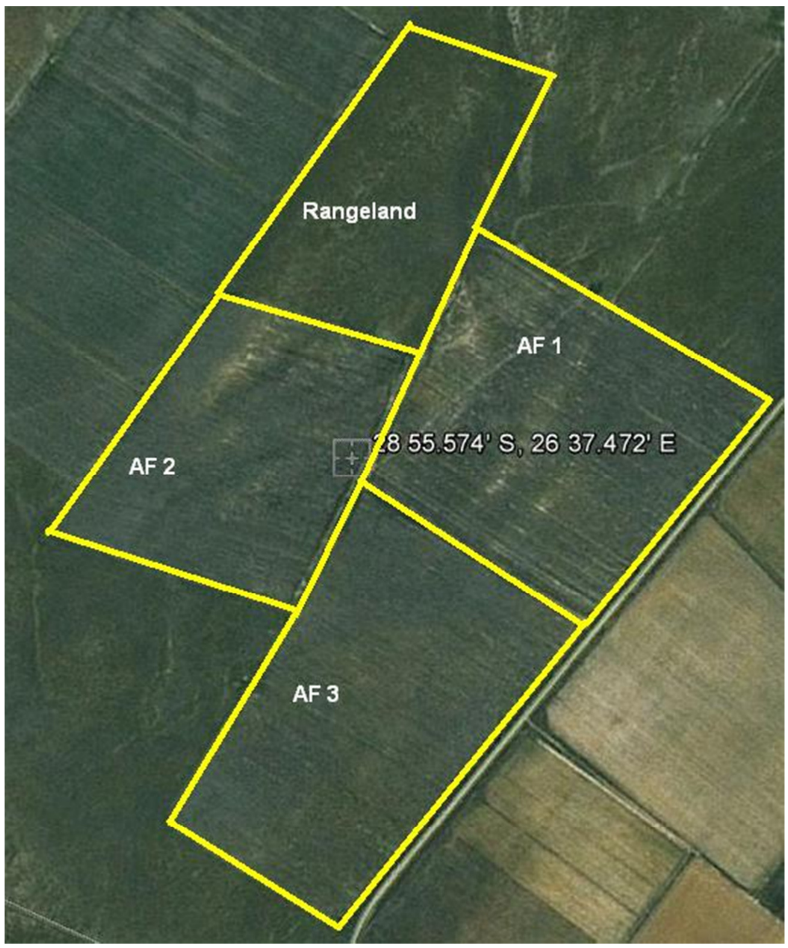

Figure 4.1 The four study sites, consisting of three abandoned fields and one rangeland site.

The fields were abandoned more or less 20 years ago, and were left without human interference to date. The only interference however, was grazing by cattle twice per year. The rangeland was grazed at the recommended long term grazing capacity of 6 ha LSU^{-1} and the abandoned fields when material was available. The vegetation recovery of the three abandoned fields was slightly different in degree of recovery. The AF3 site was the best recovered (although still very poor) and AF1 the worst recovered. The natural rangeland (NR) was used as benchmark to compare the abandoned fields against. Within each of the three abandoned fields, five blocks were demarcated. Each block was 20 m x 20 m in size and subjectively selected. These blocks were however chosen subjectively to represent a *T. triandra* frequency gradient. The aim was to subjectively choose a gradient ranging from 0% of *T. triandra* up to the highest possible occurrence of *T. triandra.* There were 15 blocks in the abandoned fields. Six blocks of 20 m X 20 m were randomly laid out on the natural rangeland, also with different percentages of *T. triandra.*

4.1.2 Species composition

Species composition was determined for each of the four study sites (AF 1-3 and NR). It was however also measured individually for each of the 21 smaller blocks (Appendix A). The species composition of the herbaceous layer of the abandoned fields and rangeland were estimated by frequency of occurrence, using the wheel-point apparatus (Tidmarsh & Havenga 1955). On each site (AF 1-3 and NR) four 200 m transects (east to west) were recorded (by the wheel-point apparatus) with transects spaced 100 m apart. In total 50 points were taken on each transect, which resulted in 200 points per site. Nearest plant was recorded when no strike occurred. The line point method, using a marked rope was used to determine species composition in the blocks. The rope was marked every one meter. Six transects (east to west), three meters apart were used and recordings were made every one meter. This gave a total of 120 points per block. As for the sites where no strike occurred, the nearest plants were recorded (Mentis 1981; Vorster 1982; Du Toit 1995).

4.1.3 Grazing capacity

Grazing capacity was determined for each of the four sites, as well as individually for each of the 21 blocks. The method used was as described by Acocks (1988) to calculate the grazing capacity. It is a dry matter yield method where the plant material of a number of quadrates of known size are cut and extrapolated to yield in kilogram per hectare. Twenty quadrates of 0.5 m^{-2} were randomly placed throughout each of the four sites. Each of the blocks were divided into quarters, after which five randomly placed quadrates were cut in each segment for the measurement of aboveground phytomass yield (Acocks 1988; Hardy & Mentis1985). The plants were defoliated to stubble height of 30 mm and oven dried at 70°C to constant weight. Aboveground phytomass was divided into utilizable and non-utilizable plant species before drying the plant material. The percentage utilizability of each species was used in relation to the time of year it was sampled (Van der Westhuizen *et al.* 1999). The technique used was an adaption of the key species index for weighted species occurrence (Heard *et al.* 1986). For this study, plant species were separated and linked with mean percentage preference utilization ratio during the growing season (Van der Westhuizen *et al.* 2001). Rare species not listed by Van der Westhuizen *et al.* (2001) were based on previous literature where the rare species' preference utilization ratio was equated with that of a species for which data were gathered. An utilizability average over the span of one year was used for the calculations (Van der Westhuizen *et al.* 2001). A large stock unit (LSU) defined as the equivalent of a steer (450 kg) gaining 500 g per day on forage with a mean digestibility of 55% (Meissner *et al.* 1983) and utilizing 10 kg dry material per day on average, was used as the unit.

4.1.4 Determination of soil seed bank

The soil seed bank was determined to quantify the potential number of plant species present and seed bank size in the soil. The soil sampling was done in September and repeated in December. Germination in the December trial could include seeds from the previous season's seed production. With these results it would be possible to determine seeds present in the soil and their role in the poor distribution and occurrence of for example climax plants such as *T. triandra* on abandoned fields.

The soil seed bank study was conducted in the greenhouse from September to May, 2012. The respective day and night temperatures were 32℃ (±2 ℃) and 18℃ (±2 ℃). Soil was randomly collected between plant species in each quarter of a block. The soil was taken from the upper 50 mm of the A horizon. The reason for this was that the soil is characterised by the species' distribution. Soil samples were evenly spread (50 mm deep) in plastic buckets (2 L) containing a 50 mm layer of Hygrotech growth medium (Canadian peat, polystyrene vermiculite and monoammonium phosphate). The buckets were randomly placed in the greenhouse and hand-watered daily to keep the top soil layer moist. Seedling emergence was recorded daily and seedlings were removed after identification over the span of three months. A weed was defined as a nongrass, which is considered undesirable (Snyman 2013).

4.1.5 Basal cover

Basal cover of the herbaceous layer of the abandoned fields and rangeland were estimated by frequency of hits in the crown and basal areas of the plant, using the wheel-point apparatus (Tidmarsh *et al.* 1955). On each site (AF 1-3 and NR) four 200 m transects (east to west) were recorded with transects spaced 100 m apart. In total 200 points were taken on each transect. The percentage basal hits expressed the basal cover of each site.

4.1.6 Statistical analyses

The effect of plant characteristics on the percentage *T. triandra* occurrence were analyzed using a fully randomized one way ANOVA design. The PROC ANOVA procedures of the SAS program (SAS 2010) were used to test for significant differences between treatments. When significant differences were identified ($P \leq 0.05$) a further multiple comparison test, Tukey's honest significant difference (HSD) test, was used to identify these differences.

4.2. Results and discussion

The species composition of rangeland dominated by unsown natural vegetation was compared to previously cultivated fields, named abandoned fields (Appendix B). Although their plant communities are natural, their maintenance depends upon management activities such as low-intensity farming, which manages these rangelands. These rangelands contain various species, with adaptability and therefore species composition which can be affected by severe drought and poor management (Snyman & Van Rensburg 1990). However, drought seasons, even without grazing, are responsible for much change in the community (Snyman *et al.* 1990).

Species on the three abandoned fields and the rangeland (control) were identified and compared to validate differences (Tables 4.1 & 4.2). These four sites were divided into 21 blocks, with soil samples taken from each block for seed bank evaluation (Tables 4.3, 4.4, 4.5, 4.6 and Figure 4.3). The comparison of grazing capacity between the abandoned fields and rangeland is presented in Figure 4.4.

4.2.1 Species composition of vegetation in the field

The observed species richness is affected not only by the number of individuals, but also by the heterogeneity of the sample (Snyman 2013). If individuals are drawn from different environmental conditions (micro-climate) such as in the abandoned fields and rangeland, the species richness of the resulting data can be expected to be higher than if all individuals are drawn from similar environments (micro-climate) (Snyman 2013). The poor basal cover in the abandoned fields led to a higher soil temperature and a lower soil water content. Increasing the sampling area, will increase observed species richness because more individuals get included in the sample area as large areas are environmentally more heterogeneous than small areas. Therefore species composition was measured over the entire study area to make it more significant.

It is clear from Table 4.1 that climax grasses, such as *T. triandra* (67.91%) and *D. eriantha* (27.93%) dominated in the rangeland (Figure 4.1). In AF3, *T. triandra* (36.9%) was more abundant because of a more natural rehabilitated state. No previously artificial rehabilitation was implemented. A clear indication of degradation is indicated by a high percentage of pioneer grasses, with a total percentage varying between 30% and 60% in the abandoned fields (Figure 4.2). In these abandoned fields, *A. congesta* dominated. The low total percentages of climax grasses in the abandoned fields indicate a lack of rehabilitation over a span of 20 years. Species in Table 4.1 with a r^2-value higher than 0.50 can be used to indicate the change in vegetation dynamics, because more than 50% of the difference in species composition follows a degradation gradient (Van der Westhuizen 2003). According to Van der Westhuizen (2003), if rangeland condition (RC) is 10%, 30%, 50%, 70% and 90% the rangeland is very poor, poor, reasonable, good and excellent, respectively. According to his research the RC of the study at Verkeerdevlei is very poor (13%), poor (32%), reasonable (54%) and good (78%) in AF1-3 and NR, respectively (Table 4.1). On average, the abandoned fields were poor in comparison to NR which was in a good condition (Figure 4.1).

Figure 4.1 Natural rangeland dominated by *Themeda triandra.*

Figure 4.2 Abandoned fields dominated by pioneer grass species.

It was also expected that *Aristida bipartita* would only occur in the abandoned fields with an early inspection of the area. In total, the climax component made up 96.99% of the botanical composition of the rangeland, of which *T. triandra* formed 67.91%. On the other hand, the abandoned fields had only 23.12% climax species and were dominated by 41.40% pioneer species. On the same rangeland type, Snyman (1998) documented a 75% dominance of *T. triandra* when rangeland is in good condition, while Snyman & Van der Westhuizen (2012) found 80% and 60% dominance of *T. triandra,* respectively, on excellent and good rangeland condition, also on the same veld type.

Table 4.1 Species composition (%) of the natural rangeland (NR) and abandoned fields (AF1-3), as well as the rangeland condition for each site.

Species	**Site**				
	AF1	**AF2**	**AF3**	**AF (AVG)**	**NR**
Climax					
Cymbopogon pospischili	0.38	0.09	0.80	0.42	
Digitaria eriantha	0.57	0.57	2.51	1.22	27.93
Heteropogon contortus	4.12	0.09	0.44	1.55	
Setaria sphacelata var. sphacelata					1.15
Sporobolus fimbriatus			0.09	0.09	
Themeda triandra	6.51	16.11	36.9	19.84	67.91
Climax total	11.59	16.87	40.74	23.12	96.99
Sub-climax					
Aristida bipartita	19.42	41.83	16.21	25.82	
Aristida diffusa	0.19			0.19	
Eragrostis bicolor	1.80	3.41	0.54	1.92	
Eragrostis chloromelas	1.36	1.24	2.72	1.77	0.08
Eragrostis lehmanniana	0.10	0.27	0.27	0.21	
Eragrostis plana	9.07	2.81	3.73	5.20	0.31
Panicum stapfianum	0.57	0.29	0.76	0.54	2.29
Sub-climax total	32.49	49.86	24.23	35.66	2.68
Pioneer					
Aristida congesta	52.78	32.9	32.39	39.36	
Cynodon dactylon	2.65	0.19	1.80	1.55	0.17
Chloris virgata	0.40	0.18	0.83	0.47	
Eragrostis obtusa					0.16
Tragus racemosa	0.08			0.08	
Pioneer total	55.91	33.27	35.02	41.45	0.33
Total	100.00	100.00	100.00	100.00	100.00
Rangeland condition (%)	13.00	32.00	54.00	33.00	78.00
Basal cover (%)	2.25	2.45	4.47	3.06	6.12

Rangeland condition was estimated in relation to the percentage *T. triandra* according to the degradation model of Van der Westhuizen (2003). If the species composition changes it can dramatically influence the soil-water balance, production, nutrient cycling, foliage quality, soil loss and fire behaviour (O'Connor & Bredenkamp 1997). In Table 4.2 the effect of vegetation degradation is statistically presented. There was significantly ($P>0.05$) more pioneer grasses in the abandoned fields than in the natural rangeland. The sub-climax species were more evenly spread throughout the studied area. The climax species were as expected, significantly more abundant ($P<0.05$) in the NR than in the abandoned fields. This botanical composition clearly showed that the NR was in a good condition at the onset of the study with the opposite true for the abandoned fields. The rangeland condition as well as the basal cover increased with improved field conditions (Table 4.1).

Table 4.2 Mean (± SE) species composition, grouped as climax, sub-climax and pioneer species. Column means with different letters are significantly different (P<0.05).

Specie	Status		
	Pioneer	Sub-climax	Climax
NR	0.33^{b}	2.68^{c}	96.99^{a}
	± 1.10	± 0.53	± 0.69
AF 1	55.91^{a}	32.49^{ab}	11.59^{b}
	± 7.24	± 8.14	± 6.38
AF 2	33.27^{a}	49.86^{a}	16.87^{b}
	± 6.55	± 6.08	± 8.57
AF 3	35.02^{a}	24.23^{bc}	40.74^{b}
	± 10.22	± 7.33	± 17.24
SE	± 5.44	± 4.75	± 8.91

4.2.2 Seed bank study in greenhouse

Seed germination depends on both internal and external environmental conditions (Bewley & Blade 1982).

4.2.2.1 Seed bank density

The seed bank for determining seed density was investigated (Figure 4.3) at the end of September (spring - before the new seed set) and at the end of December (summer - after the first seed production event). The phenological pattern of the vegetation in the study area is characterised by these two seed setting periods every season under normal rainfall conditions. Snyman (2012) mentioned the significance of allowing for seasonal variability in the availability of readily germinable seeds.

There were a decrease in species (P<0.05) germination in December with rangeland degradation. In September the seed bank density of the abandoned fields was significantly higher (P<0.05) than that of the rangeland. This might be caused by the high percentage of pioneer and sub-climax species that are dominating the abandoned fields, which are generally higher seed producers than climax species. Within a site the seed bank density was higher (P<0.05) during September than in December. The highest seed bank density of 213 seedlings m^{-2} was recorded from AF3 (Figure 4.3). The seedling densities for rangeland of 115 and 109 seedlings m^{-2} for September and December, respectively, compared well with that obtained by Snyman (2013) on the same soil form. A seed bank size as high as 138 seeds m^{-2} can be obtained for *T. triandra* (Snyman 2004). According to Snyman (2004) a mean seasonal seed bank density of rangeland in good, moderate and poor condition, was respectively 48, 74 and 98 seedlings m^{-2} for October and 28, 32 and 40 seedlings m^{-2} for January. The tendency of germination in Table 4.3 and Table 4.4 compares well to the seasonal seed bank density of Snyman (2004).

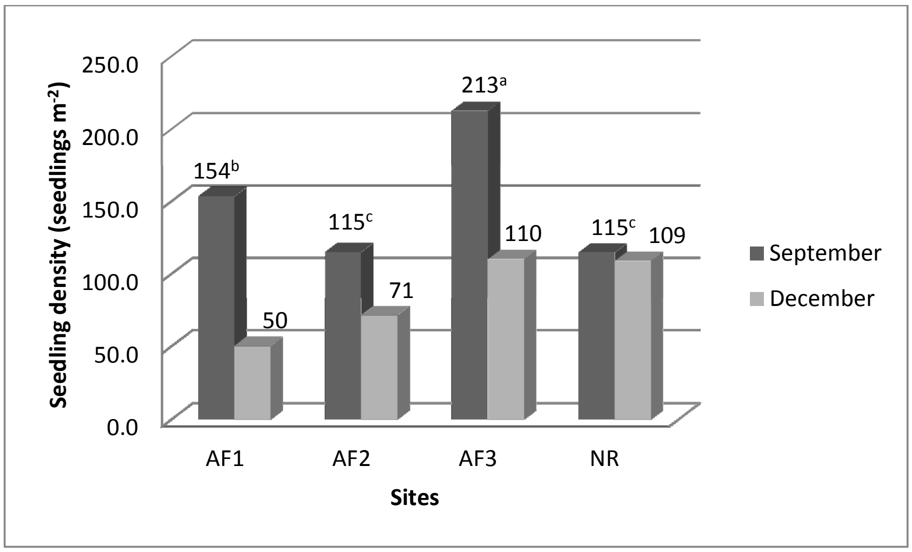

Figure 4.3 Mean seedling density (seedlings m^{-2}) of rangeland species emerging in the natural rangeland and abandoned fields. Bar means with different letters in the superscript are significantly different (P<0.05).

4.2.2.2 Seed bank composition (richness)

Emergence of climax, pioneer and weed species differed significantly (P<0.05) between the NR and abandoned fields for the September germination (Table 4.3). Climax grasses showed significantly (P<0.05) higher seedling emergence (80 seedlings m^{-2}) in the NR compared to that of the abandoned fields with 0 seedlings m^{-2}, 5 seedlings m^{-2}, 46 seedlings m^{-2} for AF1-3, respectively, (Table 4.3). By contrast, seedling emergence of pioneer grasses in AF1-3 (141 seedlings m^{-2}, 105 seedlings m^{-2}, 162 seedlings m^{-2}, respectively), were significantly (P<0.05) higher than that in the natural rangeland (14 seedlings m^{-2}). Climax grasses (plants m^{-2}) were much higher (80) in the natural rangeland than in the abandoned fields (51). In the abandoned fields pioneer species such as *A. congesta* and *C. virgata* dominated, with *T. triandra* as the leading climax grass species in the rangeland. *Cymbopogon pospischilii* was not found in the rangeland but only in AF3, which is in contrast with the species composition.

Table 4.3 Germination (seedlings m^{-2}) from soil collected on the abandoned fields and rangeland in September. Row means with different letters in the superscript are significantly different (P<0.05).

Species	**Site**				
	AF1	**AF2**	**AF3**	**AF (*avg)**	**NR**
Climax					
Cymbopogon pospischili			8.00	8.00	
Digitaria eriantha					19.00
Paspalum dilatatum			6.00	6.00	
Themeda triandra		5.00	32.00	18.50	61.00
Climax total	0.00^{b}	5.00^{b}	46.00^{ab}	17.00^{b}	80.00^{a}
SE	± 0.00	± 4.80	± 27.06	± 10.15	± 12.04
Sub-climax					
Aristida bipartita		3.00	3.00	3.00	
Eragrostis bicolor		2.00	1.00	1.50	6.00
Eragrostis chloromelas					10.00
Eragrostis lehmanniana	13.00		1.00	7.00	2.00
Panicum stapfianum					3.00
Sub-climax total	13.00^{a}	5.00^{a}	5.00^{a}	7.67^{a}	21.00^{a}
SE	± 8.24	± 3.20	± 3.20	± 3.07	± 10.66
Pioneer					
Aristida congesta	28.00	6.00	59.00	31.00	11.00
Brachiaria eruciformis		43.00		43.00	
Chloris virgata	97.00	34.00	70.00	67.00	
Cynodon dactylon	16.00	22.00	33.00	23.70	
Weeds					
Cyperus esculentus					3.00
Pioneer and weeds total	141.00^{ab}	105.00^{ab}	162.00^{a}	136.00^{a}	14.00^{b}
SE	± 28.35	± 21.08	± 55.91	± 21.32	± 8.92
Total	154.00^{b}	115.00^{c}	213.00^{a}	161.00	115.00^{c}

*avg = average

The tendency of *T. triandra* to increase with an increase in rangeland condition is also evident in the number of seedlings in the December soil seed bank germination (Table 4.4). The relatively low seed densities found in the rangeland are similar to that found on other rangelands, which usually display smaller seed banks (Bakker 1989; O'Connor & Bredenkamp 1997; Snyman 2005; Kassahum *et al.* 2009; Everson *et al.* 2009) than that of abandoned fields (Jensen 1969). Emergence of sub-climax, pioneer and weed species' seedlings was not significantly (P>0.05) different between the NR and abandoned fields for the December germination (Table 4.4). Climax grasses' seedling emergence was significantly higher (P>0.05) in the NR compared to that of the abandoned fields (Table 4.4).

September germination was characterized by fewer weed species (1) than the December germination (6) (Table 4.3 & 4.4). The fewer seedlings might be because of less competition in the soil seed bank after grass seed failed to germinate under environmental conditions not optimal for germination. The better September germination may be due to environmental factors, such as soil-water which is a key limiting factor for seedling establishment, affecting the seed after the first rain (Snyman 2004).

Table 4.4 Germination (seedlings m^{-2} from soil collected on the abandoned fields and rangeland in December). Row means with different letters in the superscript are significantly different (P<0.05).

Species	**Site**				
	AF1	**AF2**	**AF3**	**AF avg**	**NR**
Climax					
Themeda triandra	3.00	19.00	24.00	15.30	53.00
Heteropogon contortus			5.00	5.00	
Climax total	3.00^{b}	19.00^{b}	29.00^{ab}	17.07^{a}	53.00^{a}
SE	± 1.96	± 10.91	± 28.80	± 9.93	± 13.33
Sub-climax					
Aristida bipartita		1.00		1.00	
Eragrostis chloromelas			10.00	10.00	15.00
Eragrostis lehmanniana		2.00		2.00	6.00
Eragrostis plana		5.00		5.00	
Sub-climax total	0.00^{a}	8.00^{a}	9.60^{a}	5.87^{a}	21.00^{a}
SE	± 0.00	± 6.20	± 5.88	± 2.87	± 12.68
Pioneer					
Aristida congesta	13.00	26.00	5.00	14.70	
Brachiaria eruciformis					5.00
Chloris virgata	9.00	11.00	21.00	13.7.00	
Cynodon dactylon			40.00	40.00	6.00
Weeds					
Argemone ochroleuca	7.00			7.00	
Chenopodium album	3.00			3.00	
Cyperus esculentis					3.00
Gnaphalium luteo-album	9.00		6.00	7.5.00	11.00
Paronychia brasiliana					4.00
Schkuhria pinnata	6.00	7.00		6.50	6.00
Pioneer and weeds total	47.00^{a}	44.00^{a}	72.00^{a}	54.30^{a}	35.00^{a}
SE	± 14.68	± 14.99	± 30.15	± 11.81	± 14.69
Total	50.00	71.00	111.00	77.00	109.00

The December collection (Table 4.4) indicated a significant difference ($P<0.05$) in the climax germination. The climax grasses germinated less in the abandoned fields (17 seedlings m^{-2}), while the opposite happened to the pioneer grasses and weeds. Pioneer grasses and weeds were more abandoned in the abandoned fields, while sub-climax, pioneer and weed species had no significant difference ($P>0.05$) in terms of germination.

4.2.2.3 Similarity between seed bank and vegetation in the field

The species composition of both the soil seed bank and field were dominated by pioneer grass species and weeds in the abandoned fields. The same tendency was reported by Bekker *et al.* (1997) who found that previously cultivated fields reduce the heterogeneity of seed banks within the soil, thereby delaying recovery of floristically diverse rangelands. By contrast, species composition of the seed bank and field was dominated by climax grasses in the natural rangeland.

Vegetation in the field differs in species richness from the seed available in the seed bank. There were six climax grass species identified in the field while only two climax grass species emerged in December and four in September in the soil seed bank. Sub-climax species were more evenly spread with seven species identified growing in the field but only four emerged in December and five in September from the soil seed bank. There were five pioneer grass species identified in the field with four emerging in December and four in September from the soil seed bank. The reason for more weeds in December may be ascribed to temperatures which were more suitable for germination.

4.2.3 Current grazing capacity

Generally, grazing capacity is considered to be the average number of animals that a particular area will sustain over time without rangeland degradation (Van der Westhuizen *et al.* 1999). If the production potential of rangelands is over-estimated, it is called overgrazing and will result in a decrease of the palatable perennial plants in favour of less palatable, undesirable vegetation (Fourie & Fouché 1985; Danckwerts & Tainton 1996). These changes will influence the hydrological status, stability, quality, productivity, and utilization potential of the rangeland (Van der Westhuizen *et al.* 1999; Snyman & Fouché 1991; Snyman 1998). For this study, grazing capacity of the current season was measured for comparison purposes. The long-term grazing capacity may differ from what was measured. From Figure 4.4 it is clear that rangeland condition declined over the abandoned fields with grazing capacities ranging on average from 13 to 45 ha per large stock unit (ha LSU^{-1}).

Abandoned field one were the poorest (45.05 ha LSU^{-1}) with AF3 (13.13 ha LSU^{-1}) the most rehabilitated. Van der Westhuizen (2003) proposed a method to predict grazing capacity from rangeland condition, which in turn is related to the percentage of *T. triandra.*

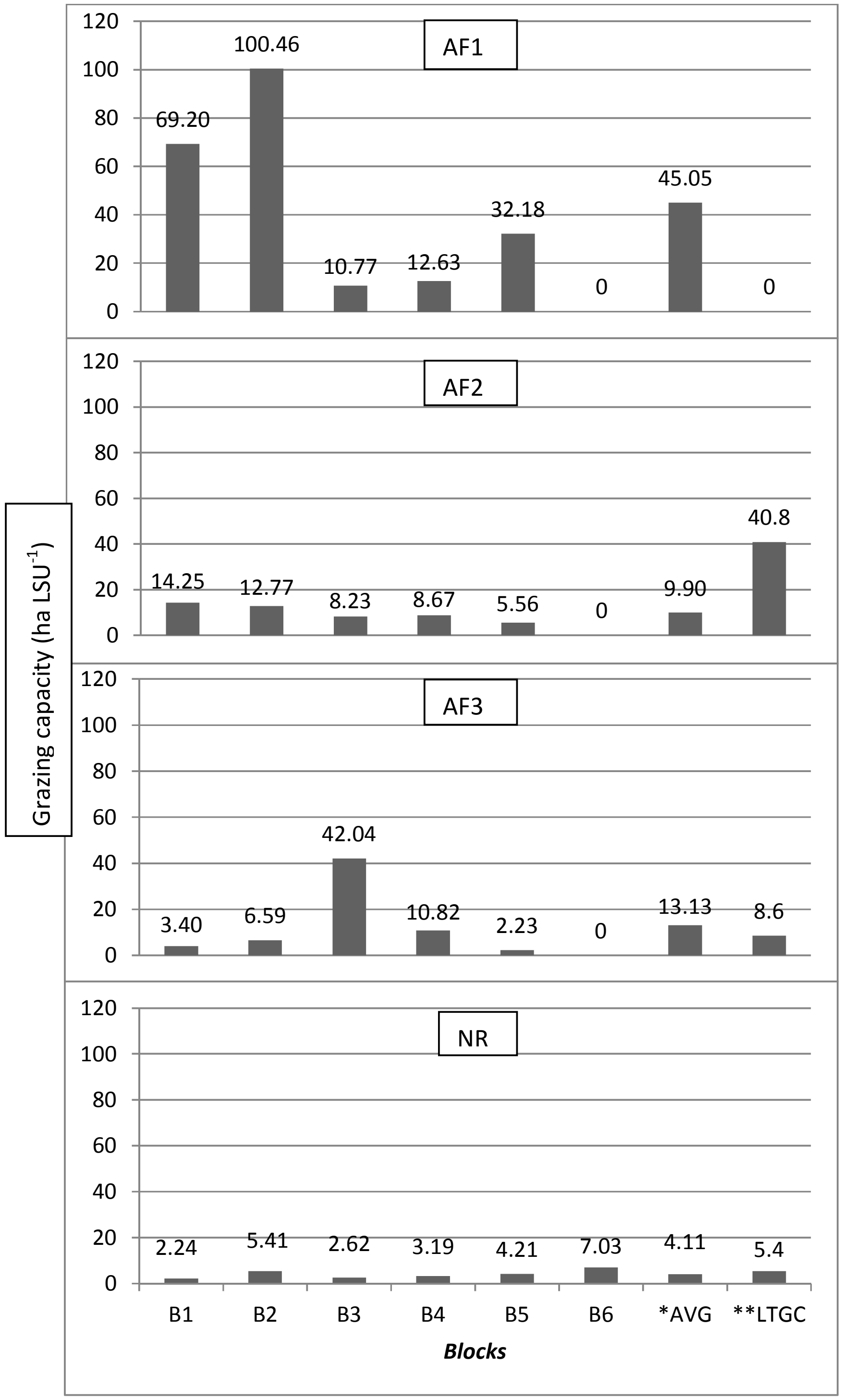

Figure 4.4 Mean grazing capacity (ha/LSU) of the abandoned fields and rangeland as well as for each block within each site. (*avg=average **LTGC=long term grazing capacity).

According to the method of Van der Westhuizen (2003), the long-term grazing capacity was estimated as 0 ha LSU^{-1}, 40.8 ha LSU^{-1} and 8.6 ha LSU^{-1} for AF1-3, respectively, and 5.4 ha LSU^{-1} for the natural rangeland. These abandoned field values indicate less income since animal production is directly related to rangeland condition (Danckwerts & Tainton 1996).

In Figure 4.4 the four sites from AF1-3 and natural rangeland were evaluated by 21 different blocks, five in each site. The average grazing capacity gives a good indication of current site productivity. Abandoned field one Block two had the lowest grazing capacity value (100 ha LSU^{-1}). Something drastically needs to be done to upgrade these unproductive areas when compared to the high grazing capacity of 4.12 ha LSU^{-1} obtained from the natural rangeland. The proposed grazing capacity of this area if in excellent, good, moderate and poor condition is: 6.3 ha LSU^{-1}, 9.7 ha LSU^{-1}, 10.4 ha LSU^{-1} and 18.9 ha LSU^{-1}, respectively (Van der Westhuizen *et al.* 2001). Livestock farmers cannot afford such low productive areas; therefore the botanical composition must be improved to increase the grazing capacity. A better botanical composition on the abandoned fields had to be the aim of the owner to increase its grazing capacity. A sustainable ecosystem is the only way of obtaining a stable fodder flow which is not possible from these abandoned fields.

Grazing capacity, according to Van der Westhuizen (2003), is determined by rainfall, ground water, soil type, evapotranspiration, rangeland condition, topography and animal type. The long-term grazing capacity is the grazing potential of the area over an 11 month period. Van der Westhuizen (2003) concluded that the long-term grazing capacity is more important than that of the immediate production potential. Long-term grazing capacity declines as rangeland condition deteriorates (Figure 4.4) (Van der Westhuizen 2003).

4.2.4 Basal cover

Species composition and basal cover characterize rangeland condition (Wiegand *et al.* 2004). The study at Verkeerdevlei had a basal cover percentage of 2.25%, 2.45%, 4.47% and 6.12% in AF1-3 and NR, respectively, (Table 4.5). The average basal cover also indicates a 50% decline from natural rangeland to the abandoned fields. According to Wiegand *et al.* (2004), mean phytomass production per unit of basal cover showed a tendency to decline from good to poor rangeland condition. A decline in basal cover will reduce the aboveground phytomass (Wiegand *et al.* 2004). The same tendency was found in the trials at Verkeerdevlei.

Table 4.5 Basal cover percentage of the three abandoned fields and the natural rangeland.

Sites	AF1	AF2	AF3	AF (avg)	NR
			%		
Basal cover	2.25	2.45	4.47	3.06	6.12

4.2.5 Conclusion

Rangeland condition determinations are of little value to a farmer if not linked to rangeland management (Van der Westhuizen *et al.* 2001). The importance of *T. triandra* as a key species for this rangeland type is continually emphasized. This species is not only the ecologically most important species in the study area, but also a very good indicator of rangeland condition (Van der Westhuizen *et al.* 2001). After 20 years of no cultivation, the abandoned fields have not recovered naturally to an acceptable state. If nothing is done to rehabilitate these areas, it might still be in the same poor condition after another few years.

Abandoned field one had a zero long-term grazing capacity (Figure 4.4) and therefore needs human intervention for the re-establishment of vegetation. Such an intervention may involve the establishment of *D. eriantha* subs. *eriantha* as a cultivated pasture. This area is still not utilizable for grazing after 20 years. Abandoned field two had a high long-term grazing capacity (40.8 ha LSU^{-1}) (Figure 4.4). A light grazing frequency throughout the winter and rest through the summer may be a good recommendation. Abandoned field three had a reasonable grazing capacity (8.6 ha LSU^{-1}) and may improve over time with a proper grazing management system (Figure 4.4).

The degree of species dissimilarity (Table 4.1) and shifts in ecological status in the seed bank (Table 4.3 and 4.4) also provided a good estimate of how far the system has diverged, indicating the potential of seed reserves to restore vegetation. Thus, differences in the soil seed bank are likely to reflect soil seed bank properties, rather than short-term changes. It clearly demonstrates that the composition of the seed bank depends not only on the composition and production of the present and previous plant communities, but also on the longevity of the seeds of each species under local conditions.

The study concluded that the weakest seed bank of climax grasses was found in the poorest abandoned field (AF1). This abandoned field needs re-establishment of climax grasses. For speedy recovery, species like *Digitaria eriantha* subs. *eriantha* could be sown into the abandoned field. In AF2 sheafs of *T. triandra* could be placed to form a suitable micro-climate to ensure a speedy improvement of the botanical composition. The best abandoned field's (AF3) botanical composition can be improved by implementing scientific rangeland management systems which include long periods of rest.

Chapter 5

Soil dynamics

5.1 Materials and methods

5.1.1 Trial layout

Trial layout was the same as discussed in detail in chapter 4.

5.1.2 Soil sampling

Soil samples for characteristic analyses were collected on a grid basis from corner to corner in each block (20 m x 20 m) (Figure 5.1). Ten samples in each block were collected at three depths resulting in 30 samples per block. The 10 samples per depth were mixed for each block and used as a representative sample per block. This constitutes three samples per block and 63 in total for the 21 blocks. A soil core sampler (250 mm by 30 mm) was used to collect soil samples at the three different depths (0-50 mm; 50-100 mm and 100-200 mm). The different depths indicate different plant root zones and also different soil characteristics (Appendix B). The 0-50 mm and 50-100 mm samples had a volume of 35.4 cm^3, while the volume of the 100-200 mm samples was 70.7 cm^3. The soil was oven-dried at 55 °C for five days until completely dry.

Textural fractions and organic matter were analysed from the core sample extractions. Bulk density samples were taken with a core sampler with a diameter of 50.5 mm and a height of 116.5 mm. This was done from the top soil layer in the centre of the two grid lines in each block (Figure 5.1). These samples were taken in duplicate. The soil surface compaction was analysed for each block by taking 10 measurements (Figure 5.1). These measurements were randomly taken to reduce error.

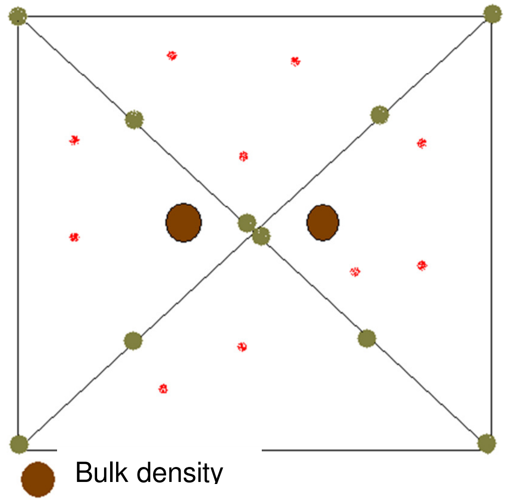

Figure 5.1 Soil sampling in each of the 21 blocks.

5.1.3 Soil chemistry

The samples were analysed in terms of pH, phosphorus (P), carbon (K), potassium (Na), calcium (Ca), magnesium (Mg), hydrogen (H^+), and cation exchange capacity (CEC). Standard methods (NASAW 1990) were used to analyse soil samples for pH (1:2.5 soil to 1.0 M KCl suspension), extractable P (Bray 1), extractable acidity (1 M KCl), exchangeable cations, and cation exchange capacity (1 mol dm^{-3} NH_4OAc at pH 7). Cation-exchange capacity (CEC) is the maximum quantity of cations that a soil is capable of holding at a given pH value available for exchange with the soil solution (Soil Conservation Service 1984). The method to analyse Ca:Mg, (Ca+Mg:K), Mg:K, and Na:K is based on exchangeable cations in the soil (FSSA 1986).

5.1.4 Soil organic matter

Two grams of each sample were burnt and analysed by a Leco Truspec Nitrogen/Carbon determinator for nitrogen and carbon (N and C) content. The instrument was connected to an external PC by using a Windows®-based software program to control the system operation and data management (The non-affiliated Soil Analysis Committee 1990).

5.1.5 Particle size distribution

The particle size distribution of soil expresses the different proportions of the mixture of particle sizes it contains. The sieve and pipette method was used for particle size distribution quantification (NASAW 1990). Soil particles are distinct units comprising the solid phase of soil. The particles cluster together most of the time as aggregates, but can be separated from each other by chemical and mechanical methods. Particles have a diverse composition and differ among soil types, as well as in size and shape.

The methods used for the 63 samples were limited to sieving and sedimentation procedures (NASAW 1990). For the coarse fraction (>2 mm), the soil sample was dried and gently crushed through a two mm sieve. Samples were weighed to 50 g, while the dispersed sample was washed through a 0.053 mm sieve. Silt and clay passed through the sieve via a funnel into a 1000 cm^3 cylinder. Samples had to be washed until the percolate was clear. The sand fraction was moved to a beaker and dried at 105°C. Dried samples were transferred to a nest of sieves arranged from top to bottom in decreasing sizes in the following order: 0.5, 0.25, 0.106 and, 0.053 mm and a pan collected the excess small particles. Samples were shaken on a sieve shaker for approximately 10 minutes. The different sieves were weighed with and without sand to determine the sand fraction (NASAW 1990).

Silt and clay fractions were determined with the pipette method (NASAW 1990). The washed silt and clay suspension were placed in a cylinder and filled to the 1 dm^3 mark. The cylinder was stored at a constant temperature of 21°C which indicated the room temperature at that time of year. After equilibration, the suspension was stirred for 30 seconds in a vertical direction. After being stirred, (Table 5.1) for the 0.05 mm fraction (coarse silt + fine silt + clay), a closed Lowry pipette was lowered to a depth of 30 cm into the suspension. In total 25 cm^3 of clay and silt in water were withdrawn by gentle suction and dried at 105°C. The same was done for the samples of the following depths namely 70 mm and 100 mm. The periods of suction are given in (Table 5.1). These samples were weighed and calculated to a percentage above 95% (NASAW 1990).

Table 5.1. Sedimentation times of fine silt and clay as a function of temperature (NASAW 1990).

Temperature	0.05 mm (coarse silt)		0.02 mm (fine silt)		0.002 mm (clay)	
°C	Minutes	Seconds	Minutes	Seconds	Hours	Minutes
15	1	31	5	17	6	10
16	1	29	5	9	6	1
17	1	27	5	1	5	51
18	1	25	4	53	5	42
19	1	22	4	46	5	34
20	1	20	4	39	5	26
21	1	18	4	32	5	30
22	1	16	4	26	5	17
23	1	15	4	20	5	3
24	1	13	4	14	4	56
25	1	11	4	8	4	49

The calculation of the different soil fractions were done as follows (NASAW 1990):

Sand fraction:

Percentage of sieved sand fractions = (A x 100)/F.

Silt and clay fractions:

Percentage coarse silt = (((B-C) x 1000 x 100)/F x 25) + (G x 100)/F,

Percentage fine silt = ((C-D) x 1000 x 100)/F x 25 and

Percentage clay = ((D-E) x 1000 x 100)/F x 25.

Where:

A = mass (g) of sand fraction on sieve,

B = mass (g) of pipette coarse silt plus fine silt plus clay,

C = mass (g) of pipette fine silt plus clay,

D = mass (g) of pipette clay,

E = mass correction of dispersing agent (0.01 g),

F = mass (g) of pre-treated oven-dried total sample and

G = mass (g) of residual silt and clay that passed through the 0.053 mm sieve.

Particle size classes are presented in (Table 5.2). Soils generally contain organic matter, gypsum and often iron oxides/hydroxides, aluminium oxides/hydroxides and carbonate coatings that bind particles and may prevent dispersion. Pre-treatments are used to overcome this problem. After pre-treatment, chemical dispersion is accomplished by using sodium hexametaphosphate (NASAW 1990).

Table 5.2. Soil particle size classes (NASAW 1990).

Class	Diameter (mm)	Method of separation
Gravel	>2	sieve
Coarse sand	2.0-0.5	sieve
Medium sand	0.5-0.25	sieve
Fine sand	0.25-0.106	sieve
Very fine sand	0.106-0.05	sieve
Coarse silt	0.05-0.02	sedimentation
Fine silt	0.02-0.002	sedimentation
Clay	<0.002	sedimentation

5.1.6 Soil physics

5.1.6.1 Bulk density

The method for determining bulk density was adapted from other methods used to calculate bulk density (Blake & Hartge 1986). The core sample consisted of a fixed volume. Two core samples were taken in each sampling area (block) in the centre of the grid lines (Figure 5.1). To prevent inaccuracy the core sampler was placed over a level area of soil devoid of any vegetation and stones that might influence the level inflow of the core sampler, to prevent inaccuracy. The edge of the cylinder was sharpened on one side to make it easier to drive the cylinder into the soil. The soil core was levelled off with a sharp object. Only the top soil layer (0-116.5 mm) was collected and sealed in a plastic bag to minimize water escaping through evaporation. Collecting wet samples enables the calculation of dry samples and also the bulk density, as well as the gravimetric and volumetric water content of the soil (Blake & Hartge 1986). The soil samples were dried at 80℃ for 72 hours and the dry mass was expressed as per unit volume of soil (Blake & Hartge 1986). By drying the soil samples, the water content of the soil was determined by the difference in mass.

The following equations were used:

- Bulk density Db = Ms/Vb

  Where Ms = soil dry mass (kg) and

  Vb = total soil volume.

- Gravimetric and volumetric water capacity

  Where Vol = (BD.Grav) x 100 and

  Grav = Wet mass-Dry mass/Dry mass.

5.1.6.2 Surface compaction

Soil compaction or penetration resistance was measured with a rod penetrometer (ELE pocket penetrometer) in each block (Friedel 1987; Snyman 2003a). Two compaction readings were taken in each block, one in the middle of two grass tufts and the second at the base of a grass tuft. With this technique, it was accepted that the more compacted the soil, the less the penetration of the penetrometer into the soil.

5.1.7 Statistical analyses

The effect of soil characteristics on the percentage *T. triandra* occurrence were analyzed using a fully randomized one way ANOVA design. The PROC ANOVA procedures of the SAS program (SAS 2010) were used to test for significant differences between treatments. When significant differences were identified ($P \leq 0.05$) a further multiple comparison test, Tukey's honest significant difference (HSD) test, was used to identify these differences.

5.2 Results and discussions

Soil characteristics that were tested are discussed under different subheadings. Soil physical and chemical characteristics were arranged separately, while organic matter content and particle size distribution were also discussed separately. The soil characteristics of the rangeland were compared to that of the abandoned fields.

5.2.1 Soil chemical characteristics

5.2.1.1 pH

Soil pH showed no significant ($P>0.05$) differences between NR and the abandoned fields over all soil layers. The soil pH therefore had no effect on the degradation gradient of rangeland condition from natural rangeland to abandoned fields. According to Memiaghe

(2008) there was a major difference in pH on abandoned fields (after 10-20 years) as a function of depth, ditch and slope. He came to the conclusion that pH might be one of the important parameters driving the persistence of undesirable grass species on abandoned fields. Nutrient and toxin availability were also related to pH (Memiaghe 2008). Garcia *et al.* (2007) concluded that pH differs between abandoned fields and was lowest where the percentage grass cover was highest, while Walton (2006) stated that pH decreased with time until neutral levels were reached in more humid areas. Likewise, Guo-Hong (2002) concluded that pH decreased with number of years following abandonment.

Table 5.3 Soil pH (KCl) (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Depth (mm)			
Sites	0-50	50-100	100-200	0-200(*avg)
NR	4.90^{ab} ± 0.04	4.87^{ab} ± 0.03	4.96^{ab} ± 0.06	4.92^{ab} ± 0.03
AF(avg)	4.91^{a} ±0.09	4.75^{a} ± 0.12	4.72^{a} ± 0.12	4.78^{a} ± 0.11
AF 1	4.60^{b} ±0.06	4.4^{b} ± 0.10	4.38^{b} ± 0.09	4.44^{b} ± 0.08
AF 2	5.23^{a} ± 0.15	5.13^{a} ± 0.21	5.10^{a} ± 0.23	5.14^{a} ± 0.20
AF 3	4.90^{ab} ± 0.12	4.72^{ab} ± 0.15	4.70^{ab} ± 0.18	4.76^{ab} ± 0.15
SE	± 0.07	± 0.08	± 0.09	± 0.08

*avg The weighted average over all three soil depths

5.2.1.2 Phosphorus and potassium.

Phosphorus differed significantly (P<0.05) between NR and the abandoned fields over all soil layers. Over the first soil layer (0-50 mm), phosphorus was significantly (P<0.05) higher in the abandoned fields (4.22 mg kg^{-1}, 3.14 mg kg^{-1} and 3.2 mg kg^{-1} (AF1-3), respectively), than in the NR (1.73 mg kg^{-1}) (Table 5.4). Phosphorus is on average 103% higher in the abandoned fields than in the natural rangeland. For the next two soil layers (50-100 mm and 100-200 mm) P was also significantly (P<0.05) higher in the abandoned fields than in the natural rangeland. On average the abandoned fields (2.04 mg kg^{-1}) differed significantly (P<0.05) from the NR (1.16 mg kg^{-1}) in terms of P, with a 76% difference. Abandoned field one (2.66 mg kg^{-1}) had a much higher P content than that of AF2 (1.69 mg kg^{-1}) and AF3 (1.79 mg kg^{-1}).

Table 5.4 Soil P and K (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	P (mg kg^{-1})				K (mg kg^{-1})			
	Depth (mm)							
Sites	0-50	50-100	100-200	0-200(*avg)	0-50	50-100	100-200	0-200(*avg)
NR	1.73^{b}	1.34^{b}	0.79^{b}	1.16^{b}	442.03^{a}	413.37^{a}	448.93^{a}	438.32^{a}
	± 0.13	± 0.20	± 0.07	± 0.09	± 30.00	± 38.46	± 67.75	± 49.56
AF(avg)	3.52^{a}	1.93^{a}	1.36^{a}	2.04^{a}	523.46^{a}	492.12^{a}	444.98^{a}	476.39^{a}
	± 0.26	± 0.22	± 0.13	± 0.16	± 24.16	± 19.05	± 26.44	± 22.48
AF 1	4.22^{a}	2.75^{a}	1.83^{a}	2.66^{a}	480.75^{a}	449.68^{a}	395.41^{a}	430.31^{a}
	± 0.47	± 0.34	± 0.23	± 0.20	± 33.06	± 23.43	± 24.51	± 24.98
AF 2	3.14^{ab}	1.55^{b}	1.03^{b}	1.69^{b}	514.06^{a}	487.62^{a}	416.10^{a}	458.47^{a}
	± 0.39	± 0.28	± 0.13	± 0.20	± 20.54	± 25.71	± 13.17	± 14.12
AF 3	3.20^{a}	1.48^{b}	1.23^{b}	1.79^{b}	575.58^{a}	539.05^{a}	522.54^{a}	539.93^{a}
	± 0.41	± 0.20	± 0.12	± 0.19	± 58.81	± 39.91	± 65.20	± 53.54
SE	± 0.26	± 0.17	± 0.11	± 0.14	± 20.59	± 18.72	± 26.03	± 21.05

*avg The weighted average over all three soil depths

Availability of P in soil may have an influence on whether ecosystems can resist invasion by exotic plant species (Herron *et al.* 2001). Phosphorus levels can also be higher in permanently grazed grasslands than in abandoned fields in the Western Cape, South Africa (Memiaghe 2008). The opposite was found by this study at Verkeerdevlei, which correlates with a study conducted by Van der Westhuizen (2003) on the same rangeland type. According to Ruecker *et al.* (1998), available P decreased with time after abandonment.

Phosphorus plays a role in photosynthesis, growth, reproduction and maintenance of genetic identity and also respiration (Buys 1990). Cell division, root development and maturation are dependent on phosphorus in the soil medium (Buys 1990). When P increases, the growth rate increases on different levels for different species (Hill *et al.* 2005). The growth rate stagnates after about 20 mg per pot in their trial (Hill *et al.* 2005).

Potassium showed no significant (P>0.05) differences between NR and the abandoned fields over all soil layers (Table 5.4). Potassium had no effect on the degradation gradient of rangeland condition from natural rangeland to abandoned fields. Soil K can also decrease with time since abandonment (Guo-Hong 2002). By contrast, there were no differences in soil K at Verkeerdevlei.

5.2.1.3 Sodium, calcium, magnesium and hydrogen.

Sodium (Na) differed significantly ($P<0.05$) between NR and the abandoned fields over the 100-200 mm soil layer. Over the 100-200 mm soil layer, sodium was significantly ($P<0.05$) lower in the abandoned fields (55.62 mg kg^{-1}, 56.02 mg kg^{-1} and 42.80 mg kg^{-1} (AF1-3), respectively), than in the NR (118.64 mg kg^{-1}) (Table 5.5). Sodium was 57% lower in the abandoned fields than in the natural rangeland. For the next two soil layers (0-50 mm and 50-100 mm) Na was not significantly ($P<0.05$) lower in the abandoned fields than in the natural rangeland. On average the abandoned fields (39.17 mg kg^{-1}) differed significantly ($P<0.05$) from the NR (77.72 mg kg^{-1}), with a 50% difference. Abandoned field two (43.95 mg kg^{-1}) had a higher Na content than that of AF1 (41.82 mg kg^{-1}) and AF3 (31.73 mg kg^{-1}).

Calcium differed significantly ($P<0.05$) between NR and the abandoned fields over the 0-50 mm and 50-100 mm soil layers. Over the 0-50 mm soil layer calcium were significantly ($P<0.05$) higher in the abandoned fields (911.04 mg kg^{-1}, 1520.33 mg kg^{-1} and 1252.92 mg kg^{-1} (AF1-3), respectively), than in the NR (981.45 mg kg^{-1}) (Table 5.5). Calcium is therefore 32% higher in the abandoned fields than in the natural rangeland. For the next soil layers (50-100 mm) Ca was also significantly ($P<0.05$) higher in the abandoned fields than in the natural rangeland. On average the abandoned fields (1355.76 mg kg^{-1}) differed significantly ($P<0.05$) from the NR (1132.81 mg kg^{-1}) with a 20% difference. Abandoned field two (1650.32 mg kg^{-1}) had a much higher Ca content than that of AF1 (984.52 mg kg^{-1}) and AF3 (1432.40 mg kg^{-1}).

No significant ($P>0.05$) differences were found for Mg over all soil layers (Table 5.5). Magnesium had no effect on the degradation gradient of rangeland condition, from natural rangeland to the abandoned fields.

Although hydrogen differed significantly ($P<0.05$) between NR and the abandoned fields over the 100-200 mm soil layer (Table 5.5), it was close to 0%, which could not possibly have had an influence on the degradation gradient of rangeland condition. This is also reflected in the pH results as discussed earlier.

Soil nutrient availability can change species composition (Blank *et al.* 2007). Vegetation removal increases the availability of nitrate, Ca and Mg (Blank *et al.* 2007). Thus nutrients may positively influence the invasion of pioneer grass species, constraining vegetative growth and organizing competitive interactions among species (Grover 1997; Blank *et al.*

2007). According to Guo-Hong (2002) Na decreases with time since abandonment. This data correlated with the Verkeerdevlei results in which Na was lower on the abandoned fields.

Table 5.5 Soil Na, Ca, Mg and H^+ (mean ± SE) of abandoned field 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Na (mg kg^{-1})				Ca (mg kg^{-1})			
	Depth (mm)							
Sites	0-50	50-100	100-200	0-200 (*avg)	0-50	50-100	100-200	0-200 (avg)
NR	28.20^{a}	45.43^{a}	118.64^{a}	77.73^{a}	891.45^{b}	973.31^{b}	1333.24^{a}	1132.81^{ab}
	±2.32	± 6.45	± 19.16	± 11.65	± 41.46	± 41.63	± 61.65	± 38.00
AF(avg)	23.20^{a}	30.50^{a}	51.48^{b}	39.17^{b}	1228.1^{a}	1281.82^{a}	1456.53^{a}	1355.75^{a}
	± 2.32	± 3.75	± 7.53	± 5.18	± 108.53	± 116.00	± 148.76	± 129.30
AF 1	25.15^{a}	30.86^{a}	55.62^{ab}	41.81^{ab}	911.04^{b}	941.62^{b}	1042.70^{a}	984.52^{b}
	± 5.06	± 7.77	± 19.15	± 12.67	± 98.07	± 98.83	± 154.73	± 125.16
AF 2	26.53^{a}	37.23^{a}	56.02^{ab}	43.95^{ab}	1520.33^{b}	1605.62^{a}	1737.67^{a}	1650.32^{a}
	± 3.86	± 7.01	± 10.34	± 7.81	± 139.24	± 130.08	± 144.71	± 137.90
AF 3	17.91^{a}	23.42^{a}	42.80^{b}	31.73^{b}	1252.92^{ab}	1298.23^{ab}	1589.22^{a}	1432.4^{ab}
	± 2.35	± 3.74	± 9.69	± 6.22	± 219.15	± 243.71	± 347.15	± 288.52
SE	± 1.83	± 3.50	± 10.03	± 6.19	± 84.66	± 88.45	± 107.20	± 94.71
	Mg (mg kg^{-1})				H^+ Cmol kg^{-1}			
NR	409.51^{a}	448.60^{a}	683.44^{a}	556.25^{a}	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}
	± 15.38	± 21.88	± 41.55	± 24.70	± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)	497.24^{a}	490.71^{a}	556.92^{a}	525.45^{a}	0.0^{a}	0.02^{a}	0.01^{a}	0.01^{b}
	± 38.71	± 39.72	± 49.42	± 43.50	± 0.00	± 0.02	± 0.00	± 0.01
AF 1	416.74^{a}	406.91^{a}	447.37^{a}	429.60^{a}	0.01^{a}	0.06^{a}	0.03^{a}	0.03^{a}
	± 67.05	± 64.09	± 83.81	± 74.20	± 0.01	± 0.04	± 0.01	± 0.01
AF 2	600.03^{a}	598.93^{a}	643.12^{a}	621.30^{a}	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}
	± 56.27	± 61.97	± 59.84	± 58.80	± 0.00	± 0.00	± 0.00	± 0.00
AF 3	474.94^{a}	466.28^{a}	580.27^{a}	525.44^{a}	0.00^{a}	0.01^{a}	0.01^{ab}	0.01^{ab}
	± 60.70	± 61.53	± 100.22	± 79.47	± 0.00	± 0.01	± 0.01	± 0.00
SE	±29.06	±29.00	±38.83	± 31.62	± 0.00	± 0.01	±0.00	± 0.00

*avg The weighted average over all three soil depths

5.2.1.4 Mineral ratios Ca:Mg, (Ca:Mg)/K, Mg:K and Na:K.

Ca:Mg ratios over the 100-200 mm soil layer were significantly (P<0.05) higher in the abandoned fields (1.47 mg kg^{-1}, 1.69 mg kg^{-1} and 1.65 mg kg^{-1} (AF1-3), respectively), than in the NR (1.20 mg kg^{-1}) (Table 5.6). Ca:Mg ratio was 33% higher in the abandoned fields than in the natural rangeland. For the next two soil layers (0-50 mm and 50-100 mm) the Ca:Mg showed no significant ($P<0.05$) difference. On average the abandoned fields (1.59 mg kg^{-1}) differed significantly ($P<0.05$) from the NR (1.27 mg kg^{-1}) with a 25% difference. Abandoned field two (1.67 mg kg^{-1}) had a much higher Ca:Mg ratio than that of AF1 (1.45 mg kg^{-1}) and AF3 (1.65 mg kg^{-1}).

The (Ca:Mg)/K ratios differed significantly ($P<0.05$) between NR and the abandoned fields over the first (0-50 mm) soil layer and was significantly ($P<0.05$) higher in AF2 (9.54 mg kg^{-1}) than in the NR, AF1 and AF3 (7.00 mg kg^{-1}, 6.40 mg kg^{-1} and 6,88 mg kg^{-1}, respectively) (Table 5.6).

Significant ($P<0.05$) differences were found for the Mg:K ratios between the NR and the abandoned fields over the 100-200 mm soil layer and was significantly ($P<0.05$) lower in the abandoned fields (4.00 mg kg^{-1}) than in the NR (5.36 mg kg^{-1}).

The Na:K ratios were significantly ($P<0.05$) lower in the abandoned fields over all soil layers. The Na:K ratios over the 100-200 mm soil layer were significantly ($P<0.05$) lower in the abandoned fields (0.23 mg kg^{-1}, 0.23 mg kg^{-1} and 0.07 mg kg^{-1} in AF1-3, respectively), than in the NR (0.49 mg kg^{-1}) (Table 5.6). The Na:K ratio was 59% lower in the abandoned fields than in the natural rangeland. For the next two soil layers (0-50 mm and 50-100 mm) Na:K was also significantly ($P<0.05$) lower in the abandoned fields than in the natural rangeland. On average the abandoned fields (0.14 mg kg^{-1}) differed significant ($P<0.05$) from the NR (0.32 mg kg^{-1}) with a 55% difference. Abandoned fields one and two (0.17 mg $kg^{-1}$and 0.17 mg kg^{-1}, respectively) had a higher Na:K content than that of AF3 (0.14 mg kg^{-1}).

Table 5.6 Soil Ca:Mg, (Ca:Mg)/K, Mg:K and Na:K ratios (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Ca:Mg (mg kg^{-1})				(Ca+Mg)/K (mg kg^{-1})			
	Depth (mm)							
Sites	0-50	50-100	100-200	0-200(*avg)	0-50	50-100	100-200	0-200(avg)
NR	1.33^{a}	1.33^{a}	1.20^{b}	1.27^{a}	7.0^{b}	8.31^{ab}	11.85^{a}	9.75^{ab}
	± 0.03	± 0.04	± 0.03	± 0.03	± 0.31	± 0.52	± 0.73	± 1.06
AF(avg)	1.53^{a}	1.61^{a}	1.6^{a}	1.59^{b}	7.6^{a}	8.24^{a}	10.33^{a}	9.13^{a}
	± 0.09	± 0.09	± 0.08	± 0.08	± 0.48	± 0.56	± 0.70	± 0.60
AF 1	1.38^{a}	1.46^{a}	1.47^{ab}	1.45^{a}	6.40^{b}	6.91^{b}	8.61^{a}	7.63^{b}
	± 0.07	± 0.07	± 0.07	± 0.08	± 0.40	± 0.53	± 0.90	± 0.70
AF 2	1.60^{a}	1.70^{a}	1.69^{a}	1.67^{a}	9.54^{a}	10.38^{a}	13.07^{a}	11.52^{a}
	± 0.22	± 0.22	± 0.17	± 0.20	± 0.56	± 0.52	± 0.78	± 0.62
AF 3	1.60^{a}	1.68^{a}	1.65^{a}	1.65^{a}	6.88^{b}	7.43^{b}	9.32^{a}	8.24^{ab}
	± 0.15	± 0.14	± 0.14	± 0.14	± 0.73	± 0.98	± 0.88	± 0. 85
SE	± 0.07	± 0.07	± 0.07	± 0.07	± 0.36	± 0.42	± 0.69	± 0.51
	Mg:K (mg kg^{-1})				Na:K (mg kg^{-1})			
NR	3.01^{ab}	3.56^{ab}	5.36^{a}	4.32^{a}	0.11^{a}	0.19^{a}	0.49^{a}	0.32^{a}
	± 0.12	± 0.20	± 0.74	± 0.44	± 0.01	± 0.03	± 0.09	± 0.05
AF(avg)	3.03^{a}	3.18^{a}	4.00^{b}	3.55^{a}	0.076^{b}	0.10^{b}	0.20^{b}	0.14^{b}
	± 0.19	± 0.22	± 0.29	± 0.24	± 0.01	± 0.01	± 0.03	± 0.02
AF 1	2.73^{b}	2.85^{ab}	3.54^{a}	3.17^{a}	0.09^{ab}	0.11^{ab}	0.23^{ab}	0.17^{ab}
	± 0.26	± 0.30	± 0.46	± 0.37	± 0.01	± 0.02	± 0.07	± 0.05
AF 2	3.73^{a}	3.94^{a}	4.96^{a}	4.40^{a}	0.09^{ab}	0.13^{ab}	0.23^{ab}	0.17^{ab}
	± 0.29	± 0.37	± 0.49	± 0.41	± 0.01	± 0.02	± 0.04	± 0.03
AF 3	2.63^{b}	2.76^{b}	3.52^{a}	3.11^{a}	0.05^{b}	0.07^{b}	0.14^{b}	0.10^{b}
	± 0.17	± 0.27	± 0.27	± 0.24	± 0.01	± 0.01	± 0.03	± 0.02
SE	± 0.14	± 0.17	± 0.32	± 0.22	± 0.01	± 0.01	± 0.04	± 0.03

*avg The weighted average over all three soil depths

5.2.1.5 Cation exchange capacity.

Cation exchange capacity (CEC) differed significantly (P<0.05) between NR and the abandoned fields over the 50-100 mm and 100-200 mm soil layers (Table 5.7). In the 100-200 mm soil layer, CEC were significantly (P<0.05) lower in the abandoned fields (16.64 cmol kg^{-1}, 19.11 cmol kg^{-1} and 19.83 cmol kg^{-1} (AF1-3), respectively), than in the NR (21.66 cmol kg^{-1}) (Table 5.7). Cation exchange capacity was 14% lower in the abandoned fields than in the natural rangeland. For the 50-100 mm soil layer CEC was also significantly ($P<0.05$) lower in the abandoned fields than in the natural rangeland. On average the abandoned fields (18.31 cmol kg^{-1}) differed significantly ($P<0.05$) from the NR (20.87 cmol kg^{-1}) with a 12% difference. Abandoned field three (19.75 cmol kg^{-1}) had a higher CEC than that of AF1 (16.26 cmol kg^{-1}) and AF2 (18.91 cmol kg^{-1}). According to Chichester *et al.* (1970) CEC were only related to soil texture, with CEC increasing in soil with particles of a lesser diameter. A higher CEC is related to an increase in root biomass and larger litter inputs (Manlay *et al.* 2000), which corresponds with the results gathered at Verkeerdevlei.

Table 5.7 Soil cation exchange capacity (Cmol kg^{-1}) (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different ($P<0.05$).

	Depth (mm)			
Sites	0-50	50-100	100-200	0-200(*avg)
NR	19.78^{a}	20.38^{a}	21.66^{a}	20.87^{a}
	± 0.64	± 0.42	± 0.21	± 0.24
AF(avg)	18.13^{a}	18.04^{b}	18.53^{b}	18.31^{b}
	± 0.45	± 0.53	± 0.44	± 0.46
AF 1	16.10^{b}	15.67^{b}	16.64^{c}	16.26^{c}
	± 0.43	± 0.70	± 0.47	± 0.49
AF 2	18.60^{a}	18.82^{a}	19.11^{b}	18.91^{b}
	± 0.30	± 0.31	± 0.27	± 0.28
AF 3	19.71^{a}	19.64^{a}	19.83^{b}	19.75^{ab}
	± 0.34	± 0.44	± 0.57	± 0.46
SE	± 0.40	± 0.46	± 0.45	± 0.42

*avg The weighted average over all three soil depths

5.2.2 Soil organic matter

Nitrogen differed significantly ($P<0.05$) between NR and the abandoned fields over all soil layers. Over the 0-50 mm soil layer nitrogen was significantly ($P<0.05$) lower in the abandoned fields (0.09%, 0.09% and 0.10% in AF1-3, respectively), than in the NR (0.13%) (Table 5.8), which indicated a 31% difference. For the next two soil layers (50-100 mm and 100-200 mm) N was also significantly ($P<0.05$) lower in the abandoned fields than in the natural rangeland. On average the abandoned fields (0.08%) differed significantly ($P<0.05$) from the NR (0.12%) with a 33% difference. Abandoned field three (0.09%) had a slightly higher N content than that of AF1 (0.08%) and AF2 (0.08%).

Carbon also differed significantly (P<0.05) between NR and the abandoned fields over all soil layers. Over the 0-50 mm soil layer, carbon was significantly (P<0.05) lower in the abandoned fields (0.1%, 1.05% and 1.2% (AF1-3), respectively), than in the NR (01.65%) (Table 5.8). Carbon was 35% lower in the abandoned fields. Over the next two soil layers (50-100 mm and 100-200 mm) C was also significantly (P<0.05) lower in the abandoned fields. On average the abandoned fields (0.87%) differed significantly (P<0.05) from the NR (1.27%) with a 31% difference. Abandoned field three (0.98%) had a higher C content than that of AF1 (0.56%) and AF2 (0.85%).

Table 5.8 Soil organic matter (mean ± SE) of abandoned fields 1-3 and natural rangeland, expressed as carbon (C) and Nitrogen (N) percentages. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	N (%)				C (%)			
	Depth (mm)							
Sites	0-50	50-100	100-200	0-200(*avg)	0-50	50-100	100-200	0-200(*avg)
NR	0.13[a] ± 0.00	0.11[a] ± 0.00	0.11[a] ± 0.00	0.12 [a] ± 0.00	1.65[a] ± 0.06	1.18[a] ± 0.03	1.12[a] ± 0.04	1.27 [a] ± 0.03
AF(avg)	0.09[b] ± 0.01	0.08[b] ± 0.08	0.08[b] ± 0.00	0.08 [b] ± 0.01	1.07[b] ± 0.08	0.83[b] ± 0.08	0.78[b] ± 0.07	0.87 [b] ± 0.07
AF 1	0.09[b] ± 0.01	0.08[b] ± 0.01	0.07[b] ± 0.00	0.08 [b] ± 0.00	0.10[b] ± 0.09	0.74[a] ± 0.05	0.69[b] ± 0.04	0.56 [b] ± 0.05
AF 2	0.09[b] ± 0.00	0.08[ab] ± 0.00	0.08[b] ± 0.00	0.08 [b] ± 0.00	1.05[b] ± 0.06	0.82[a] ± 0.04	0.77[ab] ± 0.05	0.85 [ab] ± 0.05
AF 3	0.10[ab] ± 0.01	0.09[ab] ± 0.01	0.09[ab] ± 0.01	0.09 [ab] ± 0.01	1.20[ab] ± 0.23	0.93[a] ± 0.23	0.90[ab] ± 0.19	0.98 [ab] ± 0.21
SE	± 0.01	± 0.00	± 0.00	± 0.00	± 0.09	± 0.06	± 0.06	± 0.07
	C:N							
NR	12.54[a] ± 0.23	10.87[a] ± 0.37	10.10[a] ± 0.36	10.9 [a] ± 0.29				
AF(avg)	11.09[b] ± 0.23	9.10[a] ± 0.29	9.69[a] ± 0.30	9.89 [a] ± 0.26				
AF 1	10.66[b] ± 0.43	9.88[a] ± 0.53	9.75[a] ± 0.52	10.01 [a] ± 0.44				
AF 2	11.11[b] ± 0.22	10.28[a] ± 0.17	9.73[a] ± 0.23	10.21 [a] ± 0.21				
AF 3	11.51[ab] ± 0.46	9.84[a] ± 0.74	9.57[a] ± 0.80	10.12 [a] ± 0.69				
SE	± 0.22	± 0.24	± 0.24	± 0.22				

*avg The weighted average over all three soil depths

The C:N ratio over the 0-50 mm soil layer was significantly ($P<0.05$) lower in the abandoned fields (10.66%, 11.11% and 11.51% (AF1-3), respectively), than in the NR (12.54%) (Table 5.8). The C:N ratio was therefore 12% lower in the abandoned fields than in the natural rangeland. For the next two soil layers (50-100 mm and 100-200 mm) C:N was not significantly ($P<0.05$) lower in the abandoned fields than in the natural rangeland.

Cover is essential for organic matter to accumulate in abandoned fields (Memiaghe 2008). Vegetation cover will increase the available N and C levels in abandoned fields and thus induce a proper basis for plant growth (Hester & Hobbs 1992; Eliason & Allen 1997; Garcia *et al.* 2007). According to Van der Westhuizen (2003) available nitrogen was higher when the abandoned fields were in a more degraded state, which correlates with the results at Verkeerdevlei. High concentrations of N have a positive effect on plant growth, but a negative impact on perennial plant development (Tilman 1987). Over 12 years Olsen *et al.* (2005) discovered in the top soil layer of a mouldboard plough tillage experiment that soil organic carbon was significantly lower compared to the results of no-till and chisel plough experiments. Thus, soil carbon is affected by tillage, soil erosion and depositional processes (Olsen *et al.* 2005). Soil carbon reduction can be up to 20% in rangeland after cultivation (Mann 1986). Carbon is much higher in no-till practices, but slowly increases with depth in abandoned fields (Hussain *et al.* 1999). Tillage will change the soil texture by mixing the different horizons and exposing the soil organic matter to the oxidation processes (Olsen 2010). This will result in soil organic matter removal in the form of CO_2 (Olsen 2010).

Nitrogen is very important for plant growth and the inhibition of nitrification increases with progress of succession towards a climax ecosystem (Dormaan & Smoliak 1985; Rice & Pancholy 1972). Carbon and nitrogen loss were also recorded by Schuman *et al.* (1984) when cultivation took place over five years compared to natural rangeland. According to Blank *et al.* (2007), N can increase with vegetation removal because of a major decline in nutrient uptake; mineralization then exceeds root uptake. Reeder *et al.* (1998) concluded that after 60+ years of cultivation, surface soils was 18-26% lower in total C and N. The opposite was found by Guo-Hong (2002) when soil C and N increased with years since abandonment.

Reeder *et al.* (1998) also concluded that short-term cultivated fields (with mixed tillage) may account for 60-75% of the loss in C, and 30-60% loss in nitrogen. It was shown that on average agricultural practices resulted in a 75% and 89% loss of soil N and C, respectively, (Knops & Tilman 2000). Rehabilitation of soil N to pre-agricultural levels is predicted to require 180 years and 230 years for carbon (Knops & Tilman 2000). According to Knops *et* *al.* (2000) vegetation composition had a significant role to play in the accumulation of N and carbon. They recorded an increase in the C:N ratio of the soil organic matter with C_4 grasses and thereby an increase in the rate of C accumulation, but not N accumulation. The results of this study are in line with the evidence from the literature. The abandoned fields had lower C and N values, caused by ploughing practices some 20 years ago. This effect may impact negatively on the whole ecosystem, including succession, and may take many more years to return to a normal state like in the natural rangeland.

5.2.3 Soil textures (particle size distribution)

No significant (P>0.05) differences were found between NR and the abandoned fields over all soil layers (Table 5.4) for coarse silt (Table 5.9). Coarse silt therefore may not have an effect on the degradation gradient of rangeland condition from natural rangeland to abandoned fields.

Fine silt fraction differed significantly (P<0.05) between NR and the abandoned fields over the 0-50 mm and 50-100 mm soil layers (Table 5.9). Fine silt (0-50 mm soil layer) was significantly (P<0.05) lower in the abandoned fields (10.29%, 10.24% and 10.04% (AF1-3), respectively), than in the NR (12.9%), (Table 5.9), and was 21% lower in the abandoned fields than in the natural rangeland. On average the abandoned fields (9.67%) differed significantly (P<0.05) from the NR (11.61%) with a 17% difference. Abandoned field one (10.35%) had a higher fine silt fraction than that of AF2 (9%) and AF3 (9.21%).

Clay content differed significantly (P<0.05) between NR and the abandoned fields over the 0-50 mm and 50-100 mm soil layers (Table 5.12). Clay content (0-50 mm soil layer) was significantly (P<0.05) higher in the abandoned fields (28.61%, 33.44% and 31.30% (AF1-3), respectively), than in the NR (20.81%), (Table 5.9). Clay content is therefore 50% higher in the abandoned fields than in the natural rangeland. On average the abandoned fields (35.32%) differed significantly (P<0.05) from the NR (30.56%) with a 16% difference. Abandoned field two (37.35%) had a higher clay fraction than that of AF (31.49%) and AF3 (37.12%).

Very fine sand content differed significantly (P<0.05) between NR and the abandoned fields over all soil layers (Table 5.10). Very fine sand content (50-100 mm soil layer) was significantly (P<0.05) lower in the abandoned fields (2.05%, 2.11% and 1.78% in AF1-3, respectively), than in the NR (3.17%) (Table 5.10), which constitutes a 38% difference. On average the abandoned fields (1.87%) differed significantly (P<0.05) from the NR (2.73%), with a 32% difference. Abandoned field two (2.01%) had a much higher very fine sand fraction than that of AF1 (1.98%) and AF3 (1.60%).

Fine sand content differed significantly (P<0.05) between NR and the abandoned fields over the 50-100 mm and 100-200 mm soil layers (Table 5.10). The fine sand fraction over the 50-100 mm soil layer was significantly (P<0.05) lower in the abandoned fields (2.62%, 2.27% and 2.3% in AF1-3, respectively), than in the NR (2.8%) (Table 5.10). The differences of 14% were rather small. On average the abandoned fields (2.47%) did not differ significantly (P>0.05) from the NR (2.65%). Abandoned field one (2.01%) had a higher fine sand fraction than that of AF2 (2.46%) and AF3 (2.35%).

Medium sand fraction revealed no significant (P>0.05) differences between NR and the abandoned fields over all soil layers (Table 5.10). Coarse sand content over the 0-50 mm soil layer was significantly (P<0.05) lower in the abandoned fields (21.73%, 19.58% and 21.07% (AF1-3), respectively), than in the NR (24.59%) with only a 15% difference (Table 5.10). Abandoned field one (21.63%) had a higher coarse sand fraction than that of AF2 (19.35%) and AF3 (19.91%).

Gravel content differed significantly (P<0.05) between NR and the abandoned fields over all soil layers. The gravel fraction over the 0-50 mm soil layer was significantly (P<0.05) lower in the abandoned fields (0.86%, 0.73% and 0.94% in AF1-3, respectively), than in the NR (1.71%) (Table 5.11). Gravel content is therefore 51% lower in the abandoned fields than in the natural rangeland. On average, the abandoned fields (0.82%) differed significantly (P<0.05) from the NR (1.32%) with a 38% difference in gravel fraction. Abandoned field one (0.9%) had a slightly higher gravel fraction than that of AF2 (0.70%) and AF3 (0.86%).

The differences found in the particle size distribution may largely be the result of the abandoned fields that went through various ploughing practices more than 20 years ago. A mixture of different soil layers during cultivation might cause differences in particle size distribution. Removal of some top soil through wind and water erosion, on such bare abandoned fields over a 20 year period, may also have influenced the particle size distribution, especially in the 0-50 mm soil layer.

Phosphorus concentration increased in the silty clay loam fraction of the soil in a soil trial conducted to evaluate microbial recovery (Bach *et al.* 2010). The study demonstrated that soil microbial responses to grassland restoration are modulated by soil texture with implications for estimating the true capacity of restoration efforts to rehabilitate ecosystem functions (Bach *et al.* 2010). The availability of Ca and Mg is controlled by exchange reactions with the soil clay fraction and is not likely to be affected by soil mineralization processes (Blank *et al.* 2007). Texture also had a decreasing influence on soil organic matter (Laws & Evans 1949). Decomposition increases because of structure change and thereby decreases the organic matter content (Laws & Evans 1949).

Table 5.9 Soil textures (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Coarse Silt				Fine Silt				
	Depth (mm)								
Sites	0-50	50-100	100-200	0-200(*avg)	0-50	50-100	100-200	0-200(avg)	Silt(avg)
NR	10.46^{a}	10.01^{a}	8.91^{a}	9.57^{a}	12.90^{a}	12.39^{a}	10.57^{a}	11.61^{a}	10.59
	± 0.69	± 0.87	± 0.73	± 0.74	± 0.58	± 0.74	± 0.74	± 0.69	
AF(avg)	9.99^{a}	9.98^{a}	9.72^{a}	9.85^{a}	10.19^{b}	9.78^{b}	9.35^{a}	9.67^{b}	9.76
	± 0.19	± 0.30	± 0.60	± 0.39	± 0.35	± 0.37	± 0.36	± 0.32	
AF 1	10.57^{a}	10.80^{a}	10.83^{a}	10.76^{a}	10.29^{b}	10.16^{ab}	10.47^{a}	10.35^{a}	10.56
	± 0.23	± 0.47	± 0.70	± 0.48	± 0.59	± 0.62	± 0.46	± 0.49	
AF 2	9.80^{a}	9.76^{a}	9.63^{a}	9.71^{a}	10.24^{b}	9.53^{b}	8.10^{a}	8.1^{a}	8.91
	± 0.23	± 0.43	± 0.46	± 0.34	± 0.37	± 0.55	± 0.57	± 0.45	
AF 3	9.60^{a}	9.39^{a}	8.70^{a}	9.1^{a}	10.04^{b}	9.64^{ab}	8.58^{a}	9.21^{a}	9.16
	± 0.35	± 0.55	± 1.58	± 0.95	± 0.90	± 0.83	± 0.57	± 0.67	
SE	± 0.23	± 0.32	± 0.47	± 0.34	± 0.40	± 0.42	± 0.34	± 0.35	

*avg The weighted average over all three soil depths

Table 5.10 Soil textures (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Very fine sand				Fine sand				Medium sand				Coarse sand				
	Depth (mm)																
Sites	0-50	50-100	100-200	0-200 *avg	0-50	50-100	100-200	0-200 avg	0-50	50-100	100-200	0-200 avg	0-50	50-100	100-200	0-200 avg	Sand avg
NR	3.12^{a}	3.17^{a}	2.32^{a}	2.73^{a}	2.92^{a}	2.80^{a}	2.43^{a}	2.65^{a}	22.51^{a}	22.06^{a}	16.91^{a}	19.6^{a}	24.59^{a}	22.26^{a}	19.11^{a}	21.27^{a}	11.56
	± 0.38	± 0.28	± 0.20	± 0.26	± 0.13	± 0.09	± 0.14	± 0.16	± 0.95	± 1.24	± 0.25	± 1.12	± 0.67	± 0.64	± 1.00	± 0.76	
AVG AF	2.14^{b}	1.98^{b}	1.67^{b}	1.87^{b}	3.24^{a}	2.40^{b}	2.11^{b}	2.47^{a}	20.67^{a}	19.36^{a}	17.82^{a}	18.92^{a}	20.79^{b}	20.79^{a}	19.80^{a}	20.3^{a}	10.89
	± 0.16	± 0.16	± 0.13	± 0.14	± 0.07	± 0.08	± 0.05	± 0.05	± 0.73	± 0.76	± 0.75	± 0.71	± 0.56	± 0.60	± 0.81	± 0.66	
AF 1	2.30^{a}	2.05^{ab}	1.79^{ab}	1.98^{ab}	3.37^{a}	2.62^{ab}	2.19^{a}	2.59^{a}	20.93^{a}	19.88^{a}	18.50^{a}	19.45^{a}	21.73^{ab}	21.92^{a}	21.44^{a}	21.63^{a}	11.41
	± 0.29	± 0.37	± 0.17	± 0.24	± 0.11	± 0.10	± 0.05	± 0.06	± 1.42	± 1.39	± 1.56	± 1.44	± 1.09	± 1.33	± 1.31	± 1.25	
AF 2	2.23^{a}	2.11^{ab}	1.85^{ab}	2.01^{ab}	3.30^{a}	2.27^{b}	2.13^{a}	2.46^{a}	19.90^{a}	18.37^{a}	17.74^{a}	18.44^{a}	19.58^{b}	19.84^{a}	18.98^{a}	19.35^{a}	10.57
	± 0.32	± 0.19	± 0.25	± 0.24	± 0.04	± 0.08	± 0.06	± 0.05	± 1.32	± 1.22	± 0.98	± 1.08	± 1.00	± 0.77	± 0.82	± 0.85	
AF 3	1.88^{a}	1.78^{b}	1.36^{a}	1.6^{b}	3.06^{a}	2.30^{b}	2.02^{a}	2.35^{a}	21.18^{a}	19.84^{a}	17.22^{a}	18.87^{a}	21.07^{b}	20.61^{a}	18.98^{a}	19.91^{a}	10.68
	± 0.23	± 0.27	± 0.25	± 0.24	± 0.14	± 0.16	± 0.13	± 0.12	± 1.27	± 1.50	± 1.51	± 1.38	± 0.67	± 0.96	± 1.85	± 1.27	
SE	± 0.18	± 0.18	± 0.13	± 0.15	± 0.07	± 0.07	± 0.06	± 0.05	± 0.61	± 0.69	± 0.63	± 0.59	± 0.58	± 0.48	± 0.63	± 0.52	

*avg The weighted average over all three soil depths

Table 5.11 Soil textures (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Gravel			
	Depth (mm)			
Sites	0-50	50-100	100-200	0-200(*avg)
NR	1.71[a]	1.31[a]	1.12[a]	1.32 [a]
	± 0.25	± 0.20	± 0.13	± 0.16
AF(avg)	0.84[b]	0.87[b]	0.78[b]	0.82 [b]
	± 0.04	± 0.04	± 0.04	± 0.04
AF 1	0.86[b]	0.96[ab]	0.89[ab]	0.9 [ab]
	± 0.02	± 0.07	± 0.06	± 0.04
AF 2	0.73[b]	0.73[b]	0.67[b]	0.7 [b]
	± 0.07	± 0.04	± 0.03	± 0.03
AF 3	0.94[b]	0.94[ab]	0.78[ab]	0.86 [b]
	± 0.07	± 0.07	± 0.10	± 0.08
SE	± 0.11	± 0.08	± 0.06	± 0.07

*avg The weighted average over all three soil depths

Table 5.12 Soil textures (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Clay			
	Depth (mm)			
Sites	0-50	50-100	100-200	0-200(*avg)
NR	20.81[b]	25.71[b]	37.86[a]	30.56 [a]
	± 0.98	± 0.43	± 1.92	± 1.45
AF(avg)	31.12[a]	34.34[a]	37.91[a]	35.32 [a]
	± 1.26	± 1.43	± 2.04	± 1.62
AF 1	28.61[a]	31.15[ab]	33.09[a]	31.49 [a]
	± 2.50	± 2.78	± 3.31	± 2.95
AF 2	33.44[a]	36.85[a]	39.55[a]	37.35 [a]
	± 2.01	± 2.01	± 2.11	± 2.03
AF 3	31.30[a]	35.01[a]	41.09[a]	37.12 [a]
	± 1.82	± 2.36	± 4.39	± 3.06
SE	± 1.39	± 1.39	± 1.53	± 1. 30

*avg The weighted average over all three soil depths

5.2.4 Soil physical characteristics

5.2.4.1 Bulk density, gravimetric and volumetric water content.

Soil bulk density differed significantly (P<0.05) between NR and the abandoned fields. Bulk density was significantly (P<0.05) higher in the abandoned fields (1.64 g mm^2 and 1.58 g mm^2 in AF1 and 2, respectively), than in the NR (1.47 g mm^2) (Table 5.13). Bulk density is only 7% higher in the abandoned fields than in the natural rangeland which indicated a very low (if any) possible impact on vegetation dynamics differences between abandoned fields and natural rangeland. For the gravimetric and volumetric water content there were no significant (P<0.05) differences between the abandoned fields and natural rangeland.

It is generally accepted that soil-water affects plant production and development (Memiaghe 2008). According to Memiaghe (2008) each plant species has a specific relationship with soil-water. These micro-climates are developed with vegetation growth (Memiaghe 2008).

According to Olsen *et al.* (2010) the frequency and intensity of tillage practices alter the bulk density and soil organic carbon. Organic matter in soil decreases with texture change (Laws & Evans 1949). These texturally changed soils alter the soil-water capacity of the soil and thereby change the nutrient uptake in the soil (Laws & Evans 1949).

Table 5.13 Soil bulk density, gravimetric and volumetric water content (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

Sites	Bulk density g mm^2	Gravimetric water content mm water/mm soil	Volumetric water content %
NR	1.47^b	0.16^{ab}	23.24^a
	± 0.01	± 0.01	± 1.28
AF(*avg)	1.57^a	0.14^a	21.48^a
	± 0.03	± 0.01	± 1.14
AF 1	1.64^a	0.12^b	19.43^a
	± 0.03	± 0.01	± 1.60
AF 2	1.58^{ab}	0.13^{ab}	20.12^a
	± 0.04	± 0.02	± 1.99
AF 3	1.47^b	0.17^a	24.90^a
	± 0.05	± 0.01	± 1.61
SE	± 0.02	± 0.01	± 0.89

*avg The weighted average over all three soil depths

5.2.4.2 Soil surface compaction.

Compaction differed significantly (P<0.05) between NR and the abandoned fields for all measurements. Compaction between two species was significantly (P<0.05) higher in the abandoned fields (29.3 MPa, 33.2 MPa and 22.8 MPa (AF1-3), respectively), than in the NR (4.08 MPa) (Table 5.14). Compaction between two species is therefore 597% higher in the abandoned fields than in the natural rangeland. Compaction at a distance 10 mm from species was also significantly (P<0.05) higher in the abandoned fields than in the natural rangeland.

Table 5.14 Soil surface compaction (mean ± SE) of abandoned fields 1-3 and natural rangeland. Column means, within a soil layer, with different letters are significantly different (P<0.05).

	Compaction (Mpa)		
Sites	10 mm from species	Between two species	*avg
NR	3.75^{b}	4.08^{b}	3.92^{b}
	± 0.38	± 0.33	± 0.35
AVG AF	17.67^{a}	28.43^{a}	23.05^{a}
	± 2.18	± 4.34	± 3.05
AF 1	20.10^{a}	29.30^{ab}	24.70^{a}
	± 4.42	± 5.40	± 4.25
AF 2	17.0^{a}	33.20^{a}	25.10^{a}
	± 4.06	± 11.37	± 7.58
AF 3	15.90^{a}	22.80^{ab}	19.35^{ab}
	± 3.40	± 5.09	± 4.12
SE	± 2.09	± 3.94	± 2.90

*AVG The weighted average over all three soil depths

On average compaction of the abandoned fields (23.05 MPa) differed significantly (P<0.05) from the NR (3.92 MPa) with a 489% difference. Abandoned field two (25.1 MPa) had a slightly higher compaction than that of AF1 (24.7 MPa) and AF3 (19.35 MPa).

With vegetation removal, compaction can increase because of a loss of basal cover and litter (Kruger 1984; Warren *et al.* 1986; Friedel 1987; Russel *et al.* 2001). When compaction increases, rain infiltration decreases and runoff takes place, which further enhances degradation (Lal & Elliot 1994). The same tendency was found in the study sites at Verkeerdevlei.

5.2.5 Conclusion

Most of the tested soil characteristics indicated significant differences between the abandoned fields and the natural rangeland. This emphasized the significant impact of cultivation on rangeland. These marginal soils (not suitable for crop production) that were ploughed and abandoned 20 years ago, have still not recovered towards the same potential as the adjacent natural rangeland. Soil characteristics, like C and N (organic matter) and surface compaction may never recover to the same potential as that of the natural rangeland. It is therefore important to notice that without human intervention, these abandoned fields, may never recover to the same potential as natural rangeland. The study outlines the importance of considering several soil characteristics of abandoned cultivated fields and natural rangeland. The significant ($P<0.05$) differences in soil characteristics are analyzed and discussed in more depth in Chapters six and seven where the soil characteristics that correlated the best with *T. triandra* percentage occurrence will be quantified and discussed in more detail.

Chapter 6

Soil/plant interaction

6.1 Introduction

This research tried to identify models that capture the essence of the ecosystem functioning, explaining the observed distribution and then permitting the prediction of variables (pH, P, K, Na, Ca, Mg, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, CEC, bulk density, gravimetric and volumetric water content, germination, N, C, C:N relation, soil textures and surface compaction) on the percentage of *T. triandra* occurrence. A first step toward this aim was to collect data that described the percentage grass species; together with data on factors that were suspected of influencing the percentage of grass species.

The multilinear model with dependant value *y* (% *T. triandra)*, which indicates a reference to rangeland condition, and numerous independent x_i variables (pH, P, K, Na, Ca, Mg, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, CEC, bulk density, gravimetric and volumetric water content, germination, N, C, C:N relation, soil textures and surface compaction), which might influence the *y* value were subjected to a stepwise regression procedure of SAS to determine significant variables to include in the predictive multilinear model. In the statistical procedure of SAS, values were either entered or removed as a predictor based on their partial significant *F*-contributions to the model. The test stops when no more predictors can be justifiably entered or removed ($P \leq 0.05$) from the model, thereby leading to a final model (Dos program, version 9.3, SAS 2010).

Themeda triandra was the dominant species in the natural rangeland, constituting 61 seedlings m^{-2} of the rangeland's species composition of 80 seedlings m^{-2}. The study found that the germination of pioneer and weed species in September and December was much higher with 136 and 54.57 seedlings m^{-2} respectively in the abandoned fields, versus 13.67 and 34.50 seedlings m^{-2}, respectively, in the natural rangeland (Table 6.10). After years of low infiltration, seedling emergence of climax grass species decreased in the abandoned field's seed bank, with a lower effect on pioneer grass species. Thus seed absence in the soil seed bank had the biggest influence on slow rehabilitation of abandoned fields.

A significance level is set for deciding when to enter and when to remove a predictor from the model. The significance level used for testing acceptance and removal of a variable was $\alpha = 0.05$. The model finally fitted, was then considered the "best" predictor of *y,* given the available x_i (Dos program, version 8.1, SAS 2010).

In this study *T. triandra* was used as index species to predict the rangeland condition. *Themeda triandra* is a perennial grass endemic to the region and under conditions of little or no disturbance it will eventually die out altogether, but can also vanish as a result of too much disturbance (Snyman *et al.* 2013). Thus *T. triandra* is a Decreaser species and is more abundant than any other species in the Verkeerdevlei region.

Please note: after the results of this chapter (up to 6.11) were carefully scrutinized and compared with the data, presented in previous chapters, it was realized that the stepwise analyses did not take percentage difference of single characteristics between the natural rangeland and the abandoned fields into account. For example: Potassium (K) were included in the first model (Table 6.1), but the difference of K between AF (avg) and NR were only 8%. On the contrary, phosphorus (P) were not included in the model (Table 6.1), while difference of P between AF(avg) and NR were 103 percent. In the ANOVA analyses of the data, significant differences between AF and NR were found for P, but not for potassium. It was therefore decided to do another analysis, which was a number of simple linear regressions between the occurrence of *T. triandra* and only the soil and vegetation characteristics that showed significant differences between the AF and natural rangeland. From these results only those with a R^2 value higher than 0.50 are reported on in chapter seven. For these chosen regressions ($R^2 \geq 0.50$) only soil characteristics were re-run in a stepwise analysis and are discussed in paragraph 6.12 and Table 6.11. These results are more in line with data discussed in other chapters.

6.2 Soil chemical characteristics

The cation exchange capacity (CEC), potassium (K) and hydrogen (H^+) had no significant influence ($P>0.05$) on the occurrence of *T. triandra* over the first 0-100 mm, 0-50 mm and 0-100 mm soil layers, respectively (data not shown). The CEC over the 100-200 mm soil layer contributes 62.89% to the percentage *Themeda triandra* occurrence while K in the 0-50 mm soil layer contributed to 16.22% and H^+ in the 100-200 mm soil layer to 4.91% (Table 6.1). These results showed that these elements might predict 84.02% of the percentage occurrence of *T. triandra* in the ecosystem. Soil chemical characteristics of the 50-200 mm soil layer influenced the abundance of *T. triandra* more than at a depth of 0-50 mm. This indicates that root development through the K and H^+ uptake availability is essential for effective aboveground growth. The exchangeability of the cations (CEC) in the soil can differ along with the capacity of the soil to expedite or retard the release of nutrients to plants (Brady 1984).

Table 6.1 Summary of stepwise selection of pH, P, K, Na, Ca, Mg, H^+ and CEC. The CEC, K and H^+ on a depth of 100-200 mm, 50-100 mm and 100-200 mm respectively, were significant (P<0.05).

Summary of Stepwise Selection					
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**F Value**	**Pr > F**
1	CEC (100-200 mm)	0.6289	0.6289	32.20	< 0.0001
2	K (mg/kg) (50-100 mm)	0.1622	0.7911	13.98	0.0015
3	H+ (mmol(+)/kg) (100-200 mm)	0.0491	0.8402	5.22	0.0354

With equation Y = -227.4 – K (0.13) + H (609.23) + CEC (16.16) and R^2 = 0.8402.

6.3 Mineral ratios

Over all soil layers Ca:Mg, (Ca:Mg)/K and Mg:K had no influence (P>0.05) on *T. triandra* occurrence (data not shown). The Na:K ratio had the only significant (P<0.05) contribution (23.82%) to the percentage occurrence of *T. triandra* (Table 6.2). Over the first soil layer (0-100 mm) the influence of Na:K on *T. triandra* occurrence was poor (P>0.05).

Table 6.2 Summary of stepwise selection of Ca:Mg, (Ca:Mg)/K, Mg:K and Na:K. The Na:K on a depth of 100-200 mm was significant (P<0.05).

Summary of Stepwise Selection						
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	Na:K (100 -200 mm)	0.2382	0.2382	21.38	5.94	0.025

With equation Y = 11.6 + Na:K (77.96) and R^2 = 0.2382.

6.4 Soil organic matter content

Soil organic matter loss can be attributed to reduced phytomass production, increased soil erosion and a change in the soil climate (Du Preez & Snyman 1993). Organic matter is essential in providing fertile and stable soils. Almost 60% of soils in South Africa are characterized by a very low organic matter status (Scotney *et al.* 1990). Nitrogen had no significant (P>0.05) influence on *T. triandra* occurrence over all soil layers (data not shown). Carbon, in the 50-100 mm layer, however, had a significant (P<0.05) influence and predicted the occurrence of *T. triandra* at a 62.70% accuracy (Table 6.3). The degraded rangeland condition was therefore more C related than any other element tested in this stepwise selection. The C:N interaction had no effect on *T. triandra* occurrence, and might contribute less to the establishment of *T. triandra.*

Table 6.3 Summary of stepwise selection of N, C and the C:N ratio, where only C was significant (P<0.05).

Summary of Stepwise Selection						
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	C (%) (50-100 mm)	0.627	0.627	1.2285	31.93	<0.0001

With equation Y = -44.82 + C (84.32) and R^2 = 0.6270.

6.5 Soil textures (particle size distribution) in combination with cation exchange capacity

The coarse silt, clay, very fine sand, fine sand, medium sand and gravel had no influence (P>0.05) on the occurrence of *T. triandra* over the first 0-200 mm soil layers (data not shown). The CEC (0-100 mm soil layer) and fine silt (0-50 mm and 100-200 mm soil layers) had no influence (P>0.05) on the occurrence of *T. triandra* (data not shown). Soil particles can never be changed in virgin soils, but with plough practices or any other soil structure manipulation, the soil horizons may be mixed (Brady 1984). Soil texture in the top soil layers did not contribute to the occurrence of *T. triandra*, but fine silt in the 50-100 mm depth (P<0.05) predicted 12.72% of the occurrence of *T. triandra*. On the other hand, CEC (100-200 mm), which is texture related, contributed to a 62.89% prediction of *T. triandra* (Table 6.4).

Table 6.4 Summary of stepwise selection of soil textures and CEC. The CEC and fine silt on a depth of 100-200 mm and 50-100 mm respectively, were significant (P<0.05).

Summary of Stepwise Selection					
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**F Value**	**Pr > F**
1	CEC (100-200 mm)	0.6289	0.6289	32.20	<0.0001
2	Fine silt (FS) % (50-100 mm)	0.1272	0.7561	9.39	0.0067

With equation Y = -228.60 + CEC (10.09) + FS (6.29) R^2 = 0.7561.

6.6 Soil physical characteristics

Bulk density, gravimetric and volumetric water content had no significant influence (P>0.05) on the occurrence of *T. triandra* over all soil layers (data not shown). Surface compaction had no significant influence (P>0.05) on the occurrence of *T. triandra* (measured between two species) (data not shown). Surface compaction (10 mm from species) predicted the *T. triandra* percentage occurrence by 59.31% (Table 6.5). The main reason for the low prediction can be that seed germination depends on the soil surface condition (Snyman 2003c). If the surface is too hard for rain infiltration and seed germination, rangeland condition will deteriorate. Soil condition close to the plant base has the greatest influence on species composition (Snyman 2003b). This may be ascribed to the water need close to the plant root system. Soil loss and soil depth, which contribute to surface condition, permit an estimation of differences in short-term and long-term erosion levels arising from differences in land use (Du Plessis 1986). Soil compaction may worsen, leading to a further decline in vegetation productivity. Ploughed sites have significantly higher (P<0.05) soil compaction than the natural rangeland, which can be due to less plant protection to the soil (Snyman 1998). Highest compaction occurred in abandoned fields one and two, which were the most degraded. According to Du Plessis (1986), yield may be reduced by as much 30 to 40% on such affected soils.

Table 6.5 Summary of stepwise selection of the bulk density, gravimetric and volumetric water content and surface compaction. Only the surface compaction 10 mm from the species was significant (P<0.05).

Summary of Stepwise Selection						
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	Surface compaction (SC) (10 mm from species)	0.5931	0.5931	4.0324	27.70	<0.0001

With equation Y = 68.45 – SC (2.55) R^2 = 0.5931.

6.7 Germination

Sub-climax, pioneer and weed species' germination in September, and climax species' germination in December had no significant influence (P>0.05) on the occurrence of *T. triandra* (data not shown). From Table 6.6 it is clear that climax grass germination in September predicted the *T. triandra* occurrence percentage by 75.54%. Sub-climax and pioneer plus weeds germination in December contributed 5.81% and 6.57%, respectively, (Table 6.6).

Table 6.6 Summary of stepwise selection of germination. The climax germination in September, pioneer & weed germination in December and sub-climax germination in December, were significant (P<0.05).

Summary of Stepwise Selection						
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	Climax (September)	0.7554	0.7554	16.7036	58.67	<0.0001
2	Pioneer /weed (December)	0.0657	0.8211	9.6475	6.61	0.0192
3	Sub-climax (December)	0.0581	0.8792	3.6418	8.18	0.0108

With equation Y = 19.35 + G (0.51) – F5 (0.18) + F6 (0.51) and R^2 = 0.8792.

6.8 Total analysis without germination

The pH, P, Na, Ca, Mg, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, bulk density, gravimetric and volumetric water content, N, C:N relation, soil textures and surface compaction had no influence (P>0.05) on the occurrence of *T. triandra* over all soil layers (data not shown). The CEC (0-100 mm soil layer), K (0-50 mm and 100-200 mm soil layers) and C (0-50 mm and 100-200 mm soil layers) had no significant influence (P>0.05) on the occurrence of *T. triandra* (data not shown). Cation exchange capacity, K and C dominated throughout the germination selection and predicted the abundance of *T. triandra* with 88.37% (Table 6.7). The high influence of CEC indicates that CEC, which is particle size distribution related, may be of the most importance. Plough practices influenced the exchange ability of cations and therefore damaged the ability of natural rangeland to re-establish.

Table 6.7 Summary of stepwise selection of pH, P, K, Na, Ca, Mg, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, CEC, bulk density, gravimetric and volumetric water content, N, C, C:N relation, soil textures and surface compaction. The CEC, K and C on a depth of 100-200 mm, 50-100 mm and 50-100 mm respectively, were significant (P<0.05).

Summary of Stepwise Selection					
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**F Value**	**Pr > F**
1	CEC (100-200 mm)	0.6289	0.6289	32.20	< 0.0001
2	K (mg/kg) (50-100 mm)	0.1622	0.7911	13.98	0.0015
3	C (%) (50-100 mm)	0.0926	0.8837	13.53	0.0019

With equation Y = -88.21 – K (0.15) + CEC (7.54) + C (46.92) and R^2 = 0.8837.

6.9 Total analysis - all elements and characteristics included

The pH, P, Na, Ca, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, gravimetric and volumetric water content, N, C, C:N relation and soil textures had no influence (P>0.05) on the occurrence of *T. triandra* over all soil layers (data not shown). Seed availability predicted *T. triandra* occurrence with 75.54% (germination of climax grass species early in the season), which means that if seed is not present in the soil medium, nothing else will contribute to the occurrence of *T. triandra* (Table 6.8). Compaction (10 mm from species) predicted with the second highest value, a percentage of 8.42%, which were tested non-significantly (P>0.05) when variables K (50-100 mm) and germination in December were included in the test. Potassium (50-100 mm) and germination of pioneer grass species and weeds late in the season predicted a 3.98% contribution to *T. triandra* occurrence. Magnesium (0-50 mm) and germination of pioneer grass species and weeds in September predicted a 2.55% and 3.17% contribution, respectively, and CEC (50-100 mm) only 1.27%. The bulk density (10-20 mm) was also significant (P<0.05) but irrelevant with a 0.043% prediction of occurrence of *T. triandra*. The stepwise model consisting of a total analysis had the highest prediction of *T. triandra* with a percentage of 98.96%. Thus, if all the variables which predicted a high percentage occurrence of *T. triandra* are taken in consideration, it may highlight the shortages of certain soil chemical and physical elements as well as seed availability in abandoned fields.

Table 6.8 Summary of stepwise selection of pH, P, K, Na, Ca, Mg, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, CEC, bulk density, gravimetric and volumetric water content, germination, N, C, C:N relation, soil textures and surface compaction. Only climax germination in September, K 50-100 mm, pioneer + weeds germination in December, Mg 0-50 mm, pioneer + weeds germination in September, CEC 50-100mm and BD 100-200 mm contributed significantly ($P<0.05$) to the model.

Summary of Stepwise Selection						
Step	**Variable Entered**	**Variable Removed**	**Partial R-Square**	**Model R-Square**	**F Value**	**Pr > F**
1	Germination (September) Climax		0.7554	0.7554	58.67	< 0.0001
2	Surface compaction (10 mm from species)		0.0842	0.8395	9.44	0.0066
3	K (mg/kg) (50-100 mm)		0.0398	0.8793	5.60	0.03
4	Germination (December) Pioneer/weeds		0.0417	0.9211	8.46	0.0102
5		Surface compaction (10 mm from species)	0.0057	0.9154	1.15	0.3001
6	Mg (mg/kg) (0-50 mm)		0.0255	0.9409	6.92	0.0182
7	Germination (September) Pioneer/weeds		0.0317	0.9726	17.38	0.0008
8	CEC (50-100 mm)		0.0127	0.9854	12.19	0.0036
9	BD (g/mm^2) (100-200 mm)		0.0043	0.9896	5.33	0.038

With the equation Y = 89.11 – K (0.19) + Mg (0.03) + CEC (2.49) – BD (38.46) + G (0.09) + G (0.51) + R (0.43) and $R^2 = 0.9896$

6.10 Species composition

The pioneer and sub-climax species composition had no significant influence ($P>0.05$) on the occurrence of *T. triandra* (data not shown). In Table 6.9 climax grass species predicted the *T. triandra* percentage by 92.54%. The high prediction by climax grasses indicated the high percentage of *T. triandra* occurrence, which is the key species in this natural rangeland.

Table 6.9 Summary of stepwise selection of pioneer, sub-climax and climax grass species. Only the climax species' composition contributed significantly ($P<0.05$) to the model.

Summary of Stepwise Selection						
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	Species Composition (Climax)	0.9254	0.9254	1.7179	235.69	<.0001

With equation Y = 0.85 + SC (0.75) and $R^2 = 0.9254$.

6.11 Abandoned fields in comparison with natural rangeland

The most important environmental factors influencing vegetation recovery were investigated and most of the research questions asked in Chapter 1 were answered. The study outlines the importance of considering several characteristics of abandoned fields and natural rangeland, (these characteristics include: species composition, seed abundance, P, K, Na, Ca, Mg, H^+, Ca:Mg, (Ca:Mg)/K, Mg:K, Na:K, CEC, bulk density, gravimetric and volumetric water content, N, C, C:N relation, soil textures and surface compaction), to understand the re-establishment of climax grasses on abandoned fields and the dynamics of plant communities following disturbances.

It clearly demonstrated that the composition of the seed bank depends not only on the composition and production of the present and previous plant communities, but also on the disturbance of natural rangeland. This relationship between the composition of grass species and the characteristics which may influence the species composition, is particularly important for the vegetation changes under different management regimes. Although introduction of seed will probably not induce an immediate change in vegetation composition, as adult perennial grasses will probably compete with seedlings of the new species, it may improve over time.

Sowing of rangeland is expensive and it is therefore important to select species that are suitable for the local soil and climate. The most suitable species (*T. triandra)* is the one that grows naturally in the Verkeerdevlei region (locally indigenous). Seeds can be harvested from the plants or cutting sheafs. A good example with successfully establishment of *T. triandra,* on a neighboring farm where, sheafs were collected and placed in a degraded area with no *T. triandra* occurrence (Figure 6.1). These sheafs re-established seed after 24 months, and is shown in Figure 6.1. Thus rehabilitation on abandoned fields may be accelerated by the placement of *T. triandra* sheaf bundles.

Figure 6.1 *Themeda triandra* sheaf placement for the re-establishment of seedlings in the Verkeerdevlei region.

On the other hand, a potential change in floristic composition may take place if water availability can be increased by lessening surface compaction. In summary, the degree of degradation in vegetation diversity provides a good estimate of how far the system has diverged from the natural state of succession, and indicates the potential of characteristics like CEC, K, H+, Na:K, C, fine silt, surface compaction, germination, Mg, bulk density and species composition, which correlated significantly ($P<0.05$) with the occurrence of *T. triandra* (Table 6.10).

The climax species' composition of the abandoned fields differed significantly ($P<0.05$) from that of the natural rangeland with an average of 23.07% to 96.99% respectively (Table 6.10).

Abrupt changes in vegetation are generally caused by disturbances in the soil medium; these include wild fires, trampling and ploughing practices. Such events can quickly change vegetation structure and composition and will last for long periods (Rutherford & Powrie 2011). Succession is the relatively gradual change in composition that arises as the vegetation itself modifies various environmental variables over time, including water and nutrient levels. These changes to the environment do not suit most species adapted to grow, survive and reproduce in an area, causing floristic changes. Succession can be interrupted at any time by disturbance, either reverting the system to a previous state, or to a lower state altogether. Pioneer and weed species were more abundant in the abandoned fields with percentages of 55.91%, 33.27% and 35.02%, respectively. There were only 0.33% pioneer grass species and weeds present in the natural rangeland.

Potassium, over the 50-100 mm soil layer, was not correlated ($P>0.05$) on average (Table 6.10) over four sites, but tested significantly ($P<0.05$) in the prediction of *T. triandra* over the 21 blocks in total. The same principle applied to Mg for pioneer, weeds and sub-climax plants' germination in December. The highest concentration of K in the 50-100 mm soil layer and Mg in the 0-50 mm soil layer was measured in the abandoned fields with an average value of 492.12 mg kg^{-1} and 497.24 mg kg^{-1}, respectively (Table 6.10).

Cation exchange capacity of the abandoned fields correlated lower ($P>0.05$) (18.04 and 18.53) than that of the NR on the 50-100 mm and 100-200 mm soil layers, respectively. With a lower CEC, the abandoned fields may withhold certain elements from uptake.

The bulk density was higher in the abandoned fields and might withhold water from infiltrating, and giving way to an increase in surface compaction. The surface compaction (10 mm from species) was much higher in the abandoned fields with a value of 17.67 MPa over 3.75 MPa in the NR. This indicated a low infiltration rate and a high runoff rate in the abandoned fields.

Carbon (1.18%) was higher in the NR than in the abandoned fields, with an average percentage of 0.83 (Table 6.10).

Table 6.10 Summary of stepwise selection of all elements and characteristics (mean ± SE) that contributed significantly to the model (P<0.05).

Significant soil characteristics						
Abandoned fields in comparison with natural rangeland (mean ± SE)						
Significant (P<0.05)	NR	AF 1	AF 2	AF 3	AF**(avg)	SE
K mg/kg (50-100 mm)	413.37[a]	449.68[a]	487.62[a]	539.05[a]	492.12[a]	± 18.72
Mg mg/kg (0-50 mm)	409.51[a]	416.74[a]	600.03[a]	474.94[a]	497.24[a]	± 29.06
UIT H+ cmol(+)/kg 100-200 mm	0.00[b]	0.03[a]	0.00[b]	0.01[ab]	0.01[a]	±0.00
Na:K (100-200 mm)	0.49[a]	0.23[ab]	0.23[ab]	0.14[b]	0.20[b]	± 0.04
CEC (50-100 mm)	20.38[a]	15.67[b]	18.82[a]	19.64[a]	18.04[b]	± 0.46
CEC (100-200 mm)	21.66[a]	16.64[c]	19.11[b]	19.83[b]	18.53[b]	± 0.45
BD (g cm²) 100-200 mm	1.47[b]	1.64[a]	1.58[ab]	1.47[b]	1.57[a]	± 0.02
C (%) 50-100 mm	1.18[a]	0.74[a]	0.82[a]	0.93[a]	0.83[b]	± 0.06
Fine Silt 50-100 mm	12.39[a]	10.16[ab]	9.53[b]	9.64[ab]	9.78[b]	± 0.42
10mm from species (MPa)	3.75[b]	20.10[a]	17.00[a]	15.90[a]	17.67[a]	± 2.09
Pioneer+weed (seedling m^2) September	13.67[b]	140.80[ab]	105.60[ab]	161.60[a]	136[a]	± 19.64
Pioneer+weed (seedling m^2) December	34.5[a]	47.20[a]	44.20[a]	72.00[a]	54.47[a]	± 9.45
Sub-climax (seedling m^2) December	21.33[a]	0.00[a]	8.00[a]	9.60[a]	5.87[a]	± 4.25
Climax (seedling m^2) September	80.00[a]	0.00[b]	4.80[b]	46.40[ab]	17.07[b]	± 10.11
Climax grass species composition (%)	96.99[a]	11.59[b]	16.87[b]	40.74[b]	23.07[b]	± 8.91

* Column with different letters superscripts are significantly different (P<0.05)

** avg average over all three abandoned fields

6.12 Stepwise selection of characteristics tested in a linear regression model (P<0.05, R^2≥0.50) (Re: Chapter 7).

Carbon, over all soil layers had a significant (P<0.05) influence and predicted the occurrence of *T. triandra* at a 63.96% (same as in Figure 6.12) accuracy (Table 6.11). Phosphorus contributed significantly (P<0.05) to the occurrence of *T. triandra* with a 15.21% accuracy while soil surface compaction between two species contributed 7.3% (Table 6.11). In total this model can predict *T. triandra* occurrence at an 86.47% accuracy. This data expresses a notable influence of C and P on the occurrence of *T. triandra.*

Table 6.11 Summary of stepwise selection of P (0-50 mm), P (avg), CEC (100-200 mm), CEC (avg), N (over all soil layers including the average), C (over all soil layers including the average) and C:N (100-200 mm) which tested significant ($P<0.05$) in chapter 6.

Summary of Stepwise Selection						
Step	**Variable Entered**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	C (avg)	0.6396	0.6396	12.4632	33.71	<.0001
2	P (0-50 mm)	0.1521	0.7916	2.0318	13.14	0.002
3	Compaction between two species	0.0730	0.8647	-1.9393	9.18	0.008

With equation Y = 46.74 – pH (11.94) + C (36.26) – SC (0.60) and $R^2 = 0.8647$.

6.13 Conclusion

It should be noted that although emphases is given to specific soil features, it is the association between soil and all other environmental factors that influence assessments of degradation and management needs (Scotney & McPhee 1990). Data from the abandoned fields provides insight into many chemical and physical conditions which affect the species composition. The selections of all stepwise models differ because of the different interaction combinations between different variables. If a dominating characteristic was left out of the calculation (stepwise analysis), other variables would have dominated. The interaction differences complicated the study but in general showed a few soil and plant characteristics which dominated the prediction of *T. triandra.* Germination (soil seed bank), K, C and CEC dominated the selections and could predict *T. triandra* at a high accuracy.

The analysis that was done indicates that the establishment of climax vegetation might be largely influenced by P, CEC, N, C, compaction and the soil seed bank. In Table 6.1 soil characteristics were arranged from highest to lowest significant ($P<0.05$) influence on *T. triandra* occurrence. In the stepwise model they were re-arranged to fit an interacted effect of different soil characteristics. In the stepwise model, C was still highly significant in predicting the occurrence of *T. triandra,* but with the influence of all tested variables P contributed secondarily. It was interesting to note that even though the differences of C was not that big between NR (1.18%) and AF (avg) (0.83%), it still had a significant correlation with the occurrence of *T. triandra.* Table 6.1 concluded that CEC was a dominant characteristic in predicting the occurrence of *T. triandra*, while soil compaction (Table 6.11) in the stepwise selection tested to be one of the most important ones. Cation exchange capacity was not significant ($P<0.05$) in the prediction of *T. triandra* with the interaction of all variables tested in the stepwise model.

Chapter 7

Relationship: plant/soil characteristics versus *Themeda triandra* occurrence

7.1 Introduction

Environmental factors such as soil compaction, parent material (which forms the soil and topography), and vegetation dynamics are associated with ecosystem functioning. The ecosystem functioning on abandoned fields is disturbed and therefore in the process of recovering from previous disturbances. In this study, the interaction between rangeland condition (related to the percentage *T. triandra*) (Van der Westhuizen 2003) and certain soil and plant characteristics was quantified. In evaluating ecosystem functioning, it is therefore important to identify the significance with which the different soil and plant characteristics influence *T. triandra* occurrence. The different equations presented in this chapter illustrate the relationship of some of the measured soil and vegetation characteristics to the occurrence of *T. triandra,* over the 21 blocks that were investigated, which represented a degradation gradient from natural rangeland to the three abandoned fields. Growing public awareness of soil manipulation and environmental degradation is likely to have considerable impact on the agricultural sector. Unless attitude change "our greatest problem will remain a subject of conversation rather than conservation" (Scott 1967).

7.2 Results and discussions

Soil and plant characteristics, which showed significant ($P<0.05$) differences between abandoned fields and natural rangeland were compared in regressions. Only characteristics that predicted *T. triandra* occurrence at an accuracy of higher than 50% ($R^2>0.50$) are discussed. Common linear regressions were the model that best fitted the data.

7.2.1 Phosphorus

In the 0-50 mm soil layer phosphorus differed significantly ($P<0.05$) between the abandoned fields and natural rangeland. Phosphorus had a significant ($P<0.05$) influence and predicted the occurrence of *T. triandra* at a 58% accuracy (Figure 7.1). Figure 7.1 indicates that an increase in P levels decreases the percentage *T. triandra.* The average P value of the abandoned fields (3.52 mg kg^{-1}) was much higher than that of the natural rangeland (1.73 mg kg^{-1}) (Table 5.4).

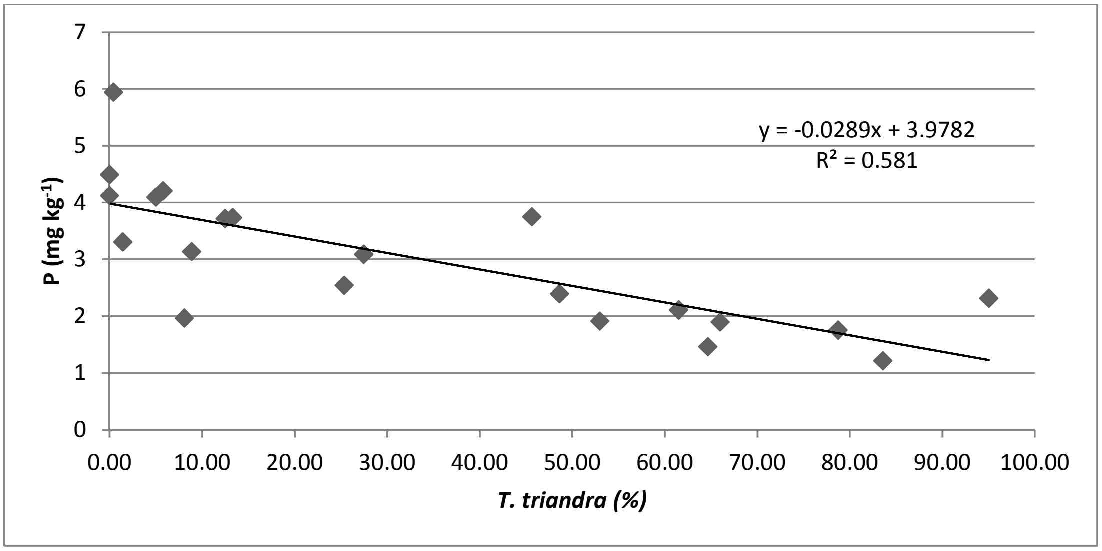

Figure 7.1 Relationship between P (0-50 mm) and *T. triandra* occurrence (n=21).

An increase in P indicated a decrease in the percentage of *T. triandra* (Figure 7.1 and Figure 7.2). Phosphorus level is 103% higher in the abandoned fields than in the natural rangeland (Table 5.4). The high P values in the abandoned fields might be a result of large quantities of P fertilization, applied 20 years ago. The average P for all soil layers has also shown a significant ($P<0.05$, $R^2=0.5425$) relationship between P and the percentage *T. triandra* (Figure 7.2). According to Morgan (1998) non-native species richness were strongly correlated with soil phosphorus, and native species were negatively correlated. In our study native climax grass species were also negatively correlated with phosphorus.

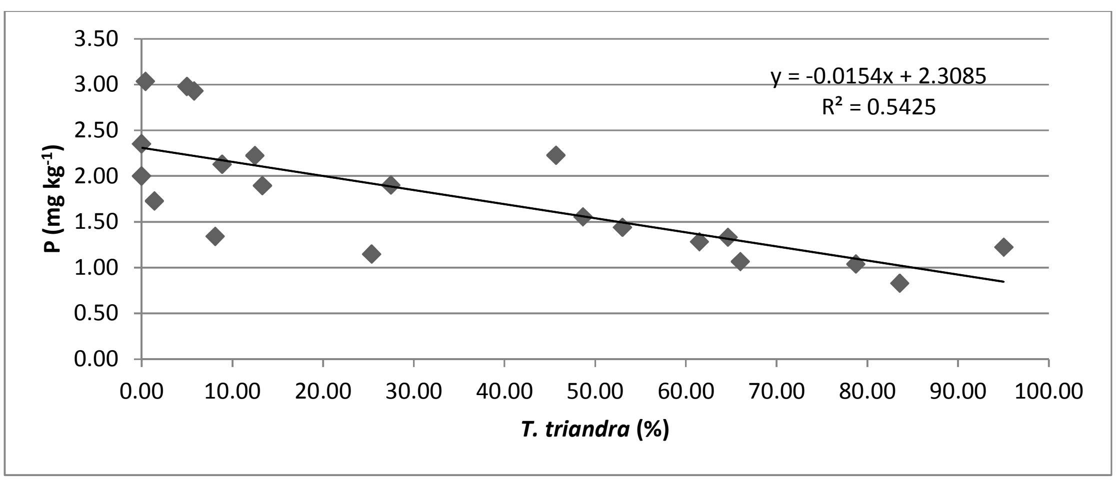

Figure 7.2 Relationship between P (average over all three soil layers) and *T. triandra* occurrence (n=21).

7.2.2 Cation exchange capacity

An increase in CEC indicated a increase in the percentage *T. triandra* (Figure 7.3 and Figure 7.4) occurrence. In chapter five Table 5.7 also indicated that CEC was significantly ($P<0.05$) lower in the 100-200 mm soil layer of the abandoned fields. There was a 63% relationship between CEC and percentage *T. triandra* occurrence. The high prediction of *T. triandra* correlated with the high CEC value in AF3 block 5 (highest percentage *T. triandra)* and AF2 block 2 (lowest percentage *T. triandra*).

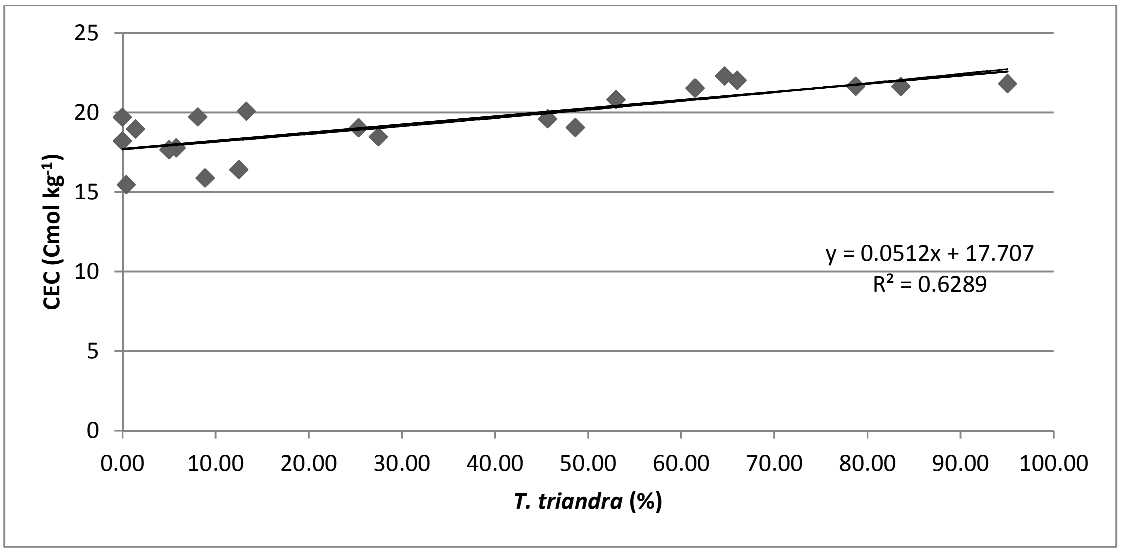

Figure 7.3 Relationship between CEC (100-200 mm) and *T. triandra* occurrence (n=21).

Cation exchange capacity was 14% lower in the abandoned fields than in the natural rangeland (Table 5.7). On average for all soil layers a statistically significant ($P<0.05$, $R^2=0.5425$) relationship was noted between CEC and the percentage *T. triandra* (Figure 7.4). The higher CEC in natural rangeland may indicate a more stable ecosystem. The cations like Na, Mg and Ca can exchange more frequently in highly fertile soils.

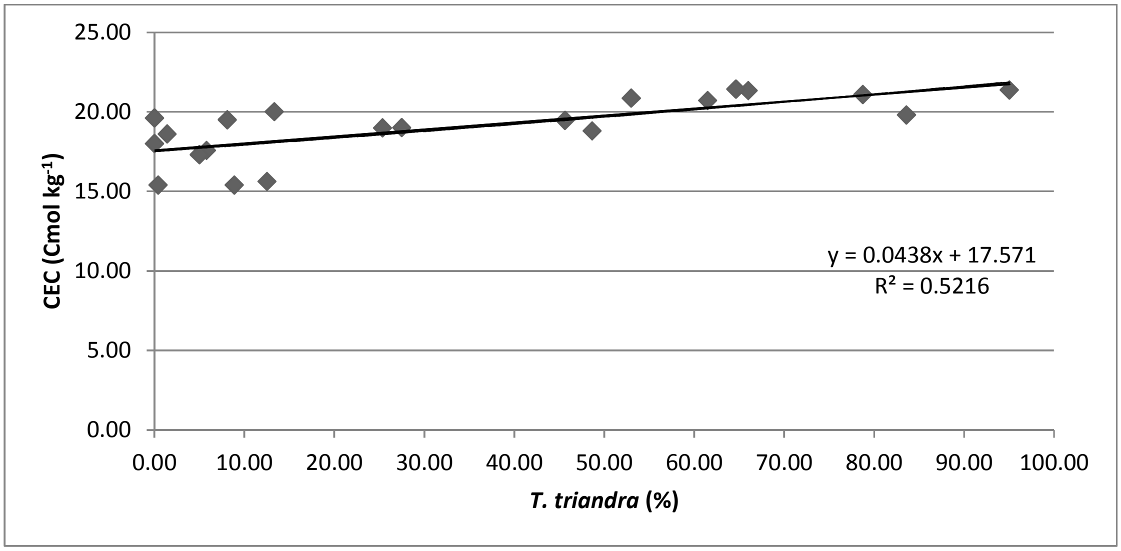

Figure 7.4 Relationship between CEC (average) and *T. triandra* occurrence (n=21).

7.2.3 Nitrogen

Nitrogen levels up to a soil depth of 50 mm showed a 57% prediction of *T. triandra* (Figure 7.5). A significant ($P<0.05$) relationship was found between N levels and the percentage *T. triandra,* which indicated more available N as rangeland condition increased.

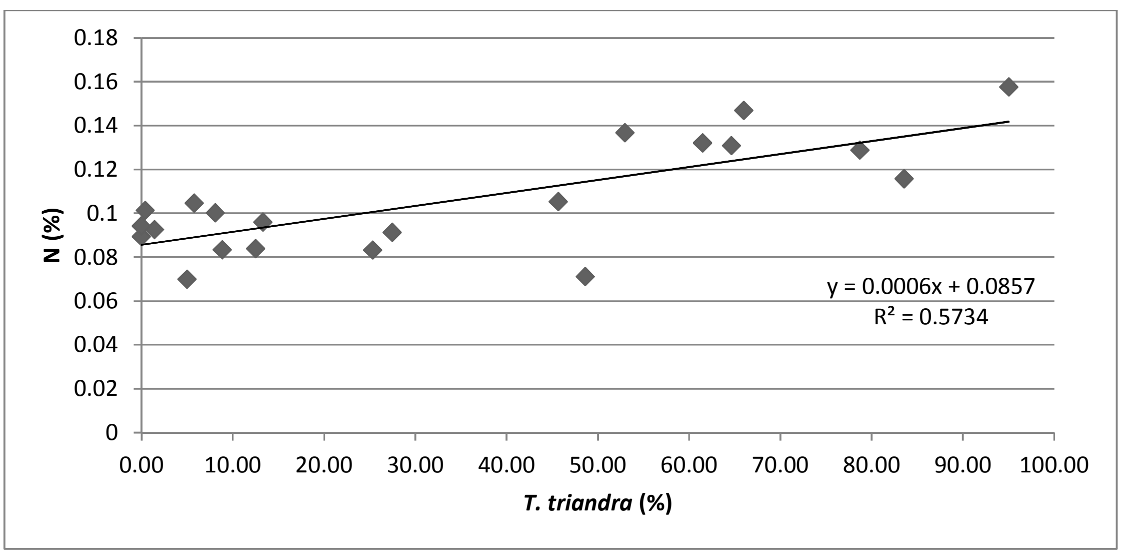

Figure 7.5 Relationship between N (0-50 mm) and *T. triandra* occurrence (n=21).

From the data it is clear that N plays an important role towards rehabilitation. There was a 53% relationship between N level (50-100 mm) and *T. triandra* percentage (Figure 7.6). Even if N is more abundant in natural rangeland it is important to notice the small variation in N value from poor to good natural vegetation.

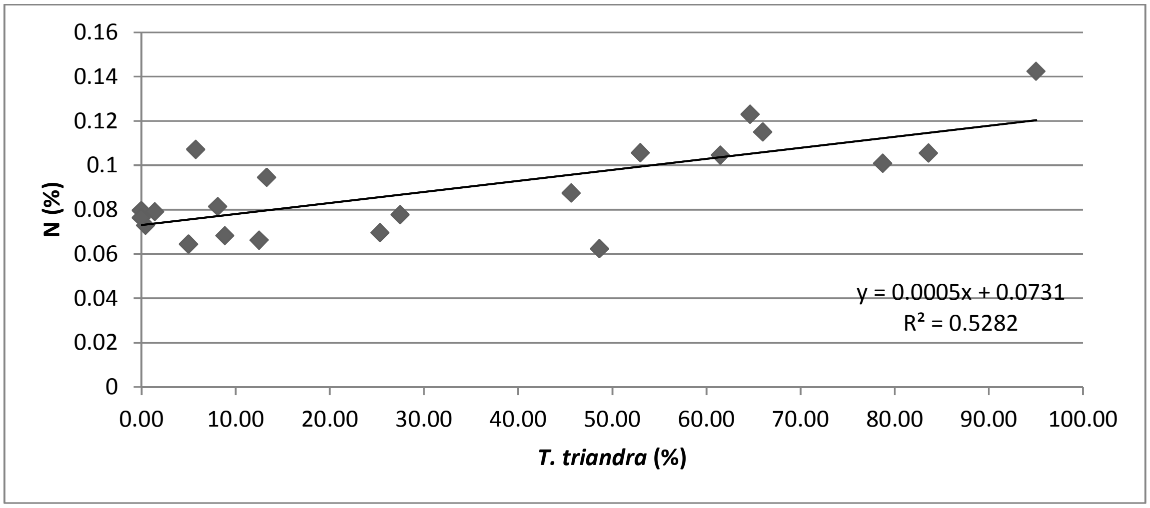

Figure 7.6 Relationship between N (50-100 mm) and *T. triandra* occurrence (n=21).

Nitrogen levels, in the 100-200 mm soil layer differed significantly ($P<0.05$) between the abandoned fields and natural rangeland (Table 5.8). Nitrogen had a significant ($P<0.05$) influence and predicted the occurrence of *T. triandra* at a 61% accuracy (Figure 7.7). Figure 7.7 indicates that an increase in N levels increase the percentage of *T. triandra.*

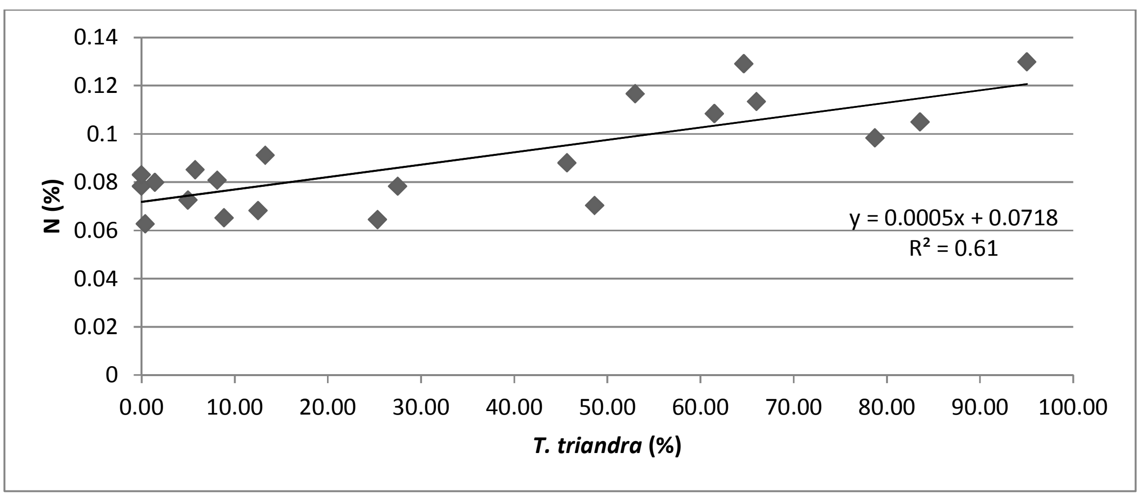

Figure 7.7 Relationship between N (100-200 mm) and *T. triandra* occurrence (n=21).

A positive relationship was found for all soil layers (Figure 7.8) in predicting the percentage *T. triandra* occurrence. An increase in N therefore indicated an increase in the percentage of *T. triandra*. Nitrogen and the percentage of *T. triandra* occurring had a 33% difference (Table 5.8). On average for all soil layers a statistically significant ($P<0.05$, $R^2=0.61$) relationship was noted between N and the percentage *T. triandra* (Figure 7.8).

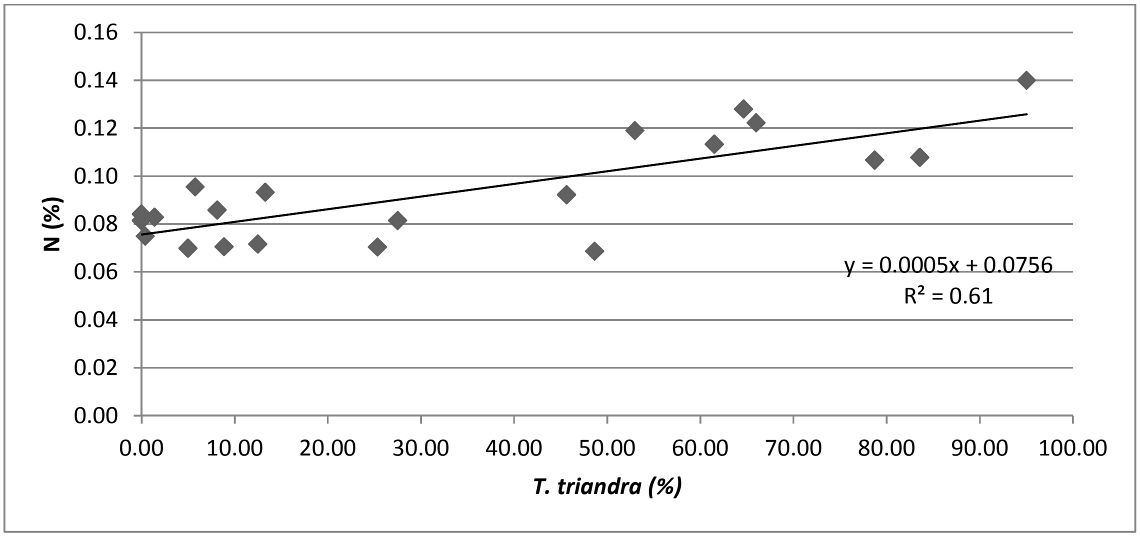

Figure 7.8 Relationship between N (average over all three soil layers) and *T. triandra* occurrence (n=21).

7.2.4 Carbon

It is clear that 62% of *T. triandra* occurrence can be predicted by carbon availability in the soil. Carbon, in the first 50 mm of the soil layer, is 35% lower in the abandoned fields. The loss of carbon indicated once again, like in the case of N, that there is a loss of organic matter in the soil profile. These losses may contribute to further decline deeper in the soil profile.

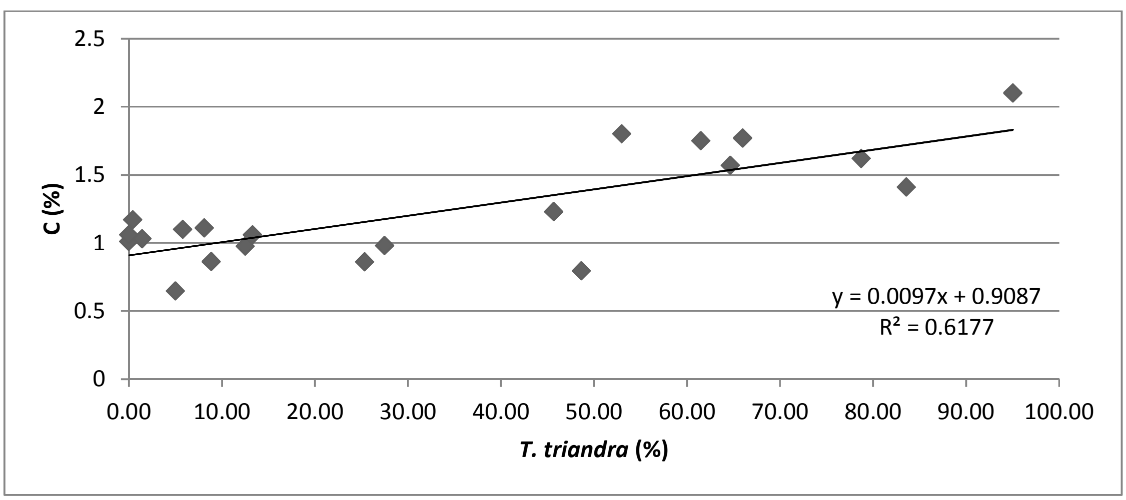

Figure 7.9 Relationship between C (0-50 mm) and *T. triandra* occurrence (n=21).

The same tendency as in Figure 7.9 was found in the 50-100 mm soil layer. A significant ($P<0.05$, R^2=0.62.7) relationship was also established between C level (50-100 mm) and the percentage *T. triandra* occurrence (Figure 7.10).

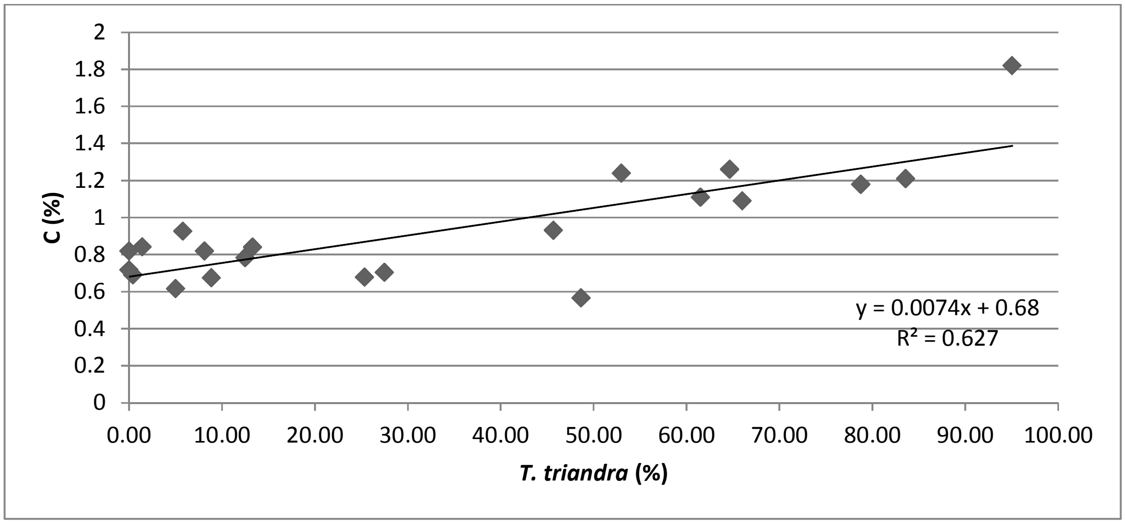

Figure 7.10 Relationship between C (50-100 mm) and *T. triandra* occurrence (n=21).

An increase in C level (100-200 mm soil depth) indicated an increase in the percentage *T. triandra* occurrence (Figure 7.11). Carbon and the percentage of *T. triandra* differed by 30% (Table 5.8). On average for all soil layers a significant ($P<0.05$, $R^2=0.6113$) relationship was found between C levels and the percentage *T. triandra* occurrence (Figure 7.11).

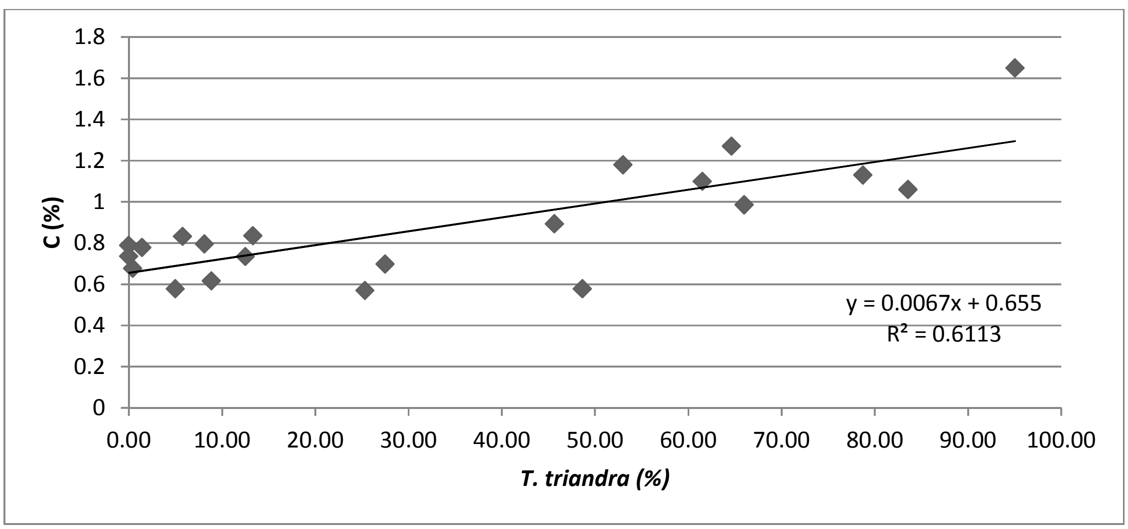

Figure 7.11 Relationship between C (100-200 mm) and *T. triandra* occurrence (n=21).

All soil layers showed more or less the same tendency in terms of C in the soil. The prediction of *T. triandra* occurrence by C levels was 64% which was the highest of all tested characteristics (Figure 7.12). The average C level on AF3 block 5 (95.04% *T. triandra*) was 1.82% with a C value of 0.86% on AF2 block 2 (0% *T. triandra*).

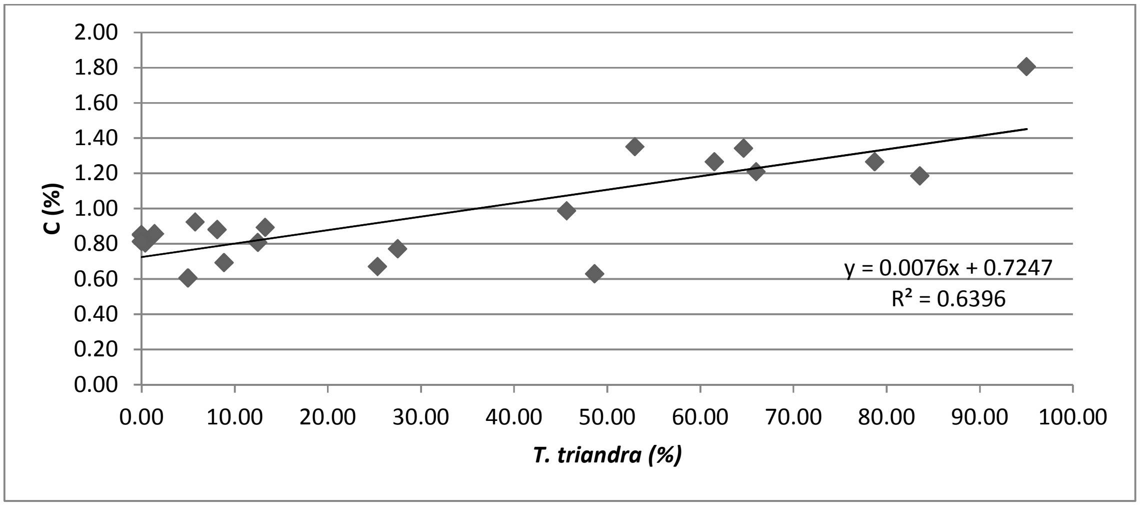

Figure 7.12 Relationship between C (average over all three soil layers) and *T. triandra* occurrence (n=21).

7.2.5 Carbon to nitrogen ratio

In the 100-200 mm soil layer, a statistically significant ($P<0.05$, $R^2=0.5469$) relationship occurred between the C:N ratio and the percentage *T. triandra* (Figure 7.13).

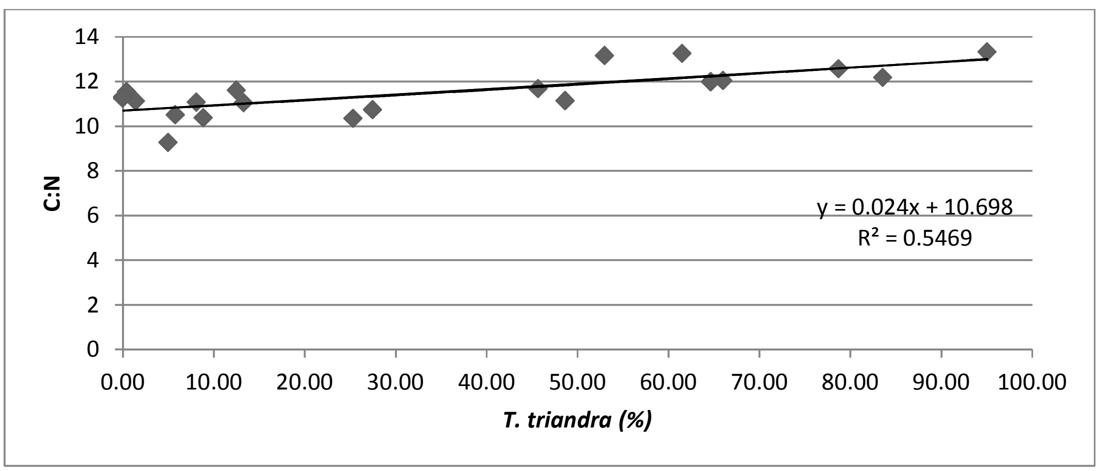

Figure 7.13 Relationship between C:N (100-200 mm) and *T. triandra* occurrence (n=21).

7.2.6 Soil compaction

Soil compaction on the bare areas between two species tested significantly in predicting the percentage *T. triandra* ($P<0.05$). Higher soil compaction accompanied a lower *T. triandra* occurrence (Figure 7.14). With soil compaction known, the *T. triandra* occurrence can be predicted by 59% (Figure 7.14).

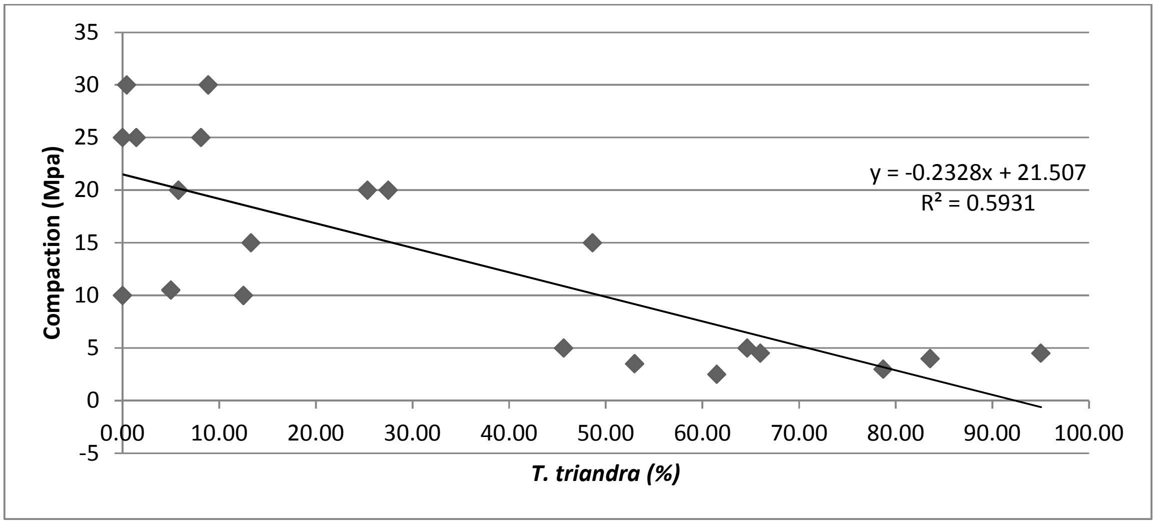

Figure 7.14 Relationship between compaction (10 mm from species) and *T. triandra* occurrence (n=21).

In Figure 7.14 soil compaction has a larger influence on the percentage *T. triandra* occurrence than in Figure 7.15, which indicates a drier micro-climate around the base of the plant. The relationship between *T. triandra* and compaction was 51% when compaction was measured between two species (Figure 7.15).

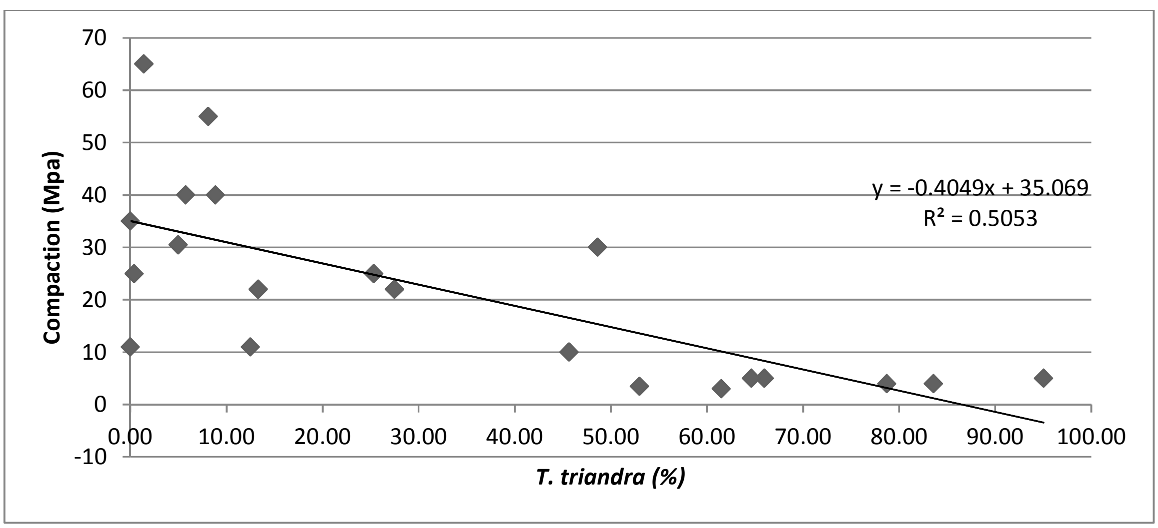

Figure 7.15 Relationship between compaction (between two species) and *T. triandra* occurrence (n=21).

An increase in soil compaction indicated a decrease in the percentage *T. triandra* occurrence (Figure 7.14 to 7.16). Compaction was 488% higher in the abandoned fields than in the natural rangeland (Table 5.11). The high compaction in the abandoned fields may indicate years of no vegetation cover with low infiltration rates. On average for all soil layers a significant ($P<0.05$, $R^2=0.5786$) relationship was measured between soil compaction and the percentage *T. triandra* occurrence (Figure 7.16).

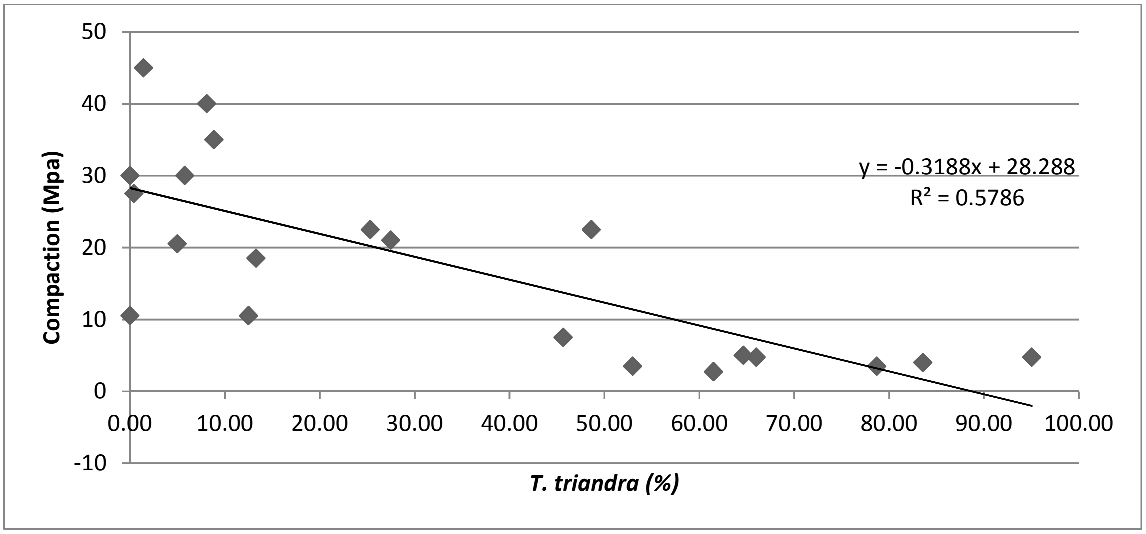

Figure 7.16 Relationship between compaction (average over measurements taken between two species and 10 mm from species) and *T. triandra* occurrence (n=21).

7.2.7 Germination

Germination of climax grasses in the greenhouse for the September trial differed significantly ($P<0.05$) between the abandoned fields and natural rangeland. Germination of climax grasses in September significantly ($P<0.05$) predicted the occurrence of *T. triandra* at a 76% accuracy (Figure 7.17). Figure 7.17 indicates that an increase in seed availability increases the percentage *T. triandra* occurring in the field, which is a good indication of rangeland condition (Van der Westhuizen 2003).

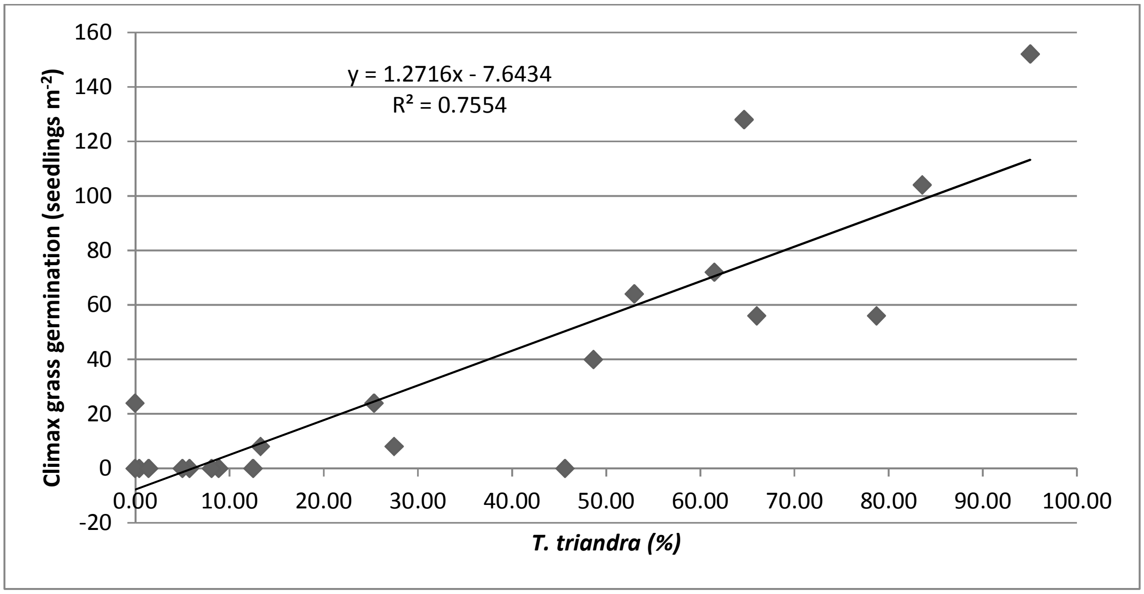

Figure 7.17 Relationship between climax grass germination (September) and *T. triandra* occurrence (n=21).

Although there was a slight decrease in the December germination of climax grasses than in the September germination trial, it was still highly significant ($P<0.05$) in predicting *T. triandra* occurrence.

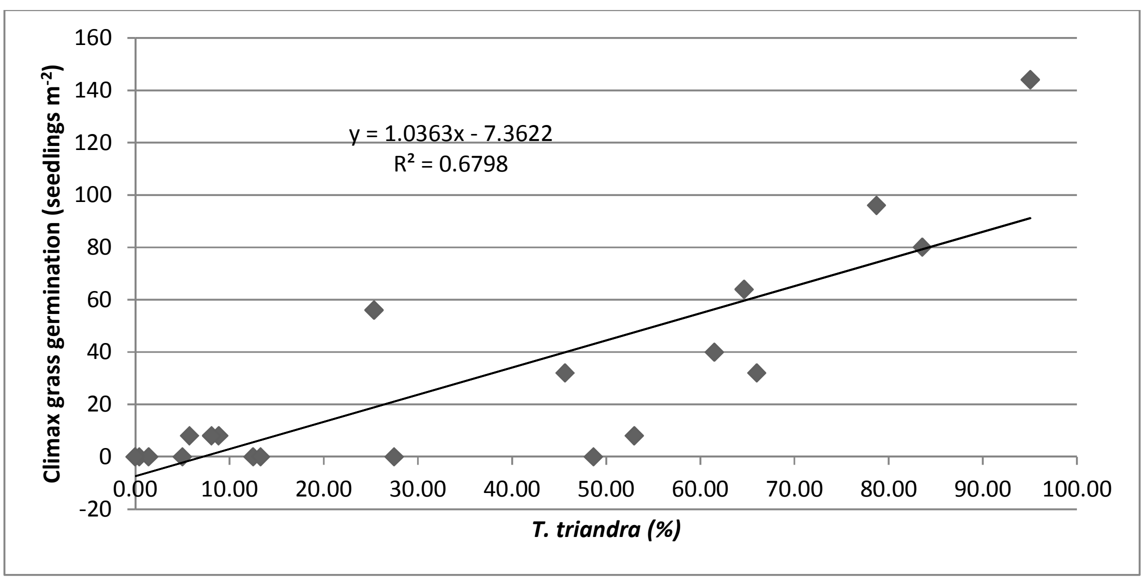

Figure 7.18 Relationship between climax grass germination (December) and *T. triandra* occurrence (n=21).

Figure 7.19 illustrates a significant ($P<0.05$) difference in seed availability of climax grasses in abandoned fields compared to that of natural rangeland. It is clear that an increase in seed density in the soil seed bank causes a significant ($P<0.05$) increase in *T. triandra* occurrence. A statistically significant ($P<0.05$, $R^2=0.7923$) relationship was established between germination of climax seed in the soil seed bank, and the percentage *T. triandra* occurrence (Figure 7.19).

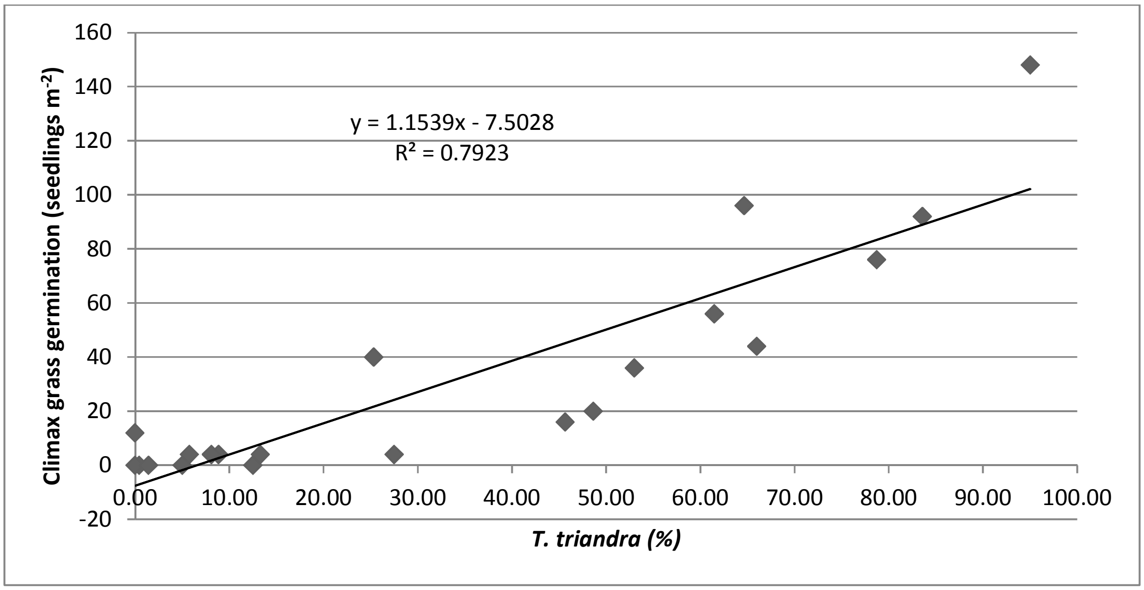

Figure 7.19 Relationship between climax grass germination (average over September and December) and *T. triandra* occurrence (n=21).

7.3 Conclusion

This study sheds more light on the poor natural rehabilitation rate of most abandoned fields in the semi-arid Free State province of South Africa. It was indicated that the establishment of climax vegetation (*T. triandra* dominated rangeland) might be largely influenced by P, CEC, N, C, soil compaction and the composition of the soil seed bank. In Table 7.1 those soil characteristics, which had the highest to the lowest prediction of *T. triandra* occurrence are listed. Table 7.1 illustrated that C and N correlated the best with the occurrence of *T. triandra*, while P and soil compaction contributed secondarily. Cation exchange capacity in the 100-200 mm soil layer had the second highest correlation at 63%.

Table 7.1 Soil characteristics (0-200 mm depths) ranging from the highest to the lowest R^2 values in prediction of *T. triandra* occurrence.

Soil characteristics	R^2
C (*avg)	0.64
CEC (100-200 mm)	0.63
C (50-100 mm)	0.62
C (0-50 mm)	0.62
C (100-200 mm)	0.61
N (100-200 mm)	0.61
N (avg)	0.61
Compaction 10 mm from species	0.59
P (0-50 mm)	0.58
Compaction (avg)	0.58
N (0-50 mm)	0.57
C:N (100-200 mm)	0.55
P (avg)	0.54
N (50-100 mm)	0.53
CEC (avg)	0.52
Compaction between species	0.51

*avg = average

These collective findings indicate that limited seed availability of climax grass species is one of the most important factors defining the habitat and therefore the chances for rehabilitation. Soil organic matter (C and N), in the 0-200 mm soil layer, contributed secondarily to rangeland rehabilitation potential. It is clear that marginal soils, withdrawn from cash-crop cultivation, are among the actively degraded areas with low soil fertility (N and C content). It is creating a more favourable habitat for pioneer grass species and therefore a better trend for plant succession is experienced.

The soil and plant characteristics, together with their interactions, indicated that natural rehabilitation of abandoned fields is a very slow process. Drastic human interference is an absolute necessity to speed up the process of plant succession (rehabilitation). Future investigation may include long-term trials to monitor the vegetation and soil characteristic's reaction to the introduction of organic matter, as well as seed of climax grass species.

Chapter 8

General conclusions and recommendations

8.1 Conclusion

The results from this study are a good indicator of secondary succession on abandoned fields in *T. triandra* dominated rangelands in the central Free State of South Africa. The first plant communities to establish themselves after abandoning cultivation, consist mostly of broad-leaved weeds and annual grasses. The grass layer includes the annual grasses *Aristida congesta, Cynodon dactylon, Eragrostis obtusa, Tragus racemosa* and the annual to weakly perennial grass *Chloris virgata*. These species are all adapted to survive in harsh environmental conditions that characterize old fields. Once environmental and soil conditions reach stability, perennial grasses such as *Panicum* and *Eragrostis* species, become established and tend to dominate the vegetation. As plant succession progresses, the perennial grass *T. triandra* increase in number and become the dominant species. It could be expected that the vegetation would return to the original *T. triandra* rangeland, depending on determinants such as climate, soil, management practices and the composition of the surrounding vegetation.

Rangeland degradation can be defined as a decrease in biological productivity and usefulness of an area due to human interference. Land degradation can also be described as deterioration of the physical, chemical and biological properties of soil and a long-term loss of natural vegetation. It is clear that soil-plant interactions across different rangeland conditions are the main determinant of plant community composition and primary production. Rainfall in semi-arid regions and consequently production as well as nutrient cycling is more unpredictable than in higher rainfall regions. This phenomenon makes rangeland restoration and re-establishment of climax grasses in abandoned fields more complex. Change in plant community composition can dramatically influence the soil-water balance, dry matter production and nutrient cycling. Unsustainable practices have resultantly intensified soil and vegetation degradation and led to a rapid decline in dry matter production and climax grass species numbers. Each livestock and game farmer should aim to keep his rangeland in optimal condition in order to obtain sustainable annual production.

The study provided a synthesis and explanation of various interactions between the natural plant-soil resources. The relation between rangeland in good condition and surrounding degraded areas was assessed and quantified in terms of various characteristics, which included the variation in floristic composition and functional attributes of species along environmental gradients. This study shed more light on the poor rehabilitation trend of abandoned fields in semi-arid areas as the vegetation dynamics of plant communities and patterns of primary production in abandoned fields are now better understood. It indicated that climax vegetation is very sensitive to P, CEC, N, C, and effected by soil surface compaction as well as a lack of an adequate soil seed bank. The collective findings indicate that seed availability was one of the most important factors defining the habitat, while soil fertility and soil surface compaction are equal contributors.

Species composition in the field is significantly influenced by seed availability in the soil seed bank. More climax seedlings were recorded in the natural rangeland compared to the abandoned fields. The lower grass seed germination in the abandoned fields clearly indicated a shortage of seed in the seed bank of all abandoned fields. Vegetation degradation may therefore be caused by a loss of cover due to depletion of seed banks. This study also indicated that some chemical elements (N, C, C:N, CEC, P and soil surface compaction) in the soil have a significant role to play in the establishment and survival of climax grasses. It is clear that without human interference, restoration of abandoned fields will not occur within 10 years or more. Something drastic has to be done after deciding to withdraw marginal soils from cash crop production. It is suggested that future long-term studies on abandoned fields monitor P- and C content of the soil over time, while continuously correlating it with climax grass species abundance.

8.2 Recommendations

Vegetation degradation is a product of sustained damaging anthropogenic activity by humans over a long period of time, as well as climatic and other factors such as soil condition.

- The main motivation for addressing vegetation degradation should be to ensure a sustainable environment for future land use.
- Secondly, in the light of such critical levels of vegetation degradation, it is imperative to adopt new grazing strategies to relieve the grazing pressure on these previously cultivated fields.
- Insufficient quantities of essential nutrients (including C) in the soil which had an influence on the appearance of *T. triandra* and other climax grasses, need to be supplemented to improve survival, adaptability and production of plants. These elements will not change the composition of vegetation dramatically, but may contribute to a more suitable environment for rehabilitation of abandoned fields.

- The predominant contributing factor to the occurrence of *T. triandra* is availability of the seed of climax plants in the soil seed bank. Short-term re-establishment of the abandoned fields requires breaking up of the soil surface and/or introduction of seed of climax species.
- The recovery of abandoned fields is a slow process, even when seed of climax species is introduced. It requires the microclimate to be built up beforehand to prepare a better environment for the establishment of climax grass species.
- A short-term re-establishment plan on the poorest rehabilitated abandoned field (nearly no grazing available) at Verkeerdevlei may be implemented by planting *Digitaria eriantha* sub. *eriantha.*

Without drastic cultivation, another 10 or more years might pass before any progress in species composition, thus increased productivity, might be observed. The moderately rehabilitated abandoned field (40.8 ha LSU^{-1} long-term grazing capacity) has already recovered to such an extent, that cultivation is not an option due to high input costs and possible degradation of soil physical characteristics. On such fields the introduction of *T. triandra* seed might be sufficient to speed up the recovery process. *Themeda triandra* sheafs can be cut at seed ripening stage and distributed over the area (based on subjective observations and not quantitative data). The sheafs might create a suitable microclimate for improved seedling establishment. Such re-establishment of *T. triandra* was done on a neighbouring farm with great success. The abandoned field in a moderate condition (40.8 ha LSU^{-1} long-term grazing capacity) has a more expectable botanical composition. A light grazing frequency throughout the winter with rest through the summer may be a good recommendation. A low grazing intensity is recommended.

The abandoned field that improved most (8.6 ha LSU^{-1} long-term grazing capacity) is almost fully rehabilitated and may improve over time by an appropriate grazing system which includes long resting periods. In this situation the abandoned field can almost be grazed at the recommended grazing capacity of natural rangeland, but with careful monitoring of rangeland condition.

Further research should focus on the ideal soil nutrient range for optimal establishment of climax grasses. The loss of soil organic matter on abandoned fields may inhibit rangeland recovery and requires further investigation. The soil surface compaction can be broken to ensure improved water infiltration and plant establishment. A compacted soil surface inhibits re-establishment of climax grasses. The detrimental effect of grazing include soil compaction and plant trampling. These factors may worsen the surface condition on abandoned fields even more, if not managed well. The abandoned fields can also be grazed in winter and rested in summer to loosen the soil but allowing it to recover during the growing season.

Marginal soils withdrawn from cash-crop cultivation rank among the most degraded areas in South Africa, and as such necessitate further research. The plant composition information of this study can therefore serve as a guideline to assist researchers and farmers in determining grass production losses and restoration trends to prevent further degradation on abandoned fields.

Chapter 9

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Appendix

Appendix A

Species composition was determined for each of the four study sites (AF 1-3 and NR). It was however also measured individually for each of the 21 smaller blocks. The species composition of the herbaceous layer of the abandoned fields and rangeland were estimated by frequency of occurrence, using the wheel-point apparatus. On each site (AF 1-3 and NR) four 200 m transects (East to West) were recorded with transects spaced 100 m apart. Appendix A specifies the different species obtained in this study. The percentage species composition of each of the 21 blocks is illustrated in Table 1.1.

Table 1.1 Percentage species composition over the 21 blocks of the study area.

	%																				
	Anandoned field one					Abandoned field two					Abandoned field three					Natural Rangeland					
Species	AF1B1	AF1B2	AF1B3	AF1B4	AF1B5	AF2B1	AF2B2	AF2B3	AF2B4	AF2B5	AF3B1	AF3B2	AF3B3	AF3B4	AF3B5	NRB1	NRB2	NRB3	NRB4	NRB5	NRB6
Eragrostis obtusa (Dew Gras)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.50
Themeda triandra (Red Grass)	0.42	8.87	12.50	5.78	5.00	0.00	1.42	25.35	8.11	45.66	48.65	27.49	0.00	13.30	95.04	61.50	53.00	66.00	64.65	78.73	83.58
Aristida congesta subsp. congesta (Tassel Three-awn)	57.74	62.56	47.12	32.00	64.50	55.39	37.91	30.88	22.97	17.35	22.52	43.13	54.11	42.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloris virgata (Feather-top Chloris)	0.00	0.49	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.91	1.35	1.42	0.00	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cynodon dactyloNR (Couch Grass)	3.35	6.90	0.00	0.00	3.00	0.00	0.95	0.00	0.00	0.00	0.90	0.00	2.60	5.50	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Pennisetum sphacelatum (Bull Grass)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sporobolus fimbriatus (Dropseed Grass)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panicum stapfianum (Stapf's Buffalo Grass)	0.42	0.49	1.92	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	3.32	0.00	0.46	0.00	2.35	0.46	3.00	3.26	2.71	1.99
Cymbopogon plirinodis (narrow-leaved Turpentine Grass)	0.00	0.00	1.92	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	2.37	0.00	0.00	1.65	0.00	0.00	0.00	0.00	0.00	0.00
Eragrostis lehmanniana (Lehmann's Love Grass)	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.37	0.45	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Digitaria eriantha (Common Finger Grass)	0.00	0.49	1.92	0.44	0.00	1.96	0.00	0.00	0.00	0.91	4.05	4.74	0.00	0.46	3.31	34.27	39.63	30.00	32.09	17.65	13.93
Eragrostis chloromelas (Curly LeAF)	6.28	0.00	0.00	0.00	0.50	3.43	0.47	0.00	0.90	1.37	6.76	3.79	2.60	0.46	0.00	0.00	0.00	0.00	0.00	0.45	0.00
Eragrostis plana (Tough Love Grass)	8.79	9.85	4.33	4.89	17.50	9.80	3.79	0.00	0.45	0.00	12.61	0.00	6.06	0.00	0.00	1.88	0.00	0.00	0.00	0.00	0.00
Aristida bipartita (Rolling Grass)	20.92	8.37	5.29	56.00	6.50	25.98	54.03	43.78	67.12	18.26	0.00	13.27	32.47	35.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteropogon contortus (Spear Grass)	0.42	0.00	20.19	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.47	1.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tragus racemosa (Carrit-seed Grass)	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aristida diffusa (Iron Grass)	0.00	0.00	0.48	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Setaria sphacelata var. sphacelate (Creeping Bristle Grass)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.91	0.00	0.00	0.00	0.00
Eragrostis bicolor (Speckled vlei grass)	1.26	1.48	4.33	0.44	1.50	1.96	0.95	0.00	0.00	14.16	2.25	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totaal	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

B1-5≈Block one to five

Appendix B

Soil physical and chemical characteristics as well as plant characteristics were compared to obtain a comparison between the abandoned fields and natural rangeland. In all Tables (Appendix B) variables were firstly (first column) compared over the four study sites. Secondly (second column) abandoned fields were compared with each other and thirdly (third column) the average of the three abandoned fields were compared with the natural rangeland. In the next three columns, the three abandoned fields (AF1-3) were compared with the natural rangeland.

Table 1.2 Composition of soil pH between NR and the three abandoned fields over all three soil depths.

Soil pH (KCl) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	4.90^{ab}		4.90^{a}	4.90^{a}	4.90^{b}	4.90^{a}
	± 0.04		± 0.04	± 0.04	± 0.04	± 0.04
AF(avg)			4.91^{a}			
			0.09			
AF 1	4.60^{b}	4.60^{b}		4.60^{b}		
	±0.06	±0.06		±0.06		
AF 2	5.23^{a}	5.23^{a}			5.23^{a}	
	± 0.15	± 0.15			± 0.15	
AF 3	4.90^{ab}	4.90^{ab}				4.90^{a}
	± 0.12	± 0.12				± 0.12
SE	± 0.07	± 0.09	± 0.07	± 0.06	± 0.08	± 0.05

Soil pH (KCl) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	4.87^{ab}		4.87^{a}	4.87^{a}	4.87^{a}	4.87^{a}
	± 0.03		± 0.03	± 0.03	± 0.03	± 0.03
AF(avg)			4.75^{a}			
			± 0.12			
AF 1	4.4^{b}	4.4^{b}		4.4^{b}		
	± 0.10	± 0.10		± 0.10		
AF 2	5.13^{a}	5.13^{a}			5.13^{a}	
	± 0.21	± 0.21			± 0.21	
AF 3	4.72^{ab}	4.72^{ab}				4.72^{a}
	± 0.15					± 0.15
SE	± 0.08	± 0.12	± 0.08	± 0.09	± 0.10	± 0.07

Soil pH (KCl) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	4.96^{ab}		4.96^{a}	4.96^{a}	4.96^{a}	4.96^{a}
	± 0.06		± 0.06	± 0.06	± 0.06	± 0.06
AF(avg)			4.72^{a}			
			± 0.12			
AF 1	4.38^{b}	4.38^{b}		4.38^{b}		
	± 0.09	± 0.09		± 0.09		
AF 2	5.10^{a}	5.10^{a}			5.10^{a}	
	± 0.23	± 0.23			± 0.23	
AF 3	4.70^{ab}	4.70^{ab}				4.70^{a}
	± 0.18	± 0.18				± 0.18
SE	± 0.09	± 0.12	± 0.09	± 0.11	± 0.11	± 0.09

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.3 Composition of soil P between NR and the three abandoned fields over all three soil depths.

Soil P (bray) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.73^{b}		1.73^{b}	1.73^{b}	1.73^{b}	1.73^{b}
	± 0.13		± 0.13	± 0.13	± 0.13	± 0.13
AF(avg)			3.52^{a}			
			± 0.26			
AF 1	4.22^{a}	4.22^{a}		4.22^{a}		
	± 0.47	± 0.47		± 0.47		
AF 2	3.14^{ab}	3.14^{a}			3.14^{a}	
	± 0.39	± 0.39			± 0.39	
AF 3	3.20^{a}	3.20^{a}				3.20^{a}
	± 0.41					± 0.41
SE	± 0.26	± 0.26	± 0.26	± 0.45	± 0.29	± 0.30

Soil P (bray) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.34^{b}		1.34^{a}	1.34^{b}	1.34^{a}	1.34^{a}
	± 0.20		± 0.20	± 0.20	± 0.20	± 0.20
AF(avg)			1.93^{a}			
			± 0.22			
AF 1	2.75^{a}	2.75^{a}		2.75^{a}		
	± 0.34	± 0.34		± 0.34		
AF 2	1.55^{b}	1.55^{b}			1.55^{a}	
	± 0.28	± 0.28			± 0.28	
AF 3	1.48^{b}	1.48^{b}				1.48^{b}
	± 0.20					± 0.20
SE	± 0.17	± 0.22	± 0.17	± 0.28	± 0.16	± 0.14

Soil P (bray) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.79^{b}		0.79^{b}	0.79^{b}	0.79^{a}	0.79^{b}
	± 0.07		± 0.07	± 0.07	± 0.07	± 0.07
AF(avg)			1.36^{a}			
			± 0.13			
AF 1	1.83^{a}	1.83^{a}		1.83^{a}		
	± 0.23	± 0.23		± 0.23		
AF 2	1.03^{b}	1.03^{b}			1.03^{a}	
	± 0.13	± 0.13			± 0.13	
AF 3	1.23^{b}	1.23^{ab}				1.23^{a}
	± 0.12	± 0.12				± 0.12
SE	± 0.11	± 0.13	± 0.11	± 0.19	± 0.08	± 0.09

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.4 Composition of soil K between NR and the three abandoned fields over all three soil depths.

Soil K (mg/kg) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	442.03^{a}		442.03^{a}	442.03^{a}	442.03^{a}	442.03^{a}
	± 30.00		± 30.00	± 30.00	± 30.00	± 30.00
AF(avg)			523.46^{a}			
			± 24.16			
AF 1	480.75^{a}	480.75^{a}		480.75^{a}		
	± 33.06	± 33.06		± 33.06		
AF 2	514.06^{a}	514.06^{a}			514.06^{a}	
	± 20.54	± 20.54			± 20.54	
AF 3	575.58^{a}	575.58^{a}				575.58^{a}
	± 58.81	± 58.81				± 58.81
SE	± 20.59	± 24.16	± 20.59	± 21.94	± 21.23	± 36.28

Soil K (mg/kg) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	413.37^{a}		413.37^{a}	413.37^{a}	413.37^{a}	413.37^{a}
	± 38.46		± 38.46	± 38.46	± 38.46	± 38.46
AF(avg)			492.12^{a}			
			± 19.05			
AF 1	449.68^{a}	449.68^{a}		449.68^{a}		
	± 23.43	± 23.43		± 23.43		
AF 2	487.62^{a}	487.62^{a}			487.62^{a}	
	± 25.71	± 25.71			± 25.71	
AF 3	539.05^{a}	539.05^{a}				539.05^{a}
	± 39.91	± 39.91				± 39.91
SE	± 18.72	± 19.05	± 18.72	± 23.15	± 25.70	± 32.94

Soil K (mg/kg) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	448.93^{a}		448.93^{a}	448.93^{a}	448.93^{a}	448.93^{a}
	± 67.75		± 67.75	± 67.75	± 67.75	± 67.75
AF(avg)			444.98^{a}			
			± 26.44			
AF 1	395.41^{a}	395.41^{a}		395.41^{a}		
	± 24.51	± 24.51		± 24.51		
AF 2	416.10^{a}	416.10^{a}			416.10^{a}	
	± 13.17	± 13.17			± 13.17	
AF 3	522.54^{a}	522.54^{a}				522.54^{a}
	± 65.20	± 65.20				± 65.20
SE	± 26.03	± 26.44	± 26.03	± 37.84	± 36.17	± 46.46

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.5 Composition of soil Na between NR and the three abandoned fields over all three soil depths.

Soil Na (mg/kg) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	28.20^{a}		28.20^{a}	28.20^{a}	28.20^{a}	28.20^{a}
	±2.32		±2.32	±2.32	±2.32	±2.32
AF(avg)			23.20^{a}			
			± 2.32			
AF 1	25.15^{a}	25.15^{a}		25.15^{a}		
	± 5.06	± 5.06		± 5.06		
AF 2	26.53^{a}	26.53^{a}			26.53^{a}	
	± 3.86	± 3.86			± 3.86	
AF 3	17.91^{a}	17.91^{a}				17.91^{b}
	± 2.35	± 2.35				± 2.35
SE	± 1.83	± 2.32	± 1.83	± 2.52	± 2.06	± 2.26

Soil Na (mg/kg) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	45.43^{a}		45.43^{a}	45.43^{a}	45.43^{a}	45.43^{a}
	± 6.45		± 6.45	± 6.45	± 6.45	± 6.45
AF(avg)			30.50^{a}			
			± 3.75			
AF 1	30.86^{a}	30.86^{a}		30.86^{a}		
	± 7.77	± 7.77		± 7.77		
AF 2	37.23^{a}	37.23^{a}			37.23^{a}	
	± 7.01	± 7.01			± 7.01	
AF 3	23.42^{a}	23.42^{a}				23.42^{b}
	± 3.74	± 3.74				± 3.74
SE	± 3.50	± 3.75	± 3.50	± 5.25	± 4.68	± 5.09

Soil Na (mg/kg) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	118.64^{a}		118.64^{a}	118.64^{a}	118.64^{a}	118.64^{a}
	± 19.16		± 19.16	± 19.16	± 19.16	± 19.16
AF(avg)			51.48^{b}			
			± 7.53			
AF 1	55.62^{ab}	55.62^{a}		55.62^{b}		
	± 19.15	± 19.15		± 19.15		
AF 2	56.02^{ab}	56.02^{a}			56.02^{b}	
	± 10.34	± 10.34			± 10.34	
AF 3	42.80^{b}	42.80^{a}				42.80^{b}
	± 9.69	± 9.69				± 9.69
SE	± 10.03	± 7.53	± 10.03	± 16.29	± 14.72	± 16.12

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.6 Composition of soil Ca between NR and the three abandoned fields over all three soil depths.

	Soil Ca (mg/kg) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	891.45^{b}		891.45^{a}	891.45^{a}	891.45^{b}	891.45^{a}
	± 41.46		± 41.46	± 41.46	± 41.46	± 41.46
AF(avg)			1228.1^{a} ± 108.53			
AF 1	911.04^{b}	911.04^{b}		911.04^{a}		
	± 98.07	± 98.07		± 98.07		
AF 2	1520.33^{b}	1520.33^{a}			1520.33^{a}	
	± 139.24	± 139.24			± 139.24	
AF 3	1252.92^{ab}	1252.92^{ab}				1252.92^{a}
	± 219.15	± 219.15				± 219.15
SE	± 84.66	± 108.53	± 84.66	± 47.19	± 117.47	± 111.54

	Soil Ca (mg/kg) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	973.31^{b}		973.31^{a}	973.31^{a}	973.31^{b}	973.31^{a}
	± 41.63		± 41.63	± 41.63	± 41.63	± 41.63
AF(avg)			1281.82^{a}			
			± 116.00			
AF 1	941.62^{b}	941.62^{b}		941.62^{a}		
	± 98.83	± 98.83		± 98.83		
AF 2	1605.62^{a}	1605.62^{a}			1605.62^{a}	
	± 130.08	± 130.08			± 130.08	
AF 3	1298.23^{ab}	1298.23^{ab}				1298.23^{a}
	± 243.71	± 243.71				± 243.71
SE	± 88.45	± 116.00	± 88.45	± 47.68	± 116.03	± 117.85

	Soil Ca (mg/kg) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1333.24^{a}		1333.24^{a}	1333.24^{a}	1333.24^{b}	1333.24^{a}
	± 61.65		± 61.65	± 61.65	± 61.65	± 61.65
AF(avg)			1456.53^{a}			
			± 148.76			
AF 1	1042.70^{a}	1042.70^{a}		1042.70^{a}		
	± 154.73	± 154.73		± 154.73		
AF 2	1737.67^{a}	1737.67^{a}			1737.67^{a}	
	± 144.71	± 144.71			± 144.71	
AF 3	1589.22^{a}	1589.22^{a}				1589.22^{a}
	± 347.15	± 347.15				± 347.15
SE	± 107.20	± 148.76	± 107.20	± 86.50	± 94.34	± 156.76

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.7 Composition of soil Mg between NR and the three abandoned fields over all three soil depths.

	Soil Mg (mg/kg) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	409.51^{a}		409.51^{a}	409.51^{a}	409.51^{b}	409.51^{a}
	± 15.38		± 15.38	± 15.38	± 15.38	± 15.38
AF(avg)			497.24^{a}			
			± 38.71			
AF 1	416.74^{a}	416.74^{a}		416.74^{a}		
	± 67.05	± 67.05		± 67.05		
AF 2	600.03^{a}	600.03^{a}			600.03^{a}	
	± 56.27	± 56.27			± 56.27	
AF 3	474.94^{a}	474.94^{a}				474.94^{a}
	± 60.70	± 60.70				± 60.70
SE	± 29.06	± 38.71	± 29.06	± 29.72	± 39.25	± 28.99

	Soil Mg (mg/kg) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	448.60^{a}		448.60^{a}	448.60^{a}	448.60^{b}	448.60^{a}
	± 21.88		± 21.88	± 21.88	± 21.88	± 21.88
AF(avg)			490.71^{a}			
			± 39.72			
AF 1	406.91^{a}	406.91^{a}		406.91^{a}		
	± 64.09	± 64.09		± 64.09		
AF 2	598.93^{a}	598.93^{a}			598.93^{a}	
	± 61.97	± 61.97			± 61.97	
AF 3	466.28^{a}	466.28^{a}				466.28^{a}
	± 61.53	± 61.53				± 61.53
SE	± 29.00	± 39.72	± 29.00	± 30.34	± 37.27	± 28.75

	Soil Mg (mg/kg) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	683.44^{a}		683.44^{a}	683.44^{a}	683.44^{a}	683.44^{a}
	± 41.55		± 41.55	± 41.55	± 41.55	± 41.55
AF(avg)			556.92^{a}			
			± 49.42			
AF 1	447.37^{a}	447.37^{a}		447.37^{b}		
	± 83.81	± 83.81		± 83.81		
AF 2	643.12^{a}	643.12^{a}			643.12^{a}	
	± 59.84	± 59.84			± 59.84	
AF 3	580.27^{a}	580.27^{a}				580.27^{a}
	± 100.22	± 100.22				± 100.22
SE	± 38.83	± 49.42	± 38.83	± 55.94	± 34.09	± 50.61

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.8 Composition of soil H between NR and the three abandoned fields over all three soil depths.

	Soil H+ mmol(+)/kg 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0^{a}		0^{a}	0^{a}	0^{a}	0^{a}
	± 0.00		± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)			0.0^{a}			
			± 0.00			
AF 1	0.01^{a}	0.01^{a}		0.01^{a}		
	± 0.01	± 0.01		± 0.01		
AF 2	0^{a}	0^{a}			0^{a}	
	± 0.00	± 0.00			± 0.00	
AF 3	0^{a}	0^{a}				0^{a}
	± 0.00	± 0.00				± 0.00
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00

	Soil H+ mmol(+)/kg 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0^{a}		0^{a}	0^{a}	0^{a}	0^{a}
	± 0.00		± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)			0.02^{a}			
			± 0.02			
AF 1	0.06^{a}	0.06^{a}		0.06^{a}		
	± 0.04	± 0.04		± 0.04		
AF 2	0^{a}	0^{a}			0^{a}	
	± 0.00	± 0.00			± 0.00	
AF 3	0.01^{a}	0.01^{a}				0.01^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.02	± 0.01	± 0.02	± 0.00	± 0.00

	Soil H+ mmol(+)/kg 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0^{b}		0^{a}	0^{b}	0^{a}	0^{a}
	± 0.00		± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)			0.01^{a}			
			± 0.00			
AF 1	0.03^{a}	0.03^{a}		0.03^{a}		
	± 0.01	± 0.01		± 0.01		
AF 2	0^{b}	0^{b}			0^{a}	
	± 0.00	± 0.00			± 0.00	
AF 3	0.01^{ab}	0.01^{ab}				0.01^{a}
	± 0.01	± 0.01				± 0.01
SE	±0.00	±0.00	± 0.01	±0.00	±0.00	±0.00

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.9 Composition of soil Ca;Mg between NR and the three abandoned fields over all three soil depths.

	Soil Ca:Mg (1.5-4.5) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.33^{a}		1.33^{a}	1.33^{a}	1.33^{a}	1.33^{a}
	± 0.03		± 0.03	± 0.03	± 0.03	± 0.03
AF(avg)			1.53^{a}			
			± 0.09			
AF 1	1.38^{a}	1.38^{a}		1.38^{a}		
	± 0.07	± 0.07		± 0.07		
AF 2	1.60^{a}	1.60^{a}			1.60^{a}	
	± 0.22	± 0.22			± 0.22	
AF 3	1.60^{a}	1.60^{a}				1.60^{a}
	± 0.15	± 0.15				± 0.15
SE	± 0.07	± 0.09	± 0.07	± 0.04	± 0.11	± 0.08

	Soil Ca:Mg (1.5-4.5) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.33^{a}		1.33^{a}	1.33^{a}	1.33^{a}	1.33^{b}
	± 0.04		± 0.04	± 0.04	± 0.04	± 0.04
AF(avg)			1.61^{a}			
			± 0.09			
AF 1	1.46^{a}	1.46^{a}		1.46^{a}		
	± 0.07	± 0.07		± 0.07		
AF 2	1.70^{a}	1.70^{a}			1.70^{a}	
	± 0.22	± 0.22			± 0.22	
AF 3	1.68^{a}	1.68^{a}				1.68^{a}
	± 0.14	± 0.14				± 0.14
SE	± 0.07	± 0.09	± 0.07	± 0.04	± 0.11	± 0.09

	Soil Ca:Mg (1.5-4.5) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.20^{b}		1.20^{b}	1.20^{b}	1.20^{b}	1.20^{b}
	± 0.03		± 0.03	± 0.03	± 0.03	± 0.03
AF(avg)			1.6^{a}			
			± 0.08			
AF 1	1.47^{ab}	1.47^{a}		1.47^{a}		
	± 0.07	± 0.07		± 0.07		
AF 2	1.69^{a}	1.69^{a}			1.69^{a}	
	± 0.17	± 0.17			± 0.17	
AF 3	1.65^{a}	1.65^{a}				1.65^{a}
	± 0.14	± 0.14				± 0.14
SE	± 0.07	± 0.08	± 0.07	± 0.06	± 0.11	± 0.09

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.10 Composition of soil (Ca:Mg/K) between NR and the three abandoned fields over all three soil depths.

Soil (Ca+Mg)/K (10.0-20.0) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	7.0^{b}		7.0^{a}	7.0^{a}	7.0^{b}	7.0^{a}
	± 0.31		± 0.31	± 0.31	± 0.31	± 0.31
AF(avg)			7.6^{a}			
			± 0.48			
AF 1	6.40^{b}	6.40^{b}		6.40^{a}		
	± 0.40	± 0.40		± 0.40		
AF 2	9.54^{a}	9.54^{a}			9.54^{a}	
	± 0.56	± 0.56			± 0.56	
AF 3	6.88^{b}	6.88^{b}				6.88^{a}
	± 0.73	± 0.73				± 0.73
SE	± 0.36	± 0.48	± 0.36	± 0.26	± 0.49	± 0.35

Soil (Ca+Mg)/K (10.0-20.0) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	8.31^{ab}		8.31^{a}	8.31^{a}	8.31^{b}	8.31^{a}
	± 0.52		± 0.52	± 0.52	± 0.52	± 0.52
AF(avg)			8.24^{a}			
			± 0.56			
AF 1	6.91^{b}	6.91^{b}		6.91^{a}		
	± 0.53	± 0.53		± 0.53		
AF 2	10.38^{a}	10.38^{a}			10.38^{a}	
	± 0.52	± 0.52			± 0.52	
AF 3	7.43^{b}	7.43^{b}				7.43^{a}
	± 0.98	± 0.98				± 0.98
SE	± 0.42	± 0.56	± 0.42	± 0.42	± 0.48	± 0.52

Soil (Ca+Mg)/K (10.0-20.0) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	11.85^{a}		11.85^{a}	11.85^{a}	11.85^{a}	11.85^{a}
	± 0.73		± 0.73	± 0.73	± 0.73	± 0.73
AF(avg)			10.33^{a}			
			± 0.70			
AF 1	8.61^{a}	8.61^{b}		8.61^{b}		
	± 0.90	± 0.90		± 0.90		
AF 2	13.07^{a}	13.07^{a}			13.07^{a}	
	± 0.78	± 0.78			± 0.78	
AF 3	9.32^{a}	9.32^{b}				9.32^{a}
	± 0.88	± 0.88				± 0.88
SE	± 0.69	± 0.70	± 0.69	± 1.11	± 0.98	± 1.06

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.11 Composition of soil Mg:K between NR and the three abandoned fields over all three soil depths.

Soil Mg:K (3.0-4.0) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	3.01^{ab}		3.01^{a}	3.01^{a}	3.01^{b}	3.01^{a}
	± 0.12		± 0.12	± 0.12	± 0.12	± 0.12
AF(avg)			3.03^{a}			
			± 0.19			
AF 1	2.73^{b}	2.73^{b}		2.73^{a}		
	± 0.26	± 0.26		± 0.26		
AF 2	3.73^{a}	3.73^{a}			3.73^{a}	
	± 0.29	± 0.29			± 0.29	
AF 3	2.63^{b}	2.63^{b}				2.63^{a}
	± 0.17	± 0.17				± 0.17
SE	± 0.14	± 0.19	± 0.14	± 0.13	± 0.18	± 0.11

Soil Mg:K (3.0-4.0) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	3.56^{ab}		3.56^{a}	3.56^{a}	3.56^{a}	3.56^{a}
	± 0.20		± 0.20	± 0.20	± 0.20	± 0.20
AF(avg)			3.18^{a}			
			± 0.22			
AF 1	2.85^{ab}	2.85^{a}		2.85^{a}		
	± 0.30	± 0.30		± 0.30		
AF 2	3.94^{a}	3.94^{a}			3.94^{a}	
	± 0.37	± 0.37			± 0.37	
AF 3	2.76^{b}	2.76^{a}				2.76^{b}
	± 0.27	± 0.27				± 0.27
SE	± 0.17	± 0.22	± 0.17	± 0.20	± 0.20	± 0.20

Soil Mg:K (3.0-4.0) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	5.36^{a}		5.36^{a}	5.36^{a}	5.36^{a}	5.36^{a}
	± 0.74		± 0.74	± 0.74	± 0.74	± 0.74
AF(avg)			4.00^{b}			
			± 0.29			
AF 1	3.54^{a}	3.54^{a}		3.54^{a}		
	± 0.46	± 0.46		± 0.46		
AF 2	4.96^{a}	4.96^{a}			4.96^{a}	
	± 0.49	± 0.49			± 0.49	
AF 3	3.52^{a}	3.52^{a}				3.52^{a}
	± 0.27	± 0.27				± 0.27
SE	± 0.32	± 0.29	± 0.32	± 0.52	± 0.44	± 0.50

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.12 Composition of soil Na:K between NR and the three abandoned fields over all three soil depths.

Soil Na:K 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.11^{a}		0.11^{a}	0.11^{a}	0.11^{a}	0.11^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			0.076^{b}			
			± 0.01			
AF 1	0.09^{ab}	0.09^{a}		0.09^{a}		
	± 0.01	± 0.01		± 0.01		
AF 2	0.09^{ab}	0.09^{a}			0.09^{a}	
	± 0.01	± 0.01			± 0.01	
AF 3	0.05^{b}	0.05^{a}				0.05^{b}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01

Soil Na:K 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.19^{a}		0.19^{a}	0.19^{a}	0.19^{a}	0.19^{a}
	± 0.03		± 0.03	± 0.03	± 0.03	± 0.03
AF(avg)			0.10^{b}			
			± 0.01			
AF 1	0.11^{ab}	0.11^{a}		0.11^{a}		
	± 0.02	± 0.02		± 0.02		
AF 2	0.13^{ab}	0.13^{a}			0.13^{a}	
	± 0.02	± 0.02			± 0.02	
AF 3	0.07^{b}	0.07^{a}				0.07^{b}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.01	± 0.01	± 0.02	± 0.02	± 0.02

Soil Na:K 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.49^{a}		0.49^{a}	0.49^{a}	0.49^{a}	0.49^{a}
	± 0.09		± 0.09	± 0.09	± 0.09	± 0.09
AF(avg)			0.20^{b}			
			± 0.03			
AF 1	0.23^{ab}	0.23^{a}		0.23^{a}		
	± 0.07	± 0.07		± 0.07		
AF 2	0.23^{ab}	0.23^{a}			0.23^{b}	
	± 0.04	± 0.04			± 0.04	
AF 3	0.14^{b}	0.14^{a}				0.14^{b}
	± 0.03	± 0.03				± 0.03
SE	± 0.04	± 0.03	± 0.04	± 0.07	± 0.06	± 0.07

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.13 Composition of soil CEC between NR and the three abandoned fields over all three soil depths.

Soil CEC 0-5 mm mmol kg-1	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	19.78^{a}		19.78^{a}	19.78^{a}	19.78^{a}	19.78^{a}
	± 0.64		± 0.64	± 0.64	± 0.64	± 0.64
AF(avg)			18.13^{a}			
			± 0.45			
AF 1	16.10^{b}	16.10^{b}		16.10^{b}		
	± 0.43	± 0.43		± 0.43		
AF 2	18.60^{a}	18.60^{a}			18.60^{a}	
	± 0.30	± 0.30			± 0.30	
AF 3	19.71^{a}	19.71^{a}				19.71^{a}
	± 0.34	± 0.34				± 0.34
SE	± 0.40	± 0.45	± 0.40	± 0.70	± 0.40	± 0.37

Soil CEC 5-10 mm mmol kg-1	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	20.38^{a}		20.38^{a}	20.38^{a}	20.38^{a}	20.38^{a}
	± 0.42		± 0.42	± 0.42	± 0.42	± 0.42
AF(avg)			18.04b			
			± 0.53			
AF 1	15.67^{b}	15.67^{b}		15.67^{b}		
	± 0.70	± 0.70		± 0.70		
AF 2	18.82^{a}	18.82^{a}			18.82^{b}	
	± 0.31	± 0.31			± 0.31	
AF 3	19.64^{a}	19.64^{a}				19.64^{a}
	± 0.44	± 0.44				± 0.44
SE	± 0.46	± 0.53	± 0.46	± 0.83	± 0.35	± 0.31

Soil CEC 10-20 mm mmol kg-1	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	21.66^{a}		21.66^{a}	21.66^{a}	21.66^{a}	21.66^{a}
	± 0.21		± 0.21	± 0.21	± 0.21	± 0.21
AF(avg)			18.53^{b}			
			± 0.44			
AF 1	16.64^{c}	16.64^{b}		16.64^{b}		
	± 0.47	± 0.47		± 0.47		
AF 2	19.11^{b}	19.11^{a}			19.11^{b}	
	± 0.27	± 0.27			± 0.27	
AF 3	19.83^{b}	19.83^{a}				19.83^{b}
	± 0.57	± 0.57				± 0.57
SE	± 0.45	± 0.44	± 0.45	± 0.82	± 0.43	± 0.39

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.14 Composition of soil bulk density between NR and the three abandoned fields over all three soil depths.

	Soil Bulk Density (g/mm²) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.47^{b}		1.47^{a}	1.47^{b}	1.47^{b}	1.47^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			1.57^{a}			
			± 0.03			
AF 1	1.64^{a}	1.64^{a}		1.64^{a}		
	± 0.03	± 0.03		± 0.03		
AF 2	1.58^{ab}	1.58^{ab}			1.58^{a}	
	± 0.04	± 0.04			± 0.04	
AF 3	1.47^{b}	1.47^{b}				1.47^{a}
	± 0.05	± 0.05				± 0.05
SE	± 0.02	± 0.03	± 0.02	± 0.03	± 0.03	± 0.02

	Soil Bulk Density (g/mm²) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.47^{b}		1.47^{a}	1.47^{b}	1.47^{b}	1.47^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			1.57^{a}			
			± 0.03			
AF 1	1.64^{a}	1.64^{a}		1.64^{a}		
	± 0.03	± 0.03		± 0.03		
AF 2	1.58^{ab}	1.58^{ab}			1.58^{a}	
	± 0.04	± 0.04			± 0.04	
AF 3	1.47^{b}	1.47^{b}				1.47^{a}
	± 0.05	± 0.05				± 0.05
SE	± 0.02	± 0.03	± 0.02	± 0.03	± 0.03	± 0.02

	Soil Bulk Density (g/mm²) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.47^{b}		1.47^{a}	1.47^{b}	1.47^{b}	1.47^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			1.57^{a}			
			± 0.03			
AF 1	1.64^{a}	1.64^{a}		1.64^{a}		
	± 0.03	± 0.03		± 0.03		
AF 2	1.58^{ab}	1.58^{ab}			1.58^{a}	
	± 0.04	± 0.04			± 0.04	
AF 3	1.47^{b}	1.47^{b}				1.47^{a}
	± 0.05	± 0.05				± 0.05
SE	± 0.02	± 0.03	± 0.02	± 0.03	± 0.03	± 0.02

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.15 Composition of soil gravimetrical water content between NR and the three abandoned fields over all three soil depths.

	Soil Grav (mm/mm) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.16^{ab}		0.16^{a}	0.16^{a}	0.16^{a}	0.16^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			0.14^{a}			
			± 0.01			
AF 1	0.12^{b}	0.12^{a}		0.12^{b}		
	± 0.01	± 0.01		± 0.01		
AF 2	0.13^{ab}	0.13^{a}			0.13^{a}	
	± 0.02	± 0.02			± 0.02	
AF 3	0.17^{a}	0.17^{a}				0.17^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01

	Soil Grav (mm/mm) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.16^{ab}		0.16^{a}	0.16^{a}	0.16^{a}	0.16^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			0.14^{a}			
			± 0.01			
AF 1	0.12^{b}	0.12^{a}		0.12^{b}		
	± 0.01	± 0.01		± 0.01		
AF 2	0.13^{ab}	0.13^{a}			0.13^{a}	
	± 0.02	± 0.02			± 0.02	
AF 3	0.17^{a}	0.17^{a}				0.17^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01

	Soil Grav (mm/mm) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.16^{ab}		0.16^{a}	0.16^{a}	0.16^{a}	0.16^{a}
	± 0.01		± 0.01	± 0.01	± 0.01	± 0.01
AF(avg)			0.14^{a}			
			± 0.01			
AF 1	0.12^{b}	0.12^{a}		0.12^{b}		
	± 0.01	± 0.01		± 0.01		
AF 2	0.13^{ab}	0.13^{a}			0.13^{a}	
	± 0.02	± 0.02			± 0.02	
AF 3	0.17^{a}	0.17^{a}				0.17^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.16 Composition of soil volumetric water content between NR and the three abandoned fields over all three soil depths.

	Soil Vol (%) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	23.24^{a}		23.24^{a}	23.24^{a}	23.24^{a}	23.24^{a}
	± 1.28		± 1.28	± 1.28	± 1.28	± 1.28
AF(avg)			21.48^{a}			
			± 1.14			
AF 1	19.43^{a}	19.43^{a}		19.43^{a}		
	± 1.60	± 1.60		± 1.60		
AF 2	20.12^{a}	20.12^{a}			20.12^{a}	
	± 1.99	± 1.99			± 1.99	
AF 3	24.90^{a}	24.90^{a}				24.90^{a}
	± 1.61	± 1.61				± 1.61
SE	± 0.89	± 1.14	± 0.89	± 1.13	± 1.19	± 0.99

	Soil Vol (%) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	23.24^{a}		23.24^{a}	23.24^{a}	23.24^{a}	23.24^{a}
	± 1.28		± 1.28	± 1.28	± 1.28	± 1.28
AF(avg)			21.48^{a}			
			± 1.14			
AF 1	19.43^{a}	19.43^{a}		19.43^{a}		
	± 1.60	± 1.60		± 1.60		
AF 2	20.12^{a}	20.12^{a}			20.12^{a}	
	± 1.99	± 1.99			± 1.99	
AF 3	24.90^{a}	24.90^{a}				24.90^{a}
	± 1.61	± 1.61				± 1.61
SE	± 0.89	± 1.14	± 0.89	± 1.13	± 1.19	± 0.99

	Soil Vol (%) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	23.24^{a}		23.24^{a}	23.24^{a}	23.24^{a}	23.24^{a}
	± 1.28		± 1.28	± 1.28	± 1.28	± 1.28
AF(avg)			21.48^{a}			
			± 1.14			
AF 1	19.43^{a}	19.43^{a}		19.43^{a}		
	± 1.60	± 1.60		± 1.60		
AF 2	20.12^{a}	20.12^{a}			20.12^{a}	
	± 1.99	± 1.99			± 1.99	
AF 3	24.90^{a}	24.90^{a}				24.90^{a}
	± 1.61	± 1.61				± 1.61
SE	± 0.89	± 1.14	± 0.89	± 1.13	± 1.19	± 0.99

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.17 Composition of soil N between NR and the three abandoned fields over all three soil depths.

	Soil N (%) 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.13^{a}		0.13^{a}	0.13^{a}	0.13^{a}	0.13^{a}
	± 0.00		± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)			0.09^{b}			
			± 0.01			
AF 1	0.09^{b}	0.09^{a}		0.09^{b}		
	± 0.01	± 0.01		± 0.01		
AF 2	0.09^{b}	0.09^{a}			0.09^{b}	
	± 0.00	± 0.00			± 0.00	
AF 3	0.10^{ab}	0.10^{a}				0.10^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01

	Soil N (%) 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.11^{a}		0.11^{a}	0.11^{a}	0.11^{a}	0.11^{a}
	± 0.00		± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)			0.08^{b}			
			± 0.08			
AF 1	0.08^{b}	0.08^{a}		0.08^{b}		
	± 0.01	± 0.01		± 0.01		
AF 2	0.08^{ab}	0.08^{a}			0.08^{b}	
	± 0.00	± 0.00			± 0.00	
AF 3	0.09^{ab}	0.09^{a}				0.09^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.00	± 0.01	± 0.00	± 0.01	± 0.01	± 0.01

	Soil N (%) 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	0.11^{a}		0.11^{a}	0.11^{a}	0.11^{a}	0.11^{a}
	± 0.00		± 0.00	± 0.00	± 0.00	± 0.00
AF(avg)			0.08^{b}			
			± 0.00			
AF 1	0.07^{b}	0.07^{a}		0.07^{b}		
	± 0.00	± 0.00		± 0.00		
AF 2	0.08^{b}	0.08^{a}			0.08^{b}	
	± 0.00	± 0.00			± 0.00	
AF 3	0.09^{ab}	0.09^{a}				0.09^{a}
	± 0.01	± 0.01				± 0.01
SE	± 0.00	± 0.00	± 0.00	± 0.01	± 0.01	± 0.01

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.18 Composition of soil C between NR and the three abandoned fields over all three soil depths.

Soil C (%) 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.65^{a}		1.65^{a}	1.65^{a}	1.65^{a}	1.65^{a}
	± 0.06		± 0.06	± 0.06	± 0.06	± 0.06
AF(avg)			1.07^{b}			
			± 0.08			
AF 1	0.10^{b}	0.10^{a}		0.10^{b}		
	± 0.09	± 0.09		± 0.09		
AF 2	1.05^{b}	1.05^{a}			1.05^{b}	
	± 0.06	± 0.06			± 0.06	
AF 3	1.20^{ab}	1.20^{a}				1.20^{a}
	± 0.23	± 0.23				± 0.23
SE	± 0.09	± 0.08	± 0.09	± 0.12	± 0.10	± 0.13

Soil C (%) 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.18^{a}		1.18^{a}	1.18^{a}	1.18^{a}	1.18^{a}
	± 0.03		± 0.03	± 0.03	± 0.03	± 0.03
AF(avg)			0.83^{b}			
			± 0.08			
AF 1	0.74^{a}	0.74^{a}		0.74^{b}		
	± 0.05	± 0.05		± 0.05		
AF 2	0.82^{a}	0.82^{a}			0.82^{b}	
	± 0.04	± 0.04			± 0.04	
AF 3	0.93^{a}	0.93^{a}				0.93^{a}
	± 0.23	± 0.23				± 0.23
SE	± 0.06	± 0.08	± 0.06	± 0.07	± 0.06	± 0.11

Soil C (%) 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.12^{a}		1.12^{a}	1.12^{a}	1.12^{a}	1.12^{a}
	± 0.04		± 0.04	± 0.04	± 0.04	± 0.04
AF(avg)			0.78^{b}			
			± 0.07			
AF 1	0.69^{b}	0.69^{a}		0.69^{b}		
	± 0.04	± 0.04		± 0.04		
AF 2	0.77^{ab}	0.77^{a}			0.77^{b}	
	± 0.05	± 0.05			± 0.05	
AF 3	0.90^{ab}	0.90^{a}				0.90^{a}
	± 0.19	± 0.19				± 0.19
SE	± 0.06	± 0.08	± 0.06	± 0.07	± 0.06	± 0.09

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.19 Composition of soil C:N ratio between NR and the three abandoned fields over all three soil depths.

Soil C:N 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	12.54^{a}		12.54^{a}	12.54^{a}	12.54^{a}	12.54^{a}
	± 0.23		± 0.23	± 0.23	± 0.23	± 0.23
AF(avg)			11.09^{b}			
			± 0.23			
AF 1	10.66^{b}	10.66^{a}		10.66^{b}		
	± 0.43	± 0.43		± 0.43		
AF 2	11.11^{b}	11.11^{a}			11.11^{b}	
	± 0.22	± 0.22			± 0.22	
AF 3	11.51^{ab}	11.51^{a}				11.51^{a}
	± 0.46	± 0.46				± 0.46
SE	± 0.22	± 0.23	± 0.22	± 0.37	± 0.27	± 0.28

Soil C:N 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	10.87^{a}		10.87^{a}	10.87^{a}	10.87^{a}	10.87^{a}
	± 0.37		± 0.37	± 0.37	± 0.37	± 0.37
AF(avg)			9.10^{a}			
			± 0.29			
AF 1	9.88^{a}	9.88^{a}		9.88^{a}		
	± 0.53	± 0.53		± 0.53		
AF 2	10.28^{a}	10.28^{a}			10.28^{a}	
	± 0.17	± 0.17			± 0.17	
AF 3	9.84^{a}	9.84^{a}				9.84^{a}
	± 0.74	± 0.74				± 0.74
SE	± 0.24	± 0.29	± 0.24	± 0.34	± 0.23	± 0.41

Soil C:N 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	10.10^{a}		10.10^{a}	10.10^{a}	10.10^{a}	10.10^{a}
	± 0.36		± 0.36	± 0.36	± 0.36	± 0.36
AF(avg)			9.69^{a}			
			± 0.30			
AF 1	9.75^{a}	9.75^{a}		9.75^{a}		
	± 0.52	± 0.52		± 0.52		
AF 2	9.73^{a}	9.73^{a}			9.73^{a}	
	± 0.23	± 0.23			± 0.23	
AF 3	9.57^{a}	9.57^{a}				9.57^{a}
	± 0.80	± 0.80				± 0.80
SE	± 0.24	± 0.30	± 0.24	± 0.30	± 0.22	± 0.40

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.20 Composition of soil coarse silt between NR and the three abandoned fields over all three soil depths.

Coarse Silt 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	10.46^{a}		10.46^{a}	10.46^{a}	10.46^{a}	10.46^{a}
	± 0.69		± 0.69	± 0.69	± 0.69	± 0.69
AF(avg)			9.99^{a}			
			± 0.19			
AF 1	10.57^{a}	10.57^{a}		10.57^{a}		
	± 0.23	± 0.23		± 0.23		
AF 2	9.80^{a}	9.80^{a}			9.80^{a}	
	± 0.23	± 0.23			± 0.23	
AF 3	9.60^{a}	9.60^{a}				9.60^{a}
	± 0.35	± 0.35				± 0.35
SE	± 0.23	± 0.19	± 0.23	± 0.38	± 0.39	± 0.42

Coarse Silt 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	10.01^{a}		10.01^{a}	10.01^{a}	10.01^{a}	10.01^{a}
	± 0.87		± 0.87	± 0.87	± 0.87	± 0.87
AF(avg)			9.98^{a}			
			± 0.30			
AF 1	10.80^{a}	10.80^{a}		10.80^{a}		
	± 0.47	± 0.47		± 0.47		
AF 2	9.76^{a}	9.76^{a}			9.76^{a}	
	± 0.43	± 0.43			± 0.43	
AF 3	9.39^{a}	9.39^{a}				9.39^{a}
	± 0.55	± 0.55				± 0.55
SE	± 0.32	± 0.30	± 0.32	± 0.51	± 0.49	± 0.52

Coarse Silt 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	8.91^{a}		8.91^{a}	8.91^{a}	8.91^{a}	8.91^{a}
	± 0.73		± 0.73	± 0.73	± 0.73	± 0.73
AF(avg)			9.72^{a}			
			± 0.60			
AF 1	10.83^{a}	10.83^{a}		10.83^{a}		
	± 0.70	± 0.70		± 0.70		
AF 2	9.63^{a}	9.63^{a}			9.63^{a}	
	± 0.46	± 0.46			± 0.46	
AF 3	8.70^{a}	8.70^{a}				8.70^{a}
	± 1.58	± 1.58				± 1.58
SE	± 0.47	± 0.60	± 0.47	± 0.57	± 0.44	± 0.77

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.21 Composition of soil fine silt between NR and the three abandoned fields over all three soil depths.

Fine Silt 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	12.90^{a}		12.90^{a}	12.90^{a}	12.90^{a}	12.90^{a}
	± 0.58		± 0.58	± 0.58	± 0.58	± 0.58
AF(avg)			10.19^{b}			
			± 0.35			
AF 1	10.29^{b}	10.29^{a}		10.29^{b}		
	± 0.59	± 0.59		± 0.59		
AF 2	10.24^{b}	10.24^{a}			10.24^{b}	
	± 0.37	± 0.37			± 0.37	
AF 3	10.04^{b}	10.04^{a}				10.04^{b}
	± 0.90	± 0.90				± 0.90
SE	± 0.40	± 0.35	± 0.40	± 0.57	± 0.54	± 0.67

Fine Silt 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	12.39^{a}		12.39^{a}	12.39^{a}	12.39^{a}	12.39^{a}
	± 0.74		± 0.74	± 0.74	± 0.74	± 0.74
AF(avg)			9.78^{b}			
			± 0.37			
AF 1	10.16^{ab}	10.16^{a}		10.16^{a}		
	± 0.62	± 0.62		± 0.62		
AF 2	9.53^{b}	9.53^{a}			9.53^{b}	
	± 0.55	± 0.55			± 0.55	
AF 3	9.64^{ab}	9.64^{a}				9.64^{b}
	± 0.83	± 0.83				± 0.83
SE	± 0.42	± 0.37	± 0.42	± 0.59	± 0.64	± 0.68

Fine Silt 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	10.57^{a}		10.57^{a}	10.57^{a}	10.57^{a}	10.57^{a}
	± 0.74		± 0.74	± 0.74	± 0.74	± 0.74
AF(avg)			9.35^{a}			
			± 0.36			
AF 1	10.47^{a}	10.47^{a}		10.47^{a}		
	± 0.46	± 0.46		± 0.46		
AF 2	8.10^{a}	8.10^{a}			8.10^{a}	
	± 0.57	± 0.57			± 0.57	
AF 3	8.58^{a}	8.58^{a}				8.58^{a}
	± 0.57	± 0.57				± 0.57
SE	± 0.34	± 0.36	± 0.34	± 0.43	± 0.52	± 0.55

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.22 Composition of soil clay between NR and the three abandoned fields over all three soil depths.

	Clay 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	20.81^{b}		20.81^{b}	20.81^{b}	20.81^{b}	20.81^{b}
	± 0.98		± 0.98	± 0.98	± 0.98	± 0.98
AF(avg)			31.12^{a}			
			± 1.26			
AF 1	28.61^{a}	28.61^{a}		28.61^{a}		
	± 2.50	± 2.50		± 2.50		
AF 2	33.44^{a}	33.44^{a}			33.44^{a}	
	± 2.01	± 2.01			± 2.01	
AF 3	31.30^{a}	31.30^{a}				31.30^{a}
	± 1.82	± 1.82				± 1.82
SE	± 1.39	± 1.26	± 1.39	± 1.70	± 2.23	± 1.90

	Clay 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	25.71^{b}		25.71^{b}	25.71^{a}	25.71^{b}	25.71^{b}
	± 0.43		± 0.43	± 0.43	± 0.43	± 0.43
AF(avg)			34.34^{a}			
			± 1.43			
AF 1	31.15^{ab}	31.15^{a}		31.15^{a}		
	± 2.78	± 2.78		± 2.78		
AF 2	36.85^{a}	36.85^{a}			36.85^{a}	
	± 2.01	± 2.01			± 2.01	
AF 3	35.01^{a}	35.01^{a}				35.01^{a}
	± 2.36	± 2.36				± 2.36
SE	± 1.39	± 1.43	± 1.39	± 1.64	± 2.09	± 1.93

	Clay 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	37.86^{a}		37.86^{a}	37.86^{a}	37.86^{a}	37.86^{a}
	± 1.92		± 1.92	± 1.92	± 1.92	± 1.92
AF(avg)			37.91^{a}			
			± 2.04			
AF 1	33.09^{a}	33.09^{a}		33.09^{a}		
	± 3.31	± 3.31		± 3.31		
AF 2	39.55^{a}	39.55^{a}			39.55^{a}	
	± 2.11	± 2.11			± 2.11	
AF 3	41.09^{a}	41.09^{a}				41.09^{a}
	± 4.39	± 4.39				± 4.39
SE	± 1.53	± 2.04	± 1.53	± 1.89	± 1.38	± 2.18

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.23 Composition of soil very fine sand between NR and the three abandoned fields over all three soil depths.

	Very fine sand 0-5 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	3.12^{a}		3.12^{a}	3.12^{a}	3.12^{a}	3.12^{a}
	± 0.38		± 0.38	± 0.38	± 0.38	± 0.38
AF(avg)			2.14^{b}			
			± 0.16			
AF 1	2.30^{a}	2.30^{a}		2.30^{a}		
	± 0.29	± 0.29		± 0.29		
AF 2	2.23^{a}	2.23^{a}			2.23^{a}	
	± 0.32	± 0.32			± 0.32	
AF 3	1.88^{a}	1.88^{a}				1.88^{b}
	± 0.23	± 0.23				± 0.23
SE	± 0.18	± 0.16	± 0.18	± 0.27	± 0.28	± 0.29

	Very fine sand 5-10 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	3.17^{a}		3.17^{a}	3.17^{a}	3.17^{a}	3.17^{a}
	± 0.28		± 0.28	± 0.28	± 0.28	± 0.28
AF(avg)			1.98^{b}			
			± 0.16			
AF 1	2.05^{ab}	2.05^{a}		2.05^{b}		
	± 0.37	± 0.37		± 0.37		
AF 2	2.11^{ab}	2.11^{a}			2.11^{b}	
	± 0.19	± 0.19			± 0.19	
AF 3	1.78^{b}	1.78^{a}				1.78^{b}
	± 0.27	± 0.27				± 0.27
SE	± 0.18	± 0.16	± 0.18	± 0.28	± 0.24	± 0.29

	Very fine sand 10-20 mm					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	2.32^{a}		2.32^{a}	2.32^{a}	2.32^{a}	2.32^{a}
	± 0.20		± 0.20	± 0.20	± 0.20	± 0.20
AF(avg)			1.67^{b}			
			± 0.13			
AF 1	1.79^{ab}	1.79^{a}		1.79^{a}		
	± 0.17	± 0.17		± 0.17		
AF 2	1.85^{ab}	1.85^{a}			1.85^{a}	
	± 0.25	± 0.25			± 0.25	
AF 3	1.36^{a}	1.36^{b}				1.36^{b}
	± 0.25	± 0.25				± 0.25
SE	± 0.13	± 0.13	± 0.13	± 0.15	± 0.17	± 0.21

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.24 Composition of soil fine sand between NR and the three abandoned fields over all three soil depths.

Fine sand 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	2.92^{a}		2.92^{b}	2.92^{b}	2.92^{b}	2.92^{a}
	± 0.13		± 0.13	± 0.13	± 0.13	± 0.13
AF(avg)			3.24^{a}			
			± 0.07			
AF 1	3.37^{a}	3.37^{a}		3.37^{a}		
	± 0.11	± 0.11		± 0.11		
AF 2	3.30^{a}	3.30^{a}			3.30^{a}	
	± 0.04	± 0.04			± 0.04	
AF 3	3.06^{a}	3.06^{a}				3.06^{a}
	± 0.14	± 0.14				± 0.14
SE	± 0.07	± 0.07	± 0.07	± 0.11	± 0.09	± 0.09

Fine sand 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	2.8^{a}		2.8^{a}	2.8^{a}	2.8^{a}	2.8^{a}
	± 0.09		± 0.09	± 0.09	± 0.09	± 0.09
AF(avg)			2.40^{b}			
			± 0.08			
AF 1	2.62^{ab}	2.62^{a}		2.62^{a}		
	± 0.10	± 0.10		± 0.10		
AF 2	2.27^{b}	2.27^{a}			2.27^{b}	
	± 0.08	± 0.08			± 0.08	
AF 3	2.30^{b}	2.30^{a}				2.30^{b}
	± 0.16	± 0.16				± 0.16
SE	± 0.07	± 0.08	± 0.07	± 0.07	± 0.10	± 0.11

Fine sand 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	2.43^{a}		2.43^{a}	2.43^{a}	2.43^{a}	2.43^{a}
	± 0.14		± 0.14	± 0.14	± 0.14	± 0.14
AF(avg)			2.11^{b}			
			± 0.05			
AF 1	2.19^{a}	2.19^{a}		2.19^{a}		
	± 0.05	± 0.05		± 0.05		
AF 2	2.13^{a}	2.13^{a}			2.13^{a}	
	± 0.06	± 0.06			± 0.06	
AF 3	2.02^{a}	2.02^{a}				2.02^{a}
	± 0.13	± 0.13				± 0.13
SE	± 0.06	± 0.05	± 0.06	± 0.09	± 0.09	± 0.11

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.25 Composition of soil medium sand between NR and the three abandoned fields over all three soil depths.

Medium sand 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	22.51^{a}		22.51^{a}	22.51^{a}	22.51^{a}	22.51^{a}
	± 0.95		± 0.95	± 0.95	± 0.95	± 0.95
AF(avg)			20.67^{a}			
			± 0.73			
AF 1	20.93^{a}	20.93^{a}		20.93^{a}		
	± 1.42	± 1.42		± 1.42		
AF 2	19.90^{a}	19.90^{a}			19.90^{a}	
	± 1.32	± 1.32			± 1.32	
AF 3	21.18^{a}	21.18^{a}				21.18^{a}
	± 1.27	± 1.27				± 1.27
SE	± 0.61	± 0.73	± 0.61	± 0.82	± 0.86	± 0.77

Medium sand 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	22.06^{a}		22.06^{a}	22.06^{a}	22.06^{a}	22.06^{a}
	± 1.24		± 1.24	± 1.24	± 1.24	± 1.24
AF(avg)			19.36^{a}			
			± 0.76			
AF 1	19.88^{a}	19.88^{a}		19.88^{a}		
	± 1.39	± 1.39		± 1.39		
AF 2	18.37^{a}	18.37^{a}			18.37^{a}	
	± 1.22	± 1.22			± 1.22	
AF 3	19.84^{a}	19.84^{a}				19.84^{a}
	± 1.50	± 1.50				± 1.50
SE	± 0.69	± 0.76	± 0.69	± 0.94	± 1.01	± 0.98

Medium sand 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	16.91^{a}		16.91^{a}	16.91^{a}	16.91^{a}	16.91^{a}
	± 0.25		± 0.25	± 0.25	± 0.25	± 0.25
AF(avg)			17.82^{a}			
			± 0.75			
AF 1	18.50^{a}	18.50^{a}		18.50^{a}		
	± 1.56	± 1.56		± 1.56		
AF 2	17.74^{a}	17.74^{a}			17.74^{a}	
	± 0.98	± 0.98			± 0.98	
AF 3	17.22^{a}	17.22^{a}				17.22^{a}
	± 1.51	± 1.51				± 1.51
SE	± 0.63	± 0.75	± 0.63	± 0.69	± 0.78	± 0.92

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.26 Composition of soil coarse sand between NR and the three abandoned fields over all three soil depths.

Coarse sand 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	24.59^{a}		24.59^{a}	24.59^{a}	24.59^{a}	24.59^{a}
	± 0.67		± 0.67	± 0.67	± 0.67	± 0.67
AF(avg)			20.79^{b}			
			± 0.56			
AF 1	21.73^{ab}	21.73^{a}		21.73^{b}		
	± 1.09	± 1.09		± 1.09		
AF 2	19.58^{b}	19.58^{a}			19.58^{b}	
	± 1.00	± 1.00			± 1.00	
AF 3	21.07^{b}	21.07^{a}				21.07^{b}
	± 0.67	± 0.67				± 0.67
SE	± 0.58	± 0.56	± 0.58	± 0.74	± 0.96	± 0.72

Coarse sand 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	22.26^{a}		22.26^{a}	22.26^{a}	22.26^{a}	22.26^{a}
	± 0.64		± 0.64	± 0.64	± 0.64	± 0.64
AF(avg)			20.79^{a}			
			± 0.60			
AF 1	21.92^{a}	21.92^{a}		21.92^{a}		
	± 1.33	± 1.33		± 1.33		
AF 2	19.84^{a}	19.84^{a}			19.84^{b}	
	± 0.77	± 0.77			± 0.77	
AF 3	20.61^{a}	20.61^{a}				20.61^{a}
	± 0.96	± 0.96				± 0.96
SE	± 0.48	± 0.60	± 0.48	± 0.66	± 0.60	± 0.59

Coarse sand 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	19.11^{a}		19.11^{a}	19.11^{a}	19.11^{a}	19.11^{a}
	± 1.00		± 1.00	± 1.00	± 1.00	± 1.00
AF(avg)			19.80^{a}			
			± 0.81			
AF 1	21.44^{a}	21.44^{a}		21.44^{a}		
	± 1.31	± 1.31		± 1.31		
AF 2	18.98^{a}	18.98^{a}			18.98^{a}	
	± 0.82	± 0.82			± 0.82	
AF 3	18.98^{a}	18.98^{a}				18.98^{a}
	± 1.85	± 1.85				± 1.85
SE	± 0.63	± 0.81	± 0.63	± 0.85	± 0.63	± 0.95

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.27 Composition of soil gravel between NR and the three abandoned fields over all three soil depths.

Gravel 0-5 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.71^{a}		1.71^{a}	1.71^{a}	1.71^{a}	1.71^{a}
	± 0.25		± 0.25	± 0.25	± 0.25	± 0.25
AF(avg)			0.84^{b}			
			± 0.04			
AF 1	0.86^{b}	0.86^{a}		0.86^{b}		
	± 0.02	± 0.02		± 0.02		
AF 2	0.73^{b}	0.73^{a}			0.73^{b}	
	± 0.07	± 0.07			± 0.07	
AF 3	0.94^{b}	0.94^{a}				0.94^{b}
	± 0.07	± 0.07				± 0.07
SE	± 0.11	± 0.04	± 0.11	± 0.19	± 0.21	± 0.18

Gravel 5-10 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.31^{a}		1.31^{a}	1.31^{a}	1.31^{a}	1.31^{a}
	± 0.20		± 0.20	± 0.20	± 0.20	± 0.20
AF(avg)			0.87^{b}			
			± 0.04			
AF 1	0.96^{ab}	0.96^{ab}		0.96^{a}		
	± 0.07	± 0.07		± 0.07		
AF 2	0.73^{b}	0.73^{b}			0.73^{b}	
	± 0.04	± 0.04			± 0.04	
AF 3	0.94^{ab}	0.94^{ab}				0.94^{a}
	± 0.07	± 0.07				± 0.07
SE	± 0.08	± 0.04	± 0.08	± 0.12	± 0.14	± 0.12

Gravel 10-20 mm	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.12^{a}		1.12^{a}	1.12^{a}	1.12^{a}	1.12^{a}
	± 0.13		± 0.13	± 0.13	± 0.13	± 0.13
AF(avg)			0.78^{b}			
			± 0.04			
AF 1	0.89^{ab}	0.89^{a}		0.89^{a}		
	± 0.06	± 0.06		± 0.06		
AF 2	0.67^{b}	0.67^{a}			0.67^{b}	
	± 0.03	± 0.03			± 0.03	
AF 3	0.78^{ab}	0.78^{a}				0.78^{a}
	± 0.10	± 0.10				± 0.10
SE	± 0.06	± 0.04	± 0.06	± 0.08	± 0.10	± 0.10

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.28 Composition of soil compaction between NR and the three abandoned fields.

	Compaction 10 mm from specie (Mpa)						Compaction Between 2 species (Mpa)					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	3.75^{b}		3.75^{b}	3.75^{b}	3.75^{b}	3.75^{b}	4.08^{b}		4.08^{b}	4.08^{b}	4.08^{b}	4.08^{b}
	± 0.38		± 0.38	± 0.38	± 0.38	± 0.38	± 0.33		± 0.33	± 0.33	± 0.33	± 0.33
AF(avg)			17.67^{a}						28.43^{a}			
			± 2.18						± 4.34			
AF 1	20.10^{a}	20.10^{a}		20.10^{a}			29.30^{ab}	29.30^{a}		29.30^{a}		
	± 4.42	± 4.42		± 4.42			± 5.40	± 5.40		± 5.40		
AF 2	17.0^{a}	17.0^{a}			17.0^{a}		33.20^{a}	33.20^{a}			33.20^{a}	
	± 4.06	± 4.06			± 4.06		± 11.37	± 11.37			± 11.37	
AF 3	15.90^{a}	15.90^{a}				15.90^{a}	22.80^{ab}	22.80^{a}				22.80^{a}
	± 3.40	± 3.40				± 3.40	± 5.09	± 5.09				± 5.09
SE	± 2.09	± 2.18	± 2.09	± 3.20	± 2.72	± 2.41	± 3.94	± 4.34	± 3.94	± 4.59	± 6.67	± 3.66

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.29 Composition of germination between NR and the three abandoned fields.

	Germination (Pioneer) September						Germination (Pioneer) December					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	13.67^{b}		13.67^{b}	13.67^{b}	13.67^{b}	13.67^{b}	34.5^{a}		34.5^{a}	34.5^{a}	34.5^{a}	34.5^{a}
	± 8.92		± 8.92	± 8.92	± 8.92	± 8.92	± 14.69		± 14.69	± 14.69	± 14.69	± 14.69
AF(avg)			136^{a}						54.47^{a}			
			± 21.32						± 11.81			
AF 1	140.80^{ab}	140.80^{a}		140.80^{a}			47.2^{a}	47.2^{a}		47.2^{a}		
	± 28.35	± 28.35		± 28.35			± 14.68	± 14.68		± 14.68		
AF 2	105.60^{ab}	105.60^{a}			105.60^{a}		44.2^{a}	44.2^{a}			44.2^{a}	
	± 21.08	± 21.08			± 21.08		± 14.99	± 14.99			± 14.99	
AF 3	161.60^{a}	161.60^{a}				161.60^{a}	72^{a}	72^{a}				72^{a}
	± 55.91					± 55.91	± 30.15	± 30.15				± 30.15
SE	± 19.64	± 21.32	± 19.64	± 23.84	± 17.66	± 33.65	± 9.45	± 11.81	± 9.45	± 10.10	± 10.10	± 16.09

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.30 Composition of germination between NR and the three abandoned fields.

	Germination (Sub-climax) September						Germination (Sub-climax) December					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	21.17^{a}		21.17^{a}	21.17^{a}	21.17^{a}	21.17^{a}	21.33^{a}		21.33^{a}	21.33^{a}	21.33^{a}	21.33^{a}
	± 10.66		± 10.66	± 10.66	± 10.66	± 10.66	± 12.68		± 12.68	± 12.68	± 12.68	± 12.68
AF(avg)			7.47^{a}						5.87^{a}			
			± 3.07						± 2.87			
AF 1	12.80^{a}	12.80^{a}		12.80^{a}			0^{a}	0^{a}		0^{a}		
	± 8.24	± 8.24		± 8.24			± 0.00	± 0.00		± 0.00		
AF 2	4.80^{a}	4.80^{a}			4.80^{a}		8^{a}	8^{a}			8^{a}	
	± 3.20	± 3.20			± 3.20		± 6.20	± 6.20			± 6.20	
AF 3	4.80^{a}	4.80^{a}				4.80^{a}	9.6^{a}	9.6^{a}				9.6^{a}
	± 3.20	± 3.20				± 3.20	± 5.88	± 5.88				± 5.88
SE	± 3.84	± 3.07	± 3.84	± 6.71	± 6.28	± 6.28	± 4.25	± 2.87	± 4.25	± 7.42	± 7.43	± 7.32

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.31 Composition of germination between NR and the three abandoned fields.

	Germination (Climax) September						Germination (Climax) December					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	80^{a}		80^{a}	80^{a}	80^{a}	80^{a}	53.33^{a}		53.33^{a}	53.33^{a}	53.33^{a}	53.33^{a}
	± 12.04		± 12.04	± 12.04	± 12.04	± 12.04	± 13.33		± 13.33	± 13.33	± 13.33	± 13.33
AF(avg)			17.07^{b}						17.07^{a}			
			± 10.15						± 9.93			
AF 1	0^{b}	0^{a}		0^{b}			3.2^{b}	3.2^{a}		3.2^{b}		
	± 0.00	± 0.00		± 0.00			± 1.96	± 1.96		± 1.96		
AF 2	4.8^{b}	4.8^{a}			4.8^{b}		19.2^{a}	19.2^{a}			19.2^{a}	
	± 4.80	± 4.80			± 4.80		± 10.91	± 10.91			± 10.91	
AF 3	46.4^{ab}	46.4^{a}				46.4^{a}	28.8^{a}	28.8^{a}				28.8^{a}
	± 27.06					± 27.06	± 28.80	± 28.80				± 28.80
SE	± 10.11	± 10.15	± 10.11	± 14.08	± 13.56	± 14.17	± 8.69	± 9.93	± 8.69	± 10.56	± 9.95	± 14.64

* Column with different letters superscripts are significantly different (P<0.05)

Table 1.32 Species composition between NR and the three abandoned fields.

	Species composition (Pioneer)					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	1.48^{b}		1.48^{b}	1.48^{b}	1.48^{b}	1.48^{b}
	± 1.10		± 1.10	± 1.10	± 1.10	± 1.10
AF(avg)			41.40^{a}			
			± 5.16			
AF 1	55.91^{a}	55.91^{a}		55.91^{a}		
	± 7.24	± 7.24		± 7.24		
AF 2	33.27^{a}	33.27^{a}			33.27^{a}	
	± 6.55	± 6.55			± 6.55	
AF 3	35.02^{a}	35.02^{a}				35.02^{a}
	± 10.22	± 10.22				± 10.22
SE	± 5.44	± 5.16	± 5.44	± 9.13	± 5.76	± 6.87

	Species composition (Sub-Climax)					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	2.68^{c}		2.68^{b}	2.68^{b}	2.68^{b}	2.68^{b}
	± 0.53		± 0.53	± 0.53	± 0.53	± 0.53
AF(avg)			35.53^{a}			
			± 4.81			
AF 1	32.49^{ab}	32.49^{a}		32.49^{a}		
	± 8.14	± 8.14		± 8.14		
AF 2	49.86^{a}	49.86^{a}			49.86^{a}	
	± 6.08	± 6.08			± 6.08	
AF 3	24.23^{bc}	24.23^{a}				24.23^{a}
	± 7.33	± 7.33				± 7.33
SE	± 4.75	± 4.81	± 4.75	± 5.85	± 7.87	± 4.62

	Species composition (Climax)					
	AF 1-3 & NR	AF 1-3	AF & NR	AF 1 & NR	AF 2 & NR	AF 3 & NR
NR	95.84^{a}		95.84^{a}	95.84^{a}	95.84^{a}	95.84^{a}
	± 0.69		± 0.69	± 0.69	± 0.69	± 0.69
AF(avg)			23.07^{b}			
			± 7.12			
AF 1	11.59^{b}	11.59^{a}		11.59^{b}		
	± 6.38	± 6.38		± 6.38		
AF 2	16.87^{b}	16.87^{a}			16.87^{b}	
	± 8.57	± 8.57			± 8.57	
AF 3	40.74^{b}	40.74^{a}				40.74^{b}
	± 17.24	± 17.24				± 17.24
SE	± 8.91	± 7.12	± 8.91	± 13.55	± 12.97	± 11.38

* Column with different letters superscripts are significantly different (P<0.05)