Adaptation of trees to the urban environment: *Acacia karroo* in Potchefstroom, South Africa.

by

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Dissertation presented in partial fulfilment of the requirements for the degree Masters in Environmental Science in the School of Environmental Sciences and Development in the Faculty of Natural Sciences of the North-West University.

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The tree which moves some to tears of joy is in the eyes of others only a
green thing that stands in the way. Some see Nature all ridicule and
deformity, and some scarce see Nature at all. But to the eyes of the
man of imagination, Nature is Imagination itself.

- William Blake, 1799, *The Letters* -

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Opsomming

Stedelike parke is van strategiese belang vir die lewenskwaliteit van ons toenemend verstedelikte gemeenskap. Bome en ander plante word in stedelike gebiede geplant en onderhou met die doel om waarde tot die besige lewens van stedelike inwoners te voeg.

Bome in dorpe en stede vorm 'n belangrike deel van komplekse stedelike ekosisteme. Die bome voorsien stedelike inwoners van belangrike ekosisteemfunksies en voordele soos byvoorbeeld: die vermindering van partikulêre besoedeling, koolstofbeslagneming, 'n verlaging van lugtemperatuur, die vermindering van stormwaterafloop, estetiese waarde en 'n toename in die gesondheid van die inwoners. Bome is 'n sonkraggedrewe tegnologie wat kan help om die balans in disfunksionele stedelike ekosisteme te herstel. Bome dra daartoe by om mense met die natuur en met mekaar verbind.

Stedelike omgewings plaas baie druk op bome deur byvoorbeeld snoei, beperkte ruimte vir wortelgroei en die vrystelling van besoedelstowwe in die lug, water en grond. Die probleem is dat die ware impak van die stedelike omgewing op die bome in ons gemeenskap onbekend is.

Die doel van die studie was om die algehele menslike en omgewingsimpakte op die bome in stedelike omgewings te bepaal deur die boom vitaliteit van *Acacia karroo* met behulp van chlorofilfluoressensiekinetika (JIP-toets) te meet en die blaarwaterpotensiaal met behulp van 'n drukbom te bepaal. Die vitaliteit van *Acacia karroo* is gekwantifiseer deur gebruik te maak van die Vitaliteitsindeks, soos bereken deur chlorofil fluoressensie (PI_{ABS}). Die boomvitaliteitsdata is gekorreleer met die grondfisiese en -chemiese data. Die benadering van 'n verstedelikingsgradiënt is gebruik om die resultate van stedelike, voorstedelike en landelike studiegebiede met mekaar te vergelyk. Die resultate van bome in landelike gebiede is as kontroles beskou. Die benadering van 'n verstedelikingsgradiënt word wêreldwyd gebruik en voorsien 'n agtergrond vir vrae oor ekologiese struktuur en funksie. Die verstedelikingsgradiënt is gekwantifiseer deur gebruik te maak van die V-I-S – model wat gebaseer is op die % plantegroei, ondeurlaatbare oppervlak en grond. Bykomend daartoe is 'n model wat die geldwaarde van bome in stedelike omgewings bepaal getoets. Die model staan bekend as die "South African Tree Appraisal Method" (Suid-Afrikaanse boomwaarderingsmetode) oftewel SATAM. Al die bogenoemde inligting kan uiteindelik bydra tot die ontwikkeling van 'n stedelike boombestuursprogram vir Potchefstroom.

Dit was duidelik uit die huidige studie dat verstedeliking 'n negatiewe impak op die vitaliteit van bome het. Die blaarwaterpotensiaal van die bome is nie noodwendig negatief beinvloed nie. Alhoewel bome in stedelike omgewings nie noodwendig 'n hoë vitaliteit (PI_{ABS}) gehad het nie, speel hulle tog 'n belangrike rol in die stedelike omgewing. Volgens die geldwaardes wat met behulp van SATAM bereken is, kan sommige bome in stedelike omgewings tot R60 000 werd wees.

Sleutelwoorde: *Acacia karroo*, boomvitaliteit, JIP-toets, SATAM, stedelike ekologie, verstedeliking, verstedelikingsgradiënt, blaarwaterpotensiaal.

Abstract

Urban open spaces are of strategic importance to the quality of life of our increasingly urbanized society. Trees and related vegetation are planted and managed within the communities and cities to create or add value to the busy lives of the city dwellers.

Trees in towns and cities form an important part of complex urban ecosystems and provide significant ecosystem services and benefits for urban dwellers, for example: reducing particulate pollution, carbon sequestration, decreasing air temperature, decreasing water runoff, aesthetic value and an increase in human health. Trees are solar-powered technology that can help restore balance to dysfunctional urban ecosystems. Trees form strands in the urban fabric that connect people to nature and to each other.

The urban environment puts tremendous strain on trees by trenching, limited space for root growth and emission of pollutants into the atmosphere, water and soil. The problem is that the real impact of the urban environment on the trees within our community is unknown.

The aim of this investigation was to assess the overall anthropogenic and environmental impacts on urban trees by measuring the tree vitality of *Acacia karroo* using chlorophyll fluorescence kinetics (JIP-test) and the leaf water potential using a pressure chamber. Tree vitality was quantified as the chlorophyll fluorescence-based performance index (PI_{ABS}). Tree vitality measurements were also correlated with soil physical and chemical data. In the comparative study, an urbanization gradient approach was followed in which results of trees in rural areas were regarded as controls. The gradient approach is used worldwide and provides a background for questions of ecological structure and function. The urbanization gradient was quantified using the V-I-S model, based on % cover of vegetation, impervious surface and soil. Additionally, a model to determine the monetary value of trees in urban environments (SATAM) was tested. All this information could eventually contribute to develop an urban tree management program for Potchefstroom.

Abstract

It was evident from the current study that urbanization has a negative impact on tree vitality. The leaf water potential of a tree was, however, not necessarily negatively impacted upon. Although trees in urban environments did not always have a high vitality (PI_{ABS}), they still played a major role in the urban environment. According to the tree appraisal method (SATAM), some of these trees have a value of R60 000.

Keywords: *Acacia karroo*, JIP test, SATAM, tree vitality, urban ecology, urbanization gradient, leaf water potential.

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Abbreviations

$\psi_0 = ET_0 / TR_0$	Probability (at time 0) that a trapped exciton moves an electron into the electron transport chain beyond Q_A^-
$\varphi_{P0} = TR_0 / ABS$	Maximum quantum yield of primary photochemistry (at t=0)
ABS/RC	Specific energy flux (per PSII reaction centre) for absorption
CS	Cross-section of leaf
CTLA	Council of Tree and Landscape Appraisers
DI_0/RC	Dissipated energy flux per RC (at t=0)
ET	Electron transport
ET_0/RC	Specific energy flux (per PSII reaction centre) for electron transport
F_0	Fluorescence intensity at 50μs
F_M	Maximal fluorescence intensity
LHC	Light harvesting chlorophyll
MEA	Millennium Ecosystem Assessment
PEA	Plant Efficiency Analyser
PI_{ABS}	Performance index expressed on absorption basis
PSI	Photosystem I
PSII	Photosystem II
φ_{E0}	Quantum yield of electron transport
Q_A	Primary quinone acceptor
RC	Reaction centre
TR	Trapping flux
TR_0/RC	Specific energy flux (per PSII reaction centre) for trapping
SATAM	South African Tree Appraisal Method
STEM	Standard Tree Evaluation Method

Chapter 1

Introduction

1.1 Background

The benefits of trees were first realised by the Victorians, who noticed that urban parks and trees reduced the amount of national working days that were lost due to human illness. They realised that trees in urban areas enhance the beauty of the concrete landscape and are important for healthy living (Beckett *et al.*, 1998:347). Interestingly, the use of green areas in and around towns for health benefits goes back to ancient times, when open spaces were used to prevent the spread of diseases (Beckett *et al.*, 1998:347).

Trees in towns and cities form a source of healthy living and a better and cleaner environment. According to McPherson (2000), trees are a solar-powered technology that can help restore balance to dysfunctional urban ecosystems. Trees form strands in the urban fabric that connect people to nature and to each other.

Trees do not only provide food and shelter for animals, but have many benefits for humans and the environment, for example the reduction of the effect of particulate pollution (Beckett *et al.*, 1998:347), the sequestration of carbon dioxide (McPherson, 1998:215), a decrease in air temperature (Simpson, 2002:1067), a decrease in water runoff (Xiao *et al.*, 1998:235), an increase in aesthetic value and a contribution to human health (Clousten & Stansfield, 1981:12). Although trees have many advantages in urban environments, they can also have a negative impact on the environment, for example the obstruction of light, blocking of gutters and damage to pavements, roads and buildings (Clousten & Stansfield, 1981:12).

According to Chiesura (2004:129), international efforts to preserve the natural environment are mainly concerned either with large, bio-diverse and relatively untouched ecosystems, or with individual animal or plant species that are endangered or threatened with extinction. Less attention is paid to the value and importance of the green spaces within the environment in which we ourselves work and play. These green spaces need more attention because they contribute to the well-being of humans.

The urban environment puts a tremendous strain on trees by trenching (Jim, 2003: 87), limited root growth (Quigley, 2004:29) and the emission of gasses into the air (Beckett *et al.,* 1998:347). The problem is that the real impact of the urban environment on the trees within our community is not always realised.

1.1.1 Urban green space

There is uncertainty amongst ecologists in defining urban ecosystems (McIntyre *et al.*, 2000:6). There is a need to remove this uncertainty and to correct oversights regarding what it means to be defined as 'urban'. For this reasons it was necessary to define 'urban' and what is meant by 'urban green spaces'. According to McIntyre *et al.* (2000:8), studies that compared urban areas to natural areas characterized 'urban' with the presence of humans and characterized 'natural' by the absence of humans. Social scientists use the term 'urban' to refer to areas with a high population density whereas a regional planner refers to the people and the buildings – the homes, offices and factories in which residents and workers live and produce (McIntyre *et al.*, 2000:12). Niemelä (1999a:120) suggested that 'urban' refers to a certain kind of human community with a high density of people, their dwellings and other constructions. A broad definition for 'urban areas' is a fairly large, densely human populated area characterized by industrial, business and residential districts (Niemelä, 1999b:58). This broad definition of 'urban' was more useful for the purpose of urban ecological research because it is often difficult to draw any definite ecological borders around an urban area (Niemelä, 1999b:58). Thus there is a continuum or gradient of decreasing human activity from the city centre to more rural areas.

An urban ecosystem could be seen as an area under profound and constant local human activity, being composed of high-density human habitation, industrial and commercial centres, and remnants of indigenous habitat (McIntyre *et al.*, 2000:12). A term that is often used to describe certain parts of urban ecosystems is 'urban forests'. McPherson *et* *al.* (2001:1) defined urban forests – trees in parks, yards, and public areas and along streets - as green spaces within communities that provided services vital to enriching quality of life. Bolund and Hunhammar (1999:294) identified seven different natural urban ecosystems: street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea and streams. Another term that can be used is 'urban woodlands', which refers to patches of forest vegetation located within, or close to, an urban settlement (Lehvävirta *et al.*, 2004:3). A collective definition that includes all the vegetation in an urban area is 'urban green spaces'. Li *et al.* (2005:326), Sanesi & Chiarello (2006:126) and Konijnendijk *et al.* (2006:93) included the following areas as urban green spaces: parks, urban forests, farmlands, natural areas, golf courses and sport fields. According to Gaston *et al.* (2005:395), gardens contribute the greatest part of vegetated land or green space. For this study, the definition of a green space will include the following: parks, urban forests, natural areas, domestic gardens, golf courses, recreation areas and sport fields, street trees and cultivated land. A natural area within an urban context is one not intensively managed by people and often includes a high proportion of intentionally and accidentally introduced organisms as well as native species (McDonnell & Pickett, 1990:1232).

According to Dwyer *et al.* (1992:228), urban forests could be viewed as a living technology, a key component of the urban infrastructure that helps maintain a healthy environment for urban dwellers (Dwyer *et al.*, 2003:50). He also explained that the urban forest has some key characteristics, namely:

- Diversity: It is the function of variation in land uses, land ownership and management objectives.
- Connectedness: Urban forests are connected to other elements of urban environments, including roads, homes, people, industrial parks and downtown centres.
- Dynamics: Urban forests undergo significant change with the growth, development, and succession of their biological components over time.

The following definitions were used for the current study:

- Urban: densely populated area characterized by industrial, business and residential districts (Niemelä, 1999b:58).
- Urban forests: trees in parks, yards, public areas and along streets (McPherson *et al.*, 2001:1).
- Urban green spaces: parks, urban forests, farmlands, natural areas, golf courses and sport fields (Li *et al.*, 2005:326; Sanesi & Chiarello, 2006:126; Konijnendijk *et al.*, 2006:93).

1.1.2 The benefits of trees in urban environments

The Millenium Ecosystem Assessment (MA) deals in detail with ecosystem services provided by green areas in natural and urban environments (Millenium Ecosystem Assessment, 2003:5). These ecosystem services include aspects such as supporting services, provisioning services, regulation services and cultural services. Assessment of the values of these ecosystem services and those of individual trees will be dealt with in Chapter 2 (Material and Methods) of this dissertation. More specific benefits of trees in urban environment will be discussed below.

1.1.2.1 Climate control

Every area within an urban environment has a different microclimate. This microclimate is caused by different factors within the urban environment, for example: the built environment intensifies rain and solar radiation and the wind is channelled through buildings (Clousten & Stansfield, 1981:12). The urban topography, buildings, the artificial supply of energy, the absence of vegetation, the presence of air pollution and the microclimate of the urban environment differ from that of the rural environment. The urban factors mentioned above, mainly affect and change the intensity of solar radiation, temperature, relative humidity, local wind distribution, range of visibility, and precipitation (Bernatzky, 1978:85). A rural environment has lower air temperature and higher relative air humidity (Bernatzky, 1978:83). According to a study done by Wong and Yu (2005:548), the maximum temperature difference between urban and rural environments is approximately 4°C. By using trees and other vegetation, the microclimate of a specific area can be changed. These changes depend on the type of vegetation and the location of the vegetation within an urban environment (Bernatzky, 1978:145).

The phenomenon of higher air and surface temperature in urban areas is known as the urban heat-island effect (Voogt, 2004; Wong & Yu, 2005:547). Figure 1.1 illustrates the higher temperatures over the urban areas and lower temperatures over the suburban and rural areas. The heat island that forms over a city is due to the absorption of solar radiation by buildings, roads, pavements and other types of impervious surfaces during the daytime. During the evening the absorbed heat is re-radiated to the surroundings and thus increases the air temperature at night (Wong & Yu, 2005:547).

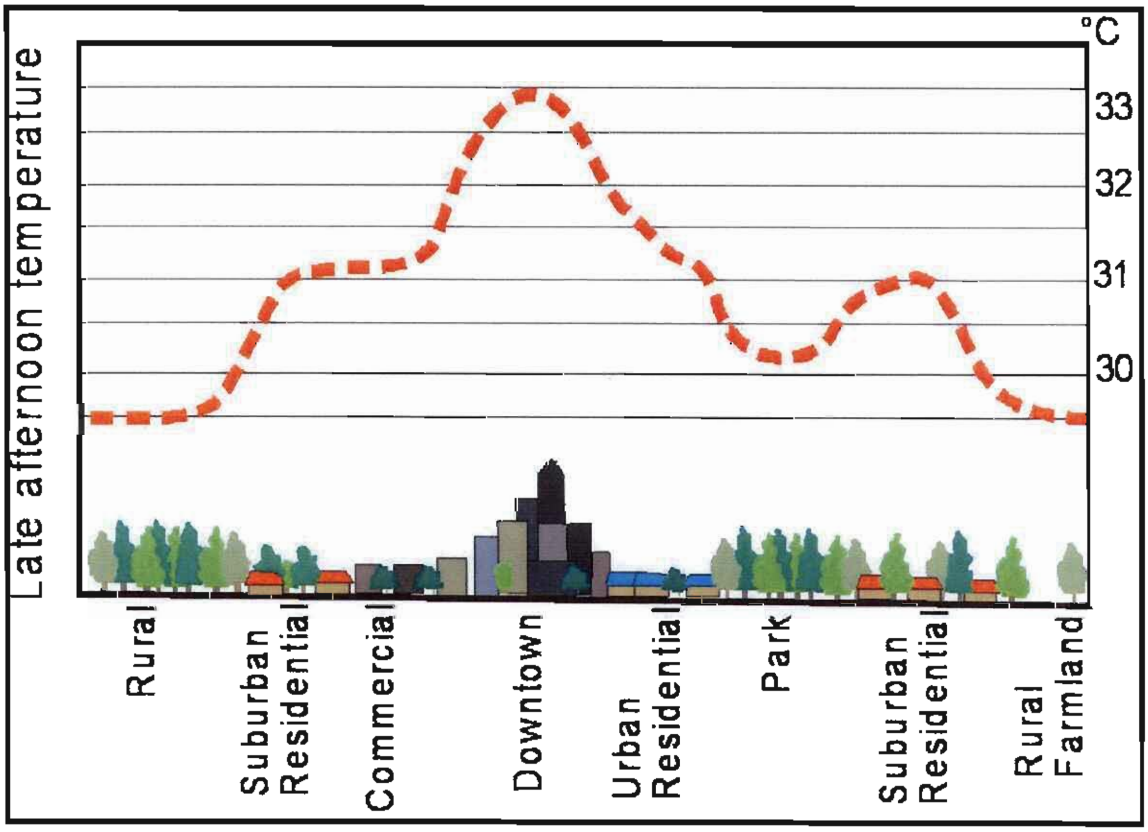

Figure 1.1 The urban heat-island that results in higher air temperature over the urban areas (Adapted from Voogt, 2004).

1.1.2.2 Temperature control

The average yearly rise of the temperature in towns is 0.5-1.5°C. The heating of the streets, pavements, buildings and other man-made structures causes an increase in air temperature (Bernatzky, 1978:132). One of the results of the higher temperatures is that spring starts earlier and autumn is later and the humidity is much lower than usual (Bernatzky, 1978:132). According to Von Stülpnagel *et al.* (1990:175), the increase in air temperature within urban environments is not only caused by the heating of man-made structures but also by the following:

- The number of structures with an increased heat capacity
- The reduction of evaporating surfaces, the increase in surface run-off and the lack of areas with vegetation cover
- The increase of air pollutants (greenhouse effect)
- The introduction of energy through heat production

This increase in air temperature depends on the weather and the size of the urban environment/city. In some cases, the increase of air temperature could be relatively large, for example in Berlin there can be a temperature difference of 9°C between urban and rural areas (Von Stülpnagel *et al.*, 1990:176).

Trees play an important role in controlling the climatic conditions of an urban environment (Federer, 1976:122; Shashua-Bar & Hoffman, 2004:1087; Li *et al.*, 2005:326). Trees reduce the temperature by shading and absorbing excessive radiation such as the reflected radiation from buildings (Clousten & Stansfield, 1981:11). Trees absorb more of the solar radiation and reflect less radiation than man-made surfaces (Figure 1.2). Figure 1.2 illustrates the absorption of solar radiation by trees. The solar radiation from the sun has a high intensity (red sun rays) and as the trees absorb some of the solar radiation the intensity decreases (yellow and orange sun rays). By shading, the trees reduce the amount of energy absorbed by built surfaces (Federer, 1976:122; Shashua-Bar & Hoffman, 2000:222; Simpson, 2002:1067). Another technique used by trees to cool the urban area is by evapotranspiration. This is a process by which liquid water in plants is converted to vapour, thereby cooling the air (Simpson, 2002:1067). The reduced air temperature due to the presence of trees can improve air quality because the emissions of many pollutants and/or ozone-forming chemicals are temperature dependent (Dwyer *et al.* 2003:50; Yang *et al.*, 2005:65).

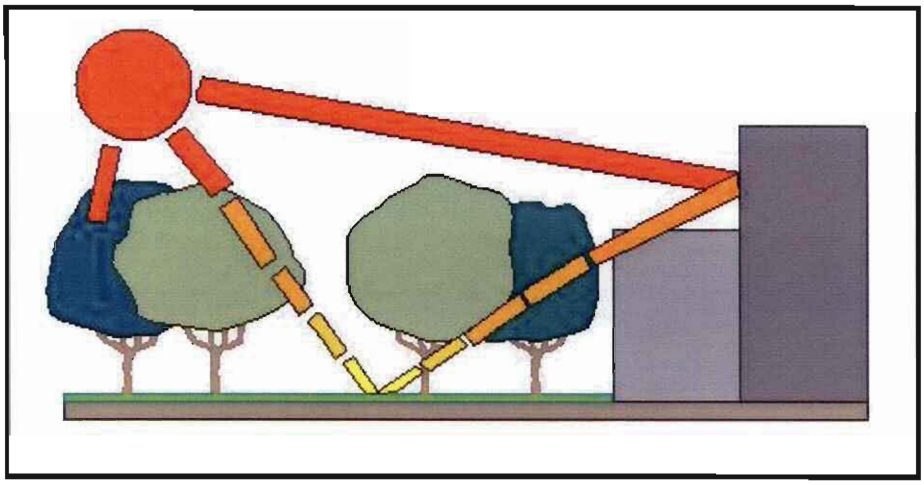

Figure 1.2 Solar radiation effects reduced by trees (Clousten & Stansfield, 1981).

Trees in a street or canyon street (street with high buildings that form a canyon) absorb a large amount of heat. The trees receive heat from direct solar radiation; reflect short wave energy from the irradiated buildings and streets, and long wave energy from the built surfaces (Federer, 1976:123; Shashua-Bar & Hoffman, 2003:65). The dissipation of this heat load occurs through evapotranspiration and convective sensible heat-exchange with the canyon street air.

Although trees usually contribute to the decrease of air temperature in the summer, their presence can also increase the air temperature in some instances. By trapping the excessive radiation in their tree canopies at night and by sheltering the buildings from cold winds, the trees increase the temperature of the area (Simpson, 2002:1067).

According to studies done by Shashua-Bar and Hoffman (2000:222), the range of the effect of vegetation on the thermal environment is a function of the green area scale and the intervals between the green areas. Smaller green areas with sufficient intervals are more effective in cooling an urban area than lumped larger green areas.

1.1.2.3 Wind control

According to Federer (1976:123) and Simpson (2002:1067), trees reduce the wind speed by forming an increased resistance to wind blow. Within the crown of a single tree or under the canopy of an urban forest, wind is light and almost unrelated to the external wind. The trees form a barrier or a shelterbelt against the forces of the wind (Federer, 1976:123). These shelterbelts or trees in the urban areas can play a significant role because in cities the wind is channelled through the buildings and along the streets and narrow passageways (Clouston & Stansfield, 1981:12). Urban forests or smaller stands of trees have a large influence on the urban ventilation (Figure 1.3). Figure 1.3 illustrates how wind that blows directly over a solid building is channelled across the building and could be funnelled along streets and narrow passage ways on the other side of the building. This creates unpleasant wind blow (a). Buildings could also form wind-breaks (b). Trees will decrease the turbulence more effectively as looser tree foliage will decrease the turbulence better (c) (Clouston & Stansfield, 1981:12).

1.1.2.4 Air cleansing

According to Dwyer *et al.* (2003:50) and Yang *et al.* (2005:66), large trees have an important contribution to cleansing the air. Trees can reduce air pollutants in two ways: 1) direct reduction of pollutants from the air, and 2) indirect reduction of air pollutants (Beckett *et al.*, 1998:350; Scott *et al.*, 1998:225; Yang *et al.*, 2005:65). In direct reduction, trees absorb gaseous pollutants like nitrogen dioxide (NO_2) and Ozone (O_3) through leaf stomata. Once the pollutants are inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids, or react with inner-leaf surfaces. Water-soluble pollutants are dissolved onto moist leaf surfaces and are thus not taken up but are removed by the plant surface (Scott *et al.*, 1998:225). Another direct method of removing air pollutants is by removing dirt, dust and pollen from the air by collecting it with their leaves. The dirt, dust and pollen are removed from the tree leaves by rain (Yang *et al.*, 2005:66). The air is also cleaned by the effect of photosynthesis, where the polluting agent is diluted with oxygen rich air (Bernatzky, 1978:141). Indirectly, trees can reduce the air temperature through shading and evapotranspiration in the summer, thus reducing the emissions of air pollutants from the process of generating energy for cooling purposes

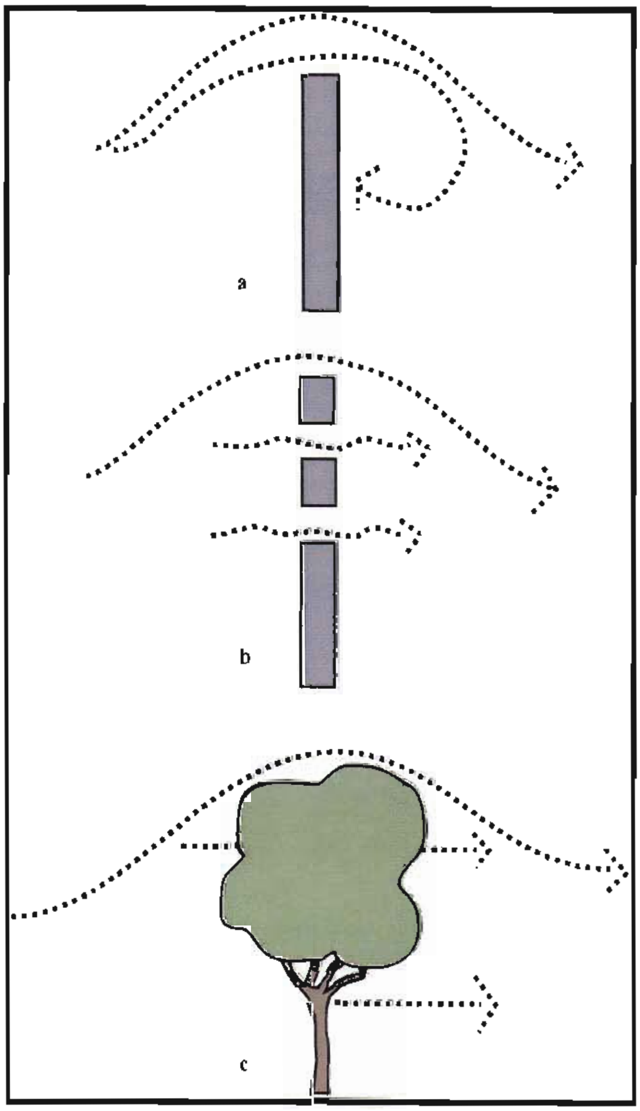

Figure 1.3 Wind effects using different types of barriers: a) solid, b) wind-break, c) tree (Clouston & Stansfield 1981).

In some urban areas trees form a shelterbelt. This shelterbelt is a protective plantation screen and can minimize the air pollution in the area. Small and light aerosol nuclei are carried in an airflow, which takes them across a screen barrier. The heavier and bigger aerosol nuclei will be filtered by the trees and not carried over. If the screen barrier has trees of various heights, then the barrier will block out the impurities more effectively. These shelterbelts act as a dust filter in urban areas (Bernatzky, 1978:141). Figure 1.4 illustrates how trees in an urban area act as air filters and how areas without any trees have a lot of pollutants in the air. In a city without any trees, the wind will pick up pollution particles. Trees and greenery in the direction of the flow will cool and purify the air. The flow of the warm air will be interrupted and split into smaller circulations. As a result of thermal processes, quantities of cooler fresh air will repeatedly be emitted into the adjoining built up areas. The fresh air supply depends almost entirely on circulations, which develop out of temperature differences between treeless and tree-stocked building areas (Bernatzky, 1978:142).

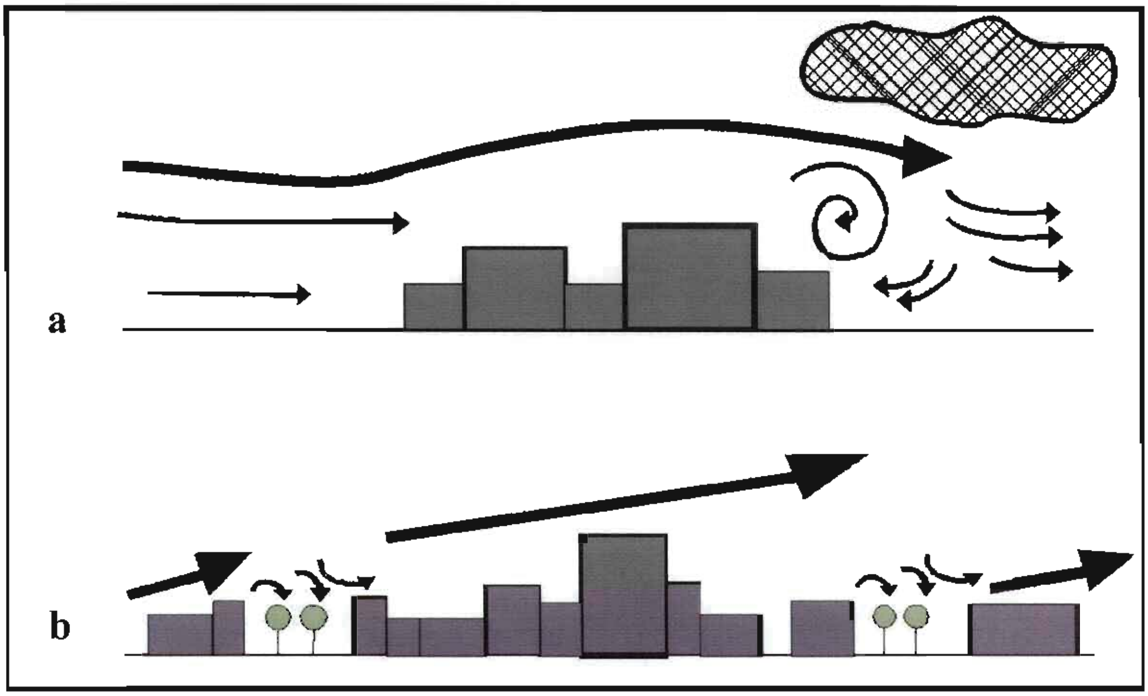

Figure 1.4 Airflow in a town in windy weather. a) Increasing pollution of the town from the main wind direction; b) air cleaning by green areas (Bernatzky 1978).

A study by Impens and Delcarte (as quoted by Beckett *et al.*, 1998:357) showed that the interception of particles by vegetation was much greater for street trees, due to their proximity to high intensities of road traffic. Their study recognized the importance of urban-tree establishment to create dust filters in towns and cities. They also realised that the areas of highest pollution concentrations, usually in central locations where trees could be most effectively used, were those most lacking in urban greenery.

Air pollutants can produce a wide variety of effects on the physiology of trees. Heavy metals and other toxic particles have been shown to accumulate, causing damage and death to some species. This damage has mainly been reported to result from the phytotoxicity of these particles (Beckett *et al.*, 1998:350). A significant source of damage can be the abrasive action of their turbulent deposition, which increases callus tissue formation on leaf surfaces. Heavy loads of atmospheric particles, such as those which can occur close to unpaved roads and open cast quarries, also result in the blocking of the stomata opening and thereby decreasing the efficiency of gaseous exchange, water uptake and photosynthesis. The resultant crust of particles that can form on leaf and bark surfaces disrupt other physiological processes, such as bud break, pollination and light absorption/reflectance. There are also a number of indirect effects such as the predisposition of plants to infection of pathogens and the long-term alteration of genetic structure (Beckett *et al.*, 1998:350).

For urban trees, critical loads of particles can be regarded as the accumulated amount of a pollutant, which will result in physical damage. Trees have certain mechanisms by which they are able to avoid damage specifically from pollutant particles. These include altering the timing of bud break or leaf fall, and the ability to produce new shoots when injured. The concordant increase in transpiration that is often present in species exhibiting high stomatal conductances can improve the efficiency with which particles are captured by leaf surfaces. This mechanism operates by the capture of particles on the film of moisture produced by transpiration (Beckett *et al.*, 1998:350).

1.1.2.5 Carbon sequestration

Carbon dioxide (CO_2) is a dominant greenhouse gas that is formed by fossil fuel combustion and deforestation (Nowak *et al.*, 2002:113). Atmospheric carbon is estimated to be increasing by approximately 2600 million metric tons annually; these increasing levels of atmospheric carbon dioxide (CO_2) and other greenhouse gas in the atmosphere are linked with the increased risk of global warming (Nowak *et al.*, 2002:113). Urban forests can reduce atmospheric carbon dioxide in two ways: 1) trees directly sequestrate CO_2 as woody and foliar biomass as they grow, and 2) trees around buildings can reduce the demand for heating and air conditioning, thereby reducing emissions from fossil fuel power plants (McPherson, 1998:215). According to Baral & Guha (2004:42), trees can also reduce carbon emissions by using forest products as substitutes for fossil fuels or fossil fuel intensive goods. Thus trees act as a sink for carbon dioxide by fixing carbon during photosynthesis and storing excess carbon as biomass (Nowak & Crane, 2002:381; Cairns & Lasserre, 2004:321).

The amount of carbon dioxide stored by urban trees are proportional to their biomass and are influenced by the amount of existing tree canopy cover, tree density and the pattern of tree diameters within a city (McPherson, 1998:215). Carbon sequestration refers to the annual rate of storage of carbon dioxide in above – and below- ground biomass over the course of one growing season. Sequestration depends on tree growth and mortality, which in turn depends on species composition and age structure of the urban forest (McPherson, 1998:216).

Total carbon storage and sequestration within urban areas generally increases with increased urban tree cover and increased proportion of large and/or healthy trees. Large healthy trees greater than 77cm in diameter sequester approximately 90 times more carbon than small healthy trees less than 8cm in diameter. Large trees also store approximately 1000 times more carbon than small trees (Nowak, 1994:83). It is, therefore, important to keep large trees in cities as long as possible before replacement by younger trees. Trees that are too big or too old require maintenance to keep them healthy and alive.

Maintenance however, has a negative effect on the net carbon sequestration of trees. The net carbon sequestered by a tree is the amount of carbon sequestered due to tree growth, reduced by the amount lost due to tree mortality (Nowak *et al.*, 2002:113). Tree care practices release carbon back into the atmosphere by fossil fuel emissions from maintenance equipment (Nowak *et al.*, 2002:113). Thus, some of the carbon that is gained by trees is lost to the atmosphere via fossil fuel used in the maintenance of the trees. When trees decompose the released carbon back into the atmosphere, a fraction of the carbon could be retained in the soil. If the trees are not maintained through maintenance equipment, driven by fossil fuels, it means that no fossil fuel is used and the net carbon sequestrate cycles through time and remains positive. If the trees are maintained the carbon emissions will offset the carbon gains through time. Eventually more carbon will be emitted due to maintenance activities than will be sequestered by a tree (Nowak *et al.*, 2002:114).

According to Nowak and Crane (2002:388), large trees with a relatively long life span will generally have the greatest overall positive effect on carbon dioxide, as fossil fuel carbon emissions resulting from tree planting and removal will happen less frequently.

Stoffberg (2005) calculated the carbon sequestration of the indigenous street trees, *Combretum erythrophyllum, Rhus lancea, Rhus pendulina* and the exotic street tree *Jacaranda mimosifolia* (Jacaranda) in the City of Tshwane, South Africa. The studies done by Stoffberg (2005) indicated that by the year 2032 a quantity of 54 630 ton carbon could be sequestrated by 115 200 indigenous street trees. This could result in an estimated 200 492 ton CO_2 equivalent reduction. If the market price of CO_2 was US$ 10 ton^{-1} than the CO_2 reduction can be valued at US$ 2 004 920. According to the study Stoffberg (2005) did on the Jacarandas in the suburbs of Tshwane, South Africa, he estimated that the carbon value could be US$ 419 786.

1.1.2.6 Storm water runoff

Trees can be used to reduce storm water runoff in an urban area. According to Xiao *et al.* (1998:325) there are three ways in which urban trees can reduce storm water runoff: 1) Trees intercept and store rainfall on their leaves, the rain evaporates and does not make contact with the ground, thereby reducing the runoff flow, 2) Root growth and decomposition increase the capacity rate of soil to infiltrate rainfall and reduce overland flow, 3) The urban forest canopy cover reduced soil erosion by reducing the impact of raindrops on barren surfaces. Although the trees can reduce storm water runoff they do not have a great effect on flood control. The bigger the storm the more likely it is that the urban forest cannot control the runoff (Xiao *et al.*, 1998:235).

1.1.2.7 Soil conservation

According to Clouston and Stansfield (1981:15) there are several ways in which trees protect the soil. Trees bind the soil with their roots and improve soil structure by humus and leaf litter. The tree canopy protects the soil surface from direct sunlight and heavy rain. Moisture is controlled by trees taking up water through their roots for transpiration and reduces excessive water movement. Trees can also help to drain areas of hard paving if channels are designed to take surface water to plant areas.

1.1.2.8 Noise control

The main source of noise in an urban as well as in rural areas is traffic. A barrier of plants can reduce the noise by absorbing the sound through foliage or deflecting it from branches or tree trunks (Clouston & Stansfield, 1981:14). The effectiveness of the plant barrier is unpredictable and depends on various factors such as nature of sound, wind direction, time of year, species numbers and density of planting (Clouston & Stansfield, 1981:14). Soft surfaces absorb more sound than hard surfaces, because of this effect the barrier should consist of both trees and shrubs. The sound level can be reduced by 7 decibels per 100 feet width of planting (Clouston & Stansfield, 1981:14).

1.1.2.9 Traffic control

It was a general belief that street trees cause accidents. According to Bernatzky (1987:86) it is not the trees along the road that endanger traffic but the reckless drivers. Thedic (as quoted by Bernatzky, 1987:86) did a case study and found that the accident rate is the highest where trees are right on the edge of the road. Where trees are more than one metre away from the road the accident rate is lower than on streets with no trees at all.

The most important contribution of trees to road safety is that they serve as an optical guide for drivers (Bernatzky, 1978:87). Trees along the roads help to make the driving less risky. The trees are used by the driver to estimate the traffic picture by the quick detection of directly approaching vehicles and more exact measurements of distances and of the speed of the driver's own car and of the approaching car. Trees along a straight long road stimulate the brain which is necessary, otherwise boredom and fatigue set in and the driver could get sleepy (Bernatzky, 1978:87). In towns the driver uses trees to identify certain streets. If the objects along the road are more familiar a driver reacts to it with little thought and this could make the trip much safer.

1.1.2.10 Economic value

Trees play an important role when it comes to the real estate value of buildings. According to several studies (Luttik, 2000:161; Laverne & Winson-Geideman, 2003:281; Perkins *et al.*, 2004:297) trees and a beautiful landscape do not only increase the property value of residential properties but also the value of commercial properties. A study by Laverne & Winson-Geideman (2003:287) indicated that there was an increase of 7% in the rental value of office buildings with aesthetical pleasing gardens or big trees that are shading the building. The real estate value of houses can increase with 5-12% if there are trees or a garden on the property (Perkins *et al.*, 2004:297).

Because of the contributions trees make to the landscape, real estate values, aesthetical beauty, health and the well-being of humans they are of great value and it is important to determine what their monetary values are. The monetary value of trees is used for insurance compensation, litigation and the management of urban forests. There are several methods that can be use to determine the value of trees for example: Council of Tree and Landscape Appraisers (CTLA, United States), Standard Tree Evaluation Method (STEM, New Zealand), Helliwell method – (Amenity Valuation of Trees and Woodlands, Great Britain) and Revised Burnley Method – Australia (Watson, 2002:11). The South African Tree Appraisal Method, SATAM, (Marx, 2005) is a newly developed method that is being used for the appraisal of trees in an urban environment. This method and the importance of tree appraisals in general will be discussed in chapter 2 (Material and methods).

1.1.2.11 Spiritual and emotional renewal

The opportunity that people get to relax and passively appreciate aesthetic settings is a major source of the value people place on the urban forests or parks. Urban forests can create an environment where people could recharge their batteries and promote feelings of well-being (Hodge, 1995:1; Grahn & Stigsdotter, 2003:1).

1.1.2.12 Privacy refuges

Urban forests and parks create an environment of privacy or refuges for people that work and live in the cities. By creating an environment for privacy people can withdraw from their everyday lives through physical or psychological means and in such a way renew their strength. According to Hammit (2002:19) there are four basic functions of privacy: 1) Personal autonomy, which is the need to safeguard one's individuality by avoiding manipulation or dominance by others, 2) Emotional release, emotional resting from the psychological tensions and stresses from the work environment, 3) Self-evaluation, recalling experiences and placing them into a meaningful pattern, and 4) Limited and protected communication.

In many cases people see the parks or urban forests as a refuge where they can hide or escape from their circumstances, such as their homes, work or even people. According to Hammit (2002:20) people are not necessarily running away from their non-preferred places or circumstances but rather are seeking an opportunity to be away to a more preferred place. The Prospect-Refuge Theory of landscape experiences postulated that the ability to see (prospect) without being seen (refuge) is a basic human need when in natural environments and that it is a source of aesthetic satisfaction and preference during landscape experiences. The urban forests and parks offer many opportunities for prospect and refuge (Hammit, 2002:20).

1.1.2.13 Neighbourhood social ties

In a lot of cities the inner-city neighbourhood common spaces all too often consists of vacant lots that are barren and deserted no-man's lands. According to Kuo *et al.* (1998:826), residents dislike and fear these spaces when there is not any vegetation in the area. According to the studies of Kuo *et al.* (1998:826), resident's preferred spaces that have trees or any kind of vegetation and the presence of trees constantly predicted greater use of outdoor spaces in the inner-city neighbourhoods. The closer the trees were to the residential buildings the more people spent time outside. The presence of trees also had a positive impact on the relationships between the neighbours in these areas. The longer the residents spent outside the better the social ties were between the neighbours and this created a sense of security. The trees in the neighbourhoods in inner-cities were, therefore, not only for recreational activities for children but social ties are formed between the residents and this created a more secure and saver neighbourhood.

1.1.2.14 Attention capacity

The view of natural elements an individual has while working can increase their direct attention capacity. According to Taylor *et al.* (2001:57) direct attention is defined as the capacity to inhibit or block competing stimuli or distractions during purposeful activity. This capacity is essential for the effective performance of daily activities; acquiring and using information, making and carrying out plans, and self-regulation of responses and behaviour to meet desired goals. According to studies done by Tennessen & Cimprich (1995:78), university dormitory residents with a natural view from their window had a better direct attention capacity than residents with a built view from their window. Students with the natural view performed better academically than those with a built view. The studies also showed that the students with the natural view had an increased capacity to direct attention (Taylor *et al.*, 2001:58).

1.1.3 Anthropogenic impacts on trees - Urban stresses

Trees in urban ecosystems provide the urban dweller with important services and benefits. These services and benefits are influenced by the quality of the urban environment in which the trees grow. People are the single biggest threat to trees (Caplan, 2004). According to Caplan (2004) the things that people do to trees, intentionally, accidentally, or through ignorance of how a tree lives, are often of much greater consequence to the tree than the effects of microbial pathogens and harmful insects (Tatter, 1980:1; Caplan, 2004). People-pressure diseases (PPD) are complex and are inhanced through an enlarging group of people related stresses that commonly affect trees (Tatter, 1980:1). The following are examples of people pressure diseases: topping, improper planting, girdling, improper herbicide use, improper watering, air pollution, nutrient abnormalities, light pollution, temperature extremes, trampling, mechanical damage and terrain changes (Roberts, 1977:75; Wilson, 1977:69; Schoeneweiss, 1978:217; Tatter, 1980:1).

1.1.3.1 Topping

Topping is the removal or cutting back of large branches in mature trees (ISA, 1995; Mckenzie, 2000).

There are many reasons why topping trees are not good for the trees health:

a) **Topping stresses trees:** Topping of trees removes approximately 50%-100% of the leaf-bearing crown (ISA, 1995). The leaves of trees manufacture starch during the process of photosynthesis. The transport system (phloem) moves starch from the leaves to the roots. When topping a tree excessively the leaves are unable to provide the roots with the necessary products. This in turn prevents the roots from growing and transporting nutrients and water to the leaves (Mckenzie, 2000). The severity of the pruning triggers a survival mechanism that activates latent buds forcing the rapid growth of multiple shoots below each cut. A new crop of leaves needs to grow to supply enough energy and food for the tree. If a tree does not have enough energy to form new leaves it will weaken and even die.

b) **Topping causes tree decay:** The large wounds caused by topping are vulnerable to insect and disease infestation. The open pruning wounds expose the sapwood and heartwood of the tree to attacks. The location and size of these cuts prevent the trees natural defence system from normal functioning (ISA, 1995; Mckenzie, 2000). The preferred location to make a pruning cut is just beyond the branch collar at the branch's point of attachment. The tree is biologically equipped to close such a wound, provided the tree is healthy enough and the wound is not too big. Cuts made along a limb between lateral branches create stubs with wounds that the tree may not be able to close. The exposed wood tissues begin to decay (ISA, 1995; McKenzie, 2000; Turnbull, 2005).

c) **Topping can lead to sunburn:** Branches within a tree's crown produce thousands of leaves that absorb the sun. This umbrella protects the rest of the leaves, branches and trunks from the damaging UV-rays of the sun. When the top branches of the tree are removed the branches and trunk as well as tissue beneath the bark are exposed to sunlight and this can lead to cankers, bark splitting, and death of some branches (ISA, 1995; McKenzie, 2000; Turnbull, 2005).

d) **Topping creates hazards:** The survival mechanism that causes a tree to produce multiple shoots below each topping cut comes at great expense to the tree because the trees need to use a lot of energy. These shoots develop from buds near the surface of old branches. Unlike normal branches that develop in a socket of overlapping wood tissue, these new shoots are anchored only in the outermost layers of the parent branches. These new shoots are not very strong and can break easily in the wind (ISA, 1995; McKenzie, 2000; Turnbull, 2005).

e) **Topping makes trees ugly:** Topping makes trees look ugly by removing most of the leaves and leaving short stubs to look at as shown in Figure1.5 (Anon, 1995; McKenzie, 2000; Turnbull, 2005).

People think that by topping the trees the trees will remain shorter but this is not true. The trees respond rapidly to the injury by producing many long sprouts. These shoots can grow as much as 20 feet per year (McKenzie, 2000; Turnbull, 2005). Trees should rather be pruned than topped as illustrated by Figure 1.5.

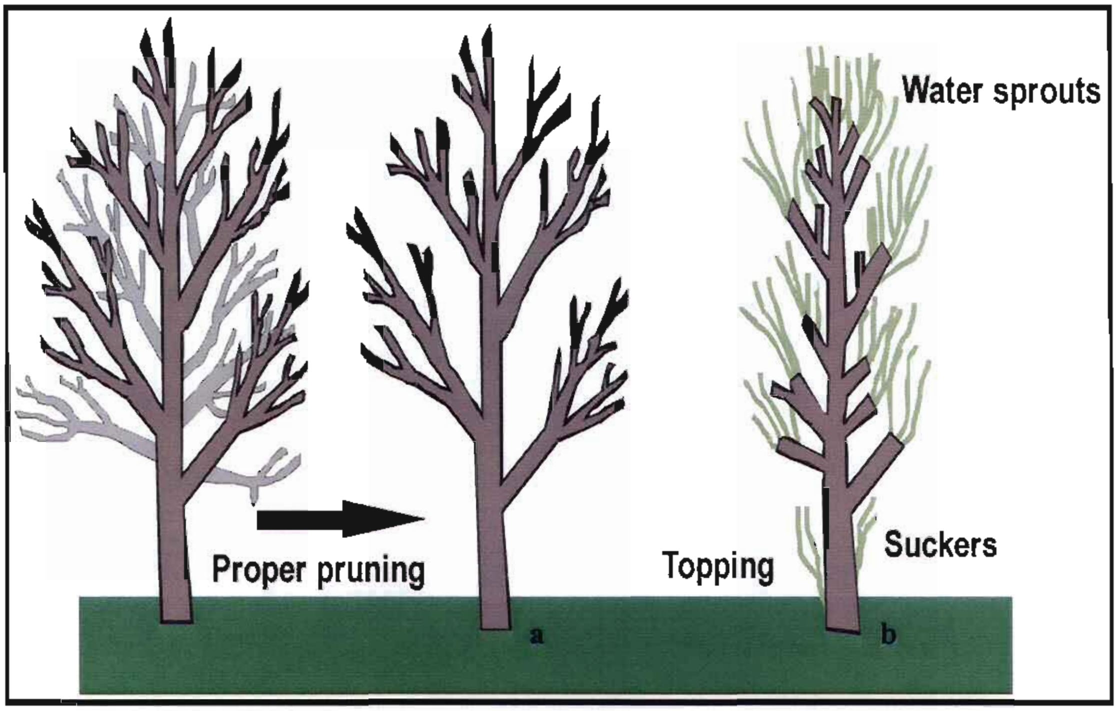

Figure 1.5 The difference between a) pruning a tree and b) topping a tree (Adapted from ISA, 1995).

1.1.3.2 Improper planting

Improper tree planting problems do not always show directly after planting. Most of these problems only show a few years after the tree has been planted. Some of the improper planting techniques include the following: 1) handling the tree improperly before planting it, 2) planting the tree too deep and 3) planting the tree the old-fashioned way. The old-fashioned way of planting a tree is in a narrow hole with straight sides and amending the backfill with organic matter. This can cause the roots to grow in a circle around the tree and in a few years this can lead to girdling (choking) of the tree trunk (Gould, 1993; Caplan, 2004). According to Gould (1993), the following techniques are the correct way of planting a tree (Figure 1.6)

- Prepare the planting hole properly to make sure the hole is big enough (2-5 times the size of root ball) and roots are not cramped.
- Plant the tree at the same depth that is was growing in the nursery.
- Water immediately after planting.
- Support the tree with rubber protected wire attached to two poles.

- Mulch soil at the base of the tree to maintain soil moisture, control weeds and minimize mower damage. Maintain mulching to a maximum depth of 2 to 3 inches.
- Do not fertilize when planting, wait until one year after planting.

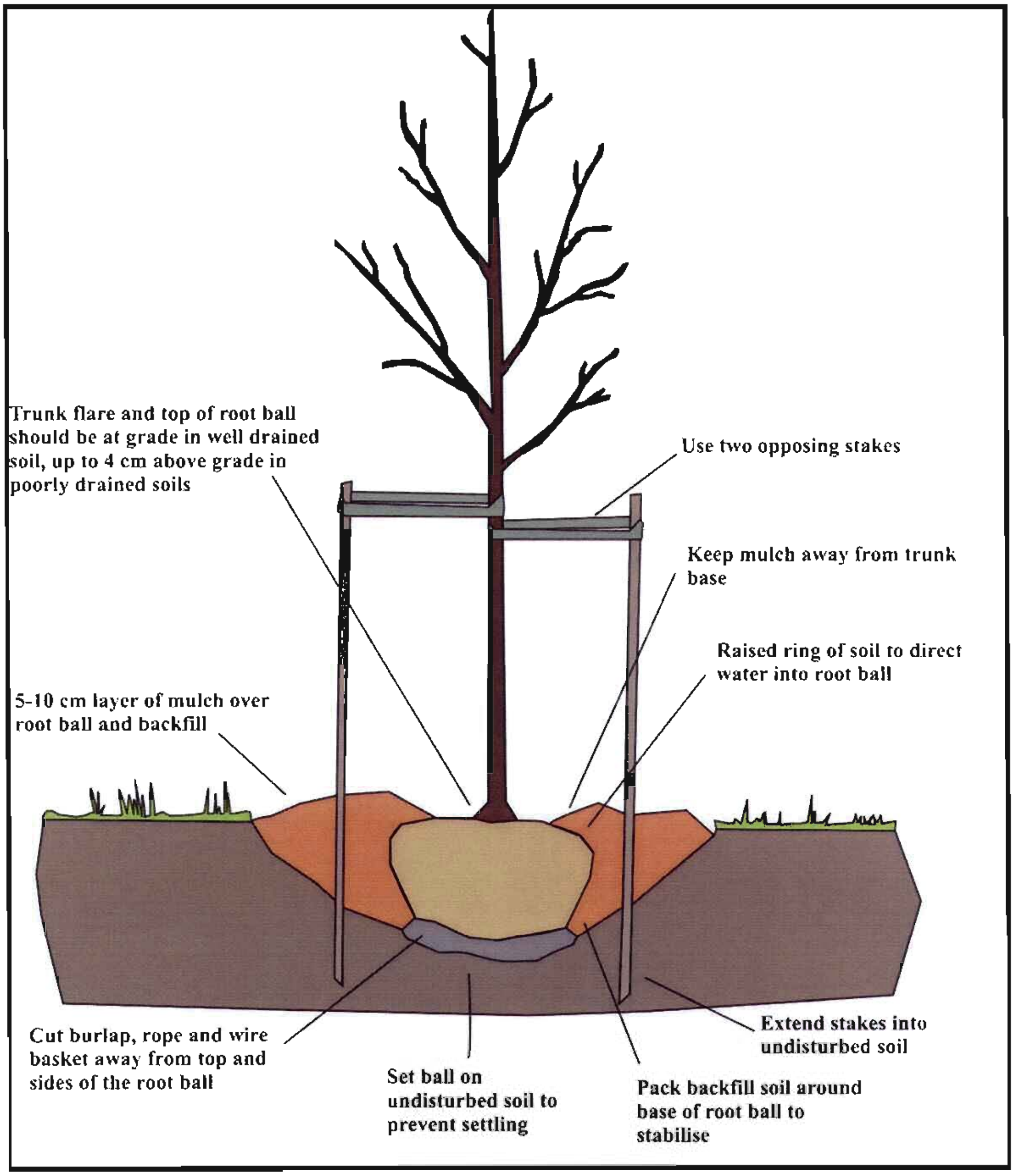

Figure 1.6 Illustration of the correct way to plant a tree (ISA, 2003).

1.1.3.3 Girdling

Tying all kinds of string or wire to trees and not removing the ties can cause girdling of the trees. Forgetting to remove the strings or wire will force the tree to strangle itself on the string or wire (Caplan, 2004).

1.1.3.4 Improper herbicide use

In urban environments, herbicides, fungicides, insecticides, fertilization, and growth regulation cause chemical stress. In Europe and North America, chemical stress is also caused by the use of chemicals for the removal of snow and ice during the winter (Roberts, 1977:76; Wilson, 1977:70; Schoeneweiss, 1978:217). These chemicals accumulate in the soil and damage the trees (Wilson, 1977:70).

1.1.3.5 Improper watering

An adequate supply of plant moisture is one of the most critical factors contributing to the physiological well-being and growth of trees in the urban environment (Roberts, 1977:75; Tatter, 1980:2). In most urban environments, a large portion of the soil is covered by pavement or impervious surfaces that prohibits adequate infiltration of water (Roberts, 1977:75; Tatter, 1980:2). Impervious surfaces not only cause inadequate infiltration of water but also restrict water movement in soil, which could saturate or flood the soil and cause root suffocation (Tatter, 1980:2). The soils around the trees are often low in organic matter and compacted, which also cause inadequate infiltration of rainwater (Roberts, 1977:75; Schoeneweiss, 1978:219; Tatter, 1980:2). In some cases the soil in an urban area is laced with drains, which accelerates downward water movement and increase drying after rain (Tatter, 1980:2). Another problem associated with moisture stress within the urban environment is turf grass and other plants that compete with tree roots for water (Tatter, 1980:2).

Studies done by van Rensburg *et al.* (1997: 25) on *Quercus robur* in Potchefstroom indicated that an inadequate supply of moisture to street trees could cause tree die back and also result in trees being susceptible to pests such as *Asterolecanium quercicola* (Bouche).

1.1.3.6 Air pollution

Air pollution damage to trees is most apparent in heavy industrialised areas or urban areas with heavy automobile traffic (Wilson, 1977:70). Air pollution cause early senescence, changes in plant-water relations, poor growth and modification of CO_2 exchange in trees (Roberts, 1977:77).

1.1.3.7 Nutrient abnormalities

In an urban environment, soil often becomes modified in ways that make nutrients unavailable to roots or lead to an addition of high concentrations of minerals around the root zone. Nutrient unavailability cause deficiencies in the tree while a high concentration of minerals cause toxicities (Tatter, 1980:2).

1.1.3.8 Light pollution

In most of the urban environments, intensive artificial lighting is used to combat crime. The intensive use of lighting influences the day length of trees, which can influence their flowering patterns. Excessive lighting also promotes continued growth, thereby preventing trees from developing dormancy, which allows them to survive extreme weather conditions (Wilson, 1977:70; William, 2006). Continued lighting is even more damaging to trees. Foliage of trees grown in continued lighting is larger in size and more susceptible to air pollution and water stress during growing seasons because the stomatal pores in leaves remain open for longer periods (William, 2006).

1.1.3.9 Temperature extremes

Extreme heating within an urban environment could put tremendous stress on trees. The heat-island, which forms over an urban area increases soil and air temperatures. The extreme heating of the air and soil has a major effect, especially where the trees are almost completely surrounded by pavements and are without the cooling effect of grass or mulches (Tatter, 1980:1). The heat effects could cause denaturation and coagulation of proteins as well as numerous metabolic disturbances (Roberts, 1977:75).

1.1.3.10 Mechanical damage and terrain changes

Mechanical damage could be caused by several human activities. Some examples include damage caused by lawnmowers, trenching and bulldozers (Wilson, 1977:69; Jim, 2003:88)

1.1.3.11 Trampling

There are two major effects of trampling on trees: 1) direct effects of mechanical forces which damage all or parts of the plants and 2) indirect effects of trampling on the physical and /or chemical characteristics of soil, which in turn affects plant establishment, growth and reproduction (De Gouvenian, 1996:279). The primary effect of trampling on soil is compaction, which is a reduction in soil volume accompanied by an increase in soil bulk density. The decrease in large soil pores and increase in small soil pores result in an increase in matrix potential and soil water potential. During the dry season this allows compacted soil to have higher moisture content per unit weight than non-compacted soils. The collapse of the large pores also restricts the air porosity of the soil, and can lead to periods of deficient soil and root aeration (de Gouvenian, 1996:279; Gliński & Stępniewski, 1983). Compaction affects the mobility of inorganic ions and therefore their availability to plant roots. It also influences the mineralization of nutrients from soil organic matter by micro-organisms. Nitrogen mineralization and nitrification can be reduced by even slight increases in compaction (De Gouvenian, 1996:280).

Plant development functions normally when the requirements of the plant do not exceed the supplying capacity of the root system, which is itself affected by: 1) soil aeration, 2) soil moisture, 3) soil strength, 4) soil temperature, 5) soil nutrient status and 6) soil organisms (De Gouvenian, 1996:280). Poor soil aeration and changes in soil water content have an impact on cell metabolism because of a decreased oxygen concentration. This could be partly responsible for low nutrient uptake and could promote the invasion of pathogens. An increase in soil bulk density and soil strength can have negative effects on the establishment of seedlings and the growth of the roots of established plants (De Gouvenian, 1996:280). Soil pore size, water content, aeration, temperature, nutrient availability, and micro-organisms are interrelated and can all be negatively impacted by soil compaction, with negative effects on plant root growth and function (De Gouvenian, 1996:280).

1.1.4 Environmental impacts on trees - Loads on trees

Trees in all environments undergo many loads during their lifetime. According to James (2003:166), loads cause stress on the branches and trunks of the trees and therefore cause them to grow in a certain direction or to fall. The loads that cause stress on the trees can be a combination of:

a) Tension (a pulling force)
b) Compression (a pushing force)
c) Bending (tension, compression and shear)
d) Torsion (a twisting force)
e) Growth (a circumferential force)

All of these loads can be applied as either static loads due to the weight of branches, foliage, snow and ice, or as dynamic loads due to wind (James, 2003:166).

1.1.4.1 Static loads

Static loads are constant loads in which there is little or no movement (James, 2003:166).

1.1.4.2 Dynamic loads

Dynamic loads are loads that are caused by movement of some kind. The largest dynamic load on trees is the wind. The wind comes in gusts, lasting for about 20 to 40s. There are many smaller gusts within these major gusts, and the effect is that a dynamically varying force is exerted on the tree canopy. The wind pushes on a tree canopy and can push upward on the branches pointing into the wind or sideways and upward on branches orientated at right angles to the wind. The branches of the tree respond with a complex sway motion in which the limbs move out of step with each other. This movement can be thought of as a de-tuned system that prevents the tree and its branches from developing dangerously large swaying motions. It is a survival mechanism to ensure that a harmonic or pendulum like sway is never developed.

The tree, using a complex damping mechanism, dissipates the energy from the wind to minimize the energy transferred from the wind to the main structure of the trunk (James, 2003:166). The energy is dissipated partly by the leaf drag; partly by internal energy losses within the wood and root/soil system, and partly by the complex branch swaying mechanism. The swaying motion is heavily damped by three main factors:

1. hydraulic damping: aerodynamic drag forces of the foliage in the wind.
2. mass damping: the interaction of the side branches attached to the main limb.
3. visco-elastic damping: the damping effects within the tree's stem and root system.

There are two major reasons why trees fail in wind, 1) wind throw, usually in high winds, and 2) major stem or limb failure, which may occur in either high winds or in still air conditions. Wind throw failure occurs at the base of the tree, where the root plate and the soil interact. This happens when the overturning forces of the wind exceed the resisting forces of the root plate. A tree limb will fail when, at some point, the applied loads create a localized stress that exceeds the strength of the material (James, 2003:169).

1.1.5 Physical problems caused by trees

Although trees have many advantages in urban environments, they can also have a negative impact on the urban environment, for example the obstruction of light, blocking of gutters and damage to pavements, roads and buildings (Campling, 1979:13; Biddle, 1981:17). In many cities, tree roots cause damage to sidewalks, curbs and sewer lines and these interferences could cost towns and cities large sums of money (McPherson & Peper, 1995:49).

1.1.5.1 Obstruction of light

Trees that are too close to windows can block lateral or vertical sunlight falling on that window. This can cause inconvenience to the people living in the house. The branches block the sunlight and thus the room is much darker than what it should be and extra light must be used in the room (Biddle, 1981:18).

1.1.5.2 Blocking of gutters

This is a big problem, especially in autumn. The trees drop their leaves and the leaves block the gutters. This can cause inconvenience for people at home (Biddle, 1981:19). Another problem with the leaves is that it makes the sidewalks very slippery and this could be dangerous to people using the sidewalks.

1.1.5.3 Trees and buildings

According to McPherson and Peper (1995:49), studies of sidewalk and curb damage due to trees indicate that many variables are responsible for damage and their relative importance depends on conditions specific to each site. In general, the following factors may be involved: tree size, species, proximity to concrete, planting strip width, age of concrete, soil conditions, horticultural practices and other environmental conditions.

According to Campling (1979:14), structural problems that do arise due to damage by trees are usually from the effect of tree roots on soil upon which the building rests, particularly in clayey soils, which change bulk as their moisture content varies. Trees lose water through transpiration from leaf surfaces; the roots absorbing water from the soil replace this water (Biddle, 1979:31). Roots are at various depths within the soil and are able to dry clay soil within the root range. The vertical depths determine the amount of subsidence the plants produce, and the lateral extent the distance from the shoot base to which they will cause soil shrinkage (Reynolds, 1979:26). The root range beneath pavements and buildings can cause shrinkage of the soil and thus damage the pavements and buildings. If the tree crown is pruned and is small, the water needs of the tree would probably be smaller and consequently the drying of the soil less (Biddle, 1979:38).

From the above mentioned it is evident that trees and urban open spaces play an important role in nature as well as in the everyday life of humans. Not only do trees contribute to the physical health of humans but they also play a role in their mental and spiritual health. Trees in urban environments have negative impacts such as littering damage to pavements. Although trees have a negative impact on the physical environment of urban areas, the role trees play in nature and a human's life is far greater than the negative impact. Trees in urban environments are, however, influenced by human activities and this could have a negative impact on the tree's vitality and the role trees play in nature and their influence on human health and well–being.

1.2 Aim of the study

The main aim of this investigation was to determine the general anthropogenic and environmental impacts on trees along an urbanization gradient in the Potchefstroom Municipal Area. *Acacia karroo*, one of the most common trees along the entire urban-rural gradient, was selected as the object of the study. The following aspects were included in the study.

- The description of the habitat of the tree along the urbanization gradient in terms of soil contents and associated vegetation;
- The measurement of tree vitality using chlorophyll fluorescence kinetics (JIP-test);
- The measurement of leaf water potential using a pressure chamber;
- The determination of the monetary value of trees in urban environments by using SATAM (South African Tree Appraisal Method);
- The association of tree vitality and leaf water potential measurements with soil and vegetation information and tree monetary values.

1.3 Hypothesis of the study

The tree vitality and leaf water potential values of trees will decrease along the urbanization gradient from the rural areas to the more urbanized areas, while the monetary values of the trees will increase along the urbanization gradient from a rural to a more urbanized area.

1.4 Contents of this thesis

This thesis consists of the following chapters:

- Chapter 2, which describes the methods that were used during the current study, including the discussion of the urbanization gradient approach.
- Chapter 3, which describes the habitat in which the different trees are found by discussing the soil content and vegetation composition of associated plants along the urbanization gradient.
- Chapter 4, the discussion of the tree appraisal , which includes the discussion of the monetary values of trees at each, study site.
- Chapter 5 includes all the physiological aspects and the influence of urbanization on the tree vitality and leaf water potential.
- Chapter 6, which is the association between the ecophysiological components (tree vitality and leaf water potential), the soil content and vegetation composition as well as the tree appraisal characteristics.
- Chapter 7 offers some concluding remarks

Chapter 2

Materials and Methods

2.1 Study area

The study area was the Potchefstroom Municipal Area (North West Province). See Figure 2.1 for a map of the study area and Figure 2.2 for an aerial photograph.

2.1.1 General information

Potchefstroom is situated in the southern part of the North West Province of South Africa (between 27° 04' and 27° 07' longitude and 26° 40' and 26° 44' latitude). The temperatures vary between –12°C and 39°C, with an average of about 16°C. Potchefstroom lies in the summer rainfall area and receives approximately 650mm-750mm per year (Low & Rebelo, 1996:39). The habitat consists of rocky mountains, hills, ridges and plains of quartzite, conglomerate, shale, dolomite and sometimes andesitic lava. Potchefstroom forms part of the Bankenveld, which is also called "klipveld" owing to the abundance of surface rock (Acocks, 1988:112). Potchefstroom is situated in the Dry Sandy Highveld Grassland (Bredenkamp & Van Rooyen, 1996: 49) of the Grassland Biome (Rutherford &Westfall, 1994:48), which is dominated by a single layer of grasses. The Grassland Biome is considered to have an extremely high biodiversity with rare species or endangered species comprising mainly of endemic geophytes or dicotyledonous herbaceous plants (Rutherford &Westfall, 1994:48). In the newest attempt to map the Vegetation of South Africa (VEGMAP), three vegetation types can be recognised in the Potchefstroom municipal area, namely Carletonville Dolomite Grassland, Rand Highveld Grassland and Andesite Mountain Bushveld (Mucina *et al.*, 2005).

The Potchefstroom area is classified under the Bc and Fb land type (Land Type Survey Staff, 1984:11). A land type is an area that shows a degree of uniformity with respect to terrain form, soil pattern and climate. The Bc land type is characterized by flat or slightly undulating plains and widespread eutrophic, red soils (Land Type Survey Staff, 1984:10).

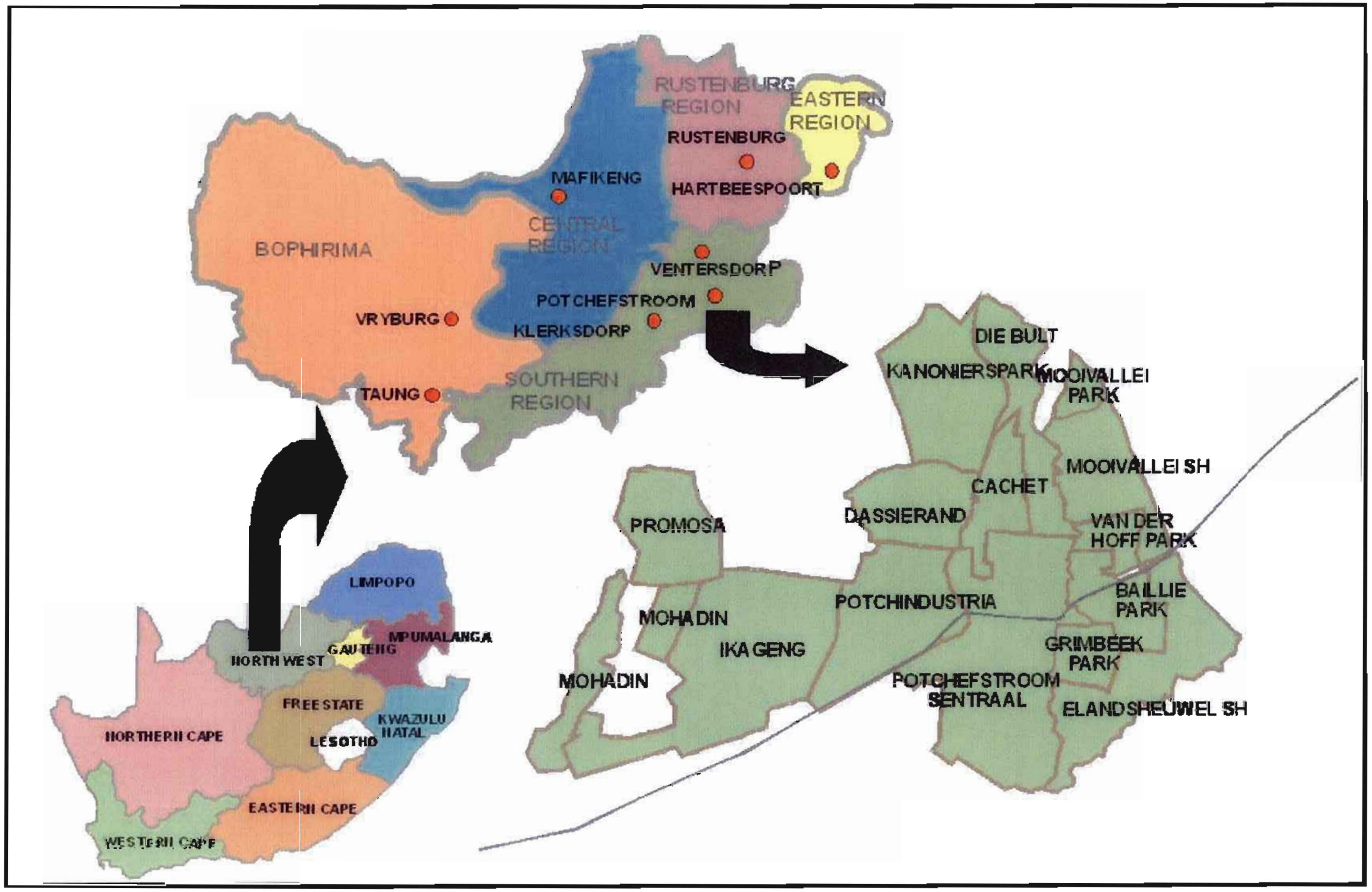

Figure 2.1 Map of Potchefstroom Municipal Area, which falls in the North-West Province, South Africa

The Fb land type has Glenrosa and Mispah soil forms with exposed rocks; the landscapes are without lime but with accumulations of soluble salts in the soil (Land Type Survey Staff, 1984:11).

According to studies done by Bredenkamp *et al.* (1989:201), Bezuidenhout and Bredenkamp (1991:503) and Bezuidenhout *et al.* (1993:144), *Acacia karroo* communities are found on the footslopes and bottomland flats of the Bc land type as well as on the footslopes and midslopes of the rocky outcrops and hills of the Fb land types. Cilliers (1998) conducted phytosociological studies on the urban open spaces in Potchefstroom and found *Acacia karroo* in the following land-use areas in Potchefstroom: along railway lines, residential and industrial areas on the city margin, natural areas inside the city and rural areas. The vegetation composition of each study site will be discussed in detail in chapter 4 (Soil contents and vegetation composition).

2.2 Study Sites

A thorough investigation of the Potchefstroom area as well as the periphery of Potchefstroom was conducted to find study sites with *Acacia karroo* that were appropriate for this study. The potential study sites had to meet the following requirements: a) there had to be a minimum of four trees on the site, b) the trees had to be more or less evenly sized. All the sites that complied with the criteria were plotted on an aerial photograph, which was then used to choose 20 specific study sites (See Figure 2.2). The 20 study sites are representatives of one of the classes along the urbanization gradient – urban, suburban or rural (See Figure 2.3). The urbanization gradient was quantified using Ridd's V-I-S-model (1995:2166). The quantification of the urbanization gradient will be discussed in section 2.3 of this chapter. The six rural sites were used as controls. Some of the sites were on private properties and a letter requesting permission was addressed to the owners of the land. See appendix A for the request for permission.

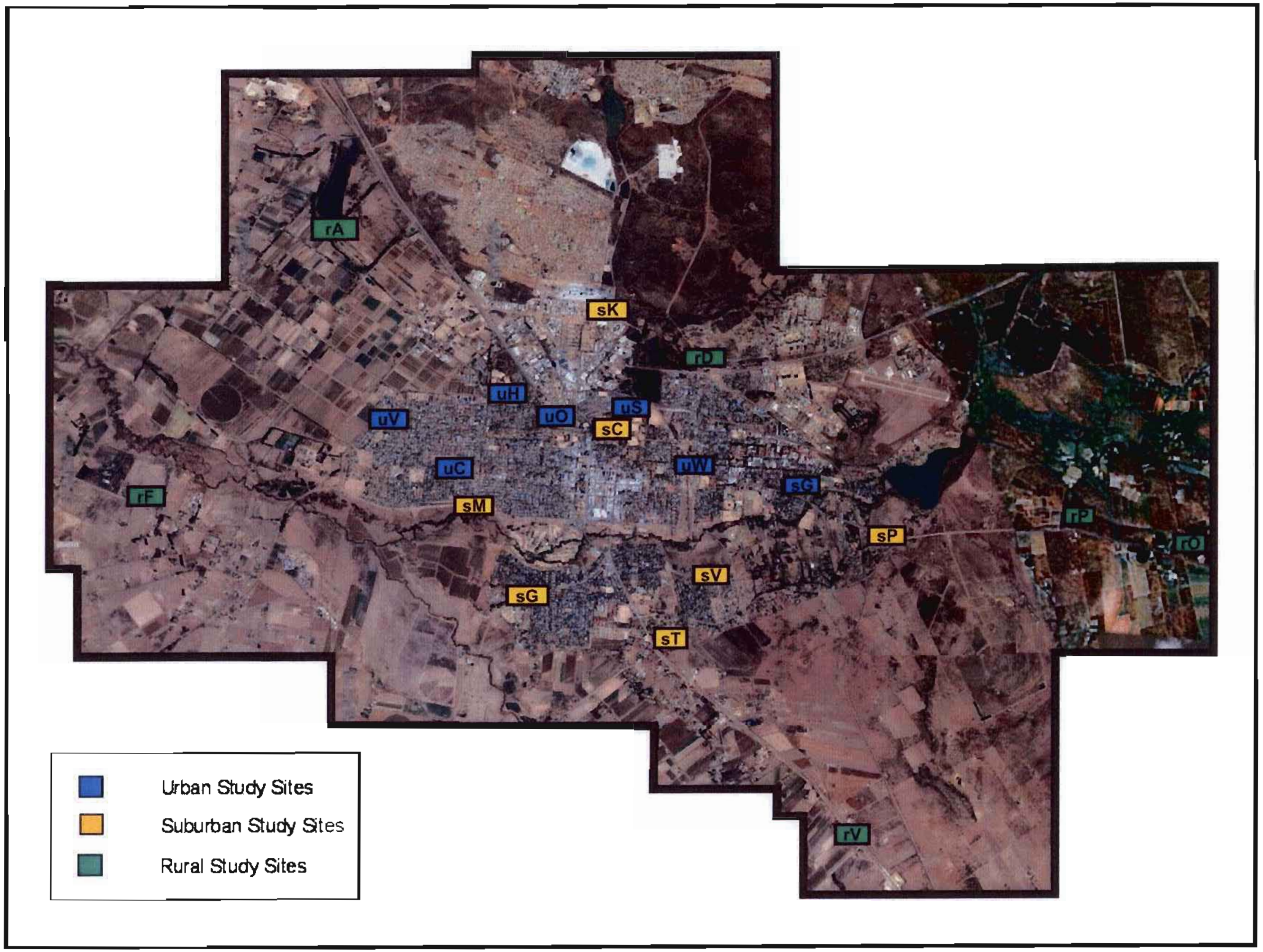

Figure 2.2 Aerial Photograph showing the position of the different study sites in the Potchefstroom Municipal Area

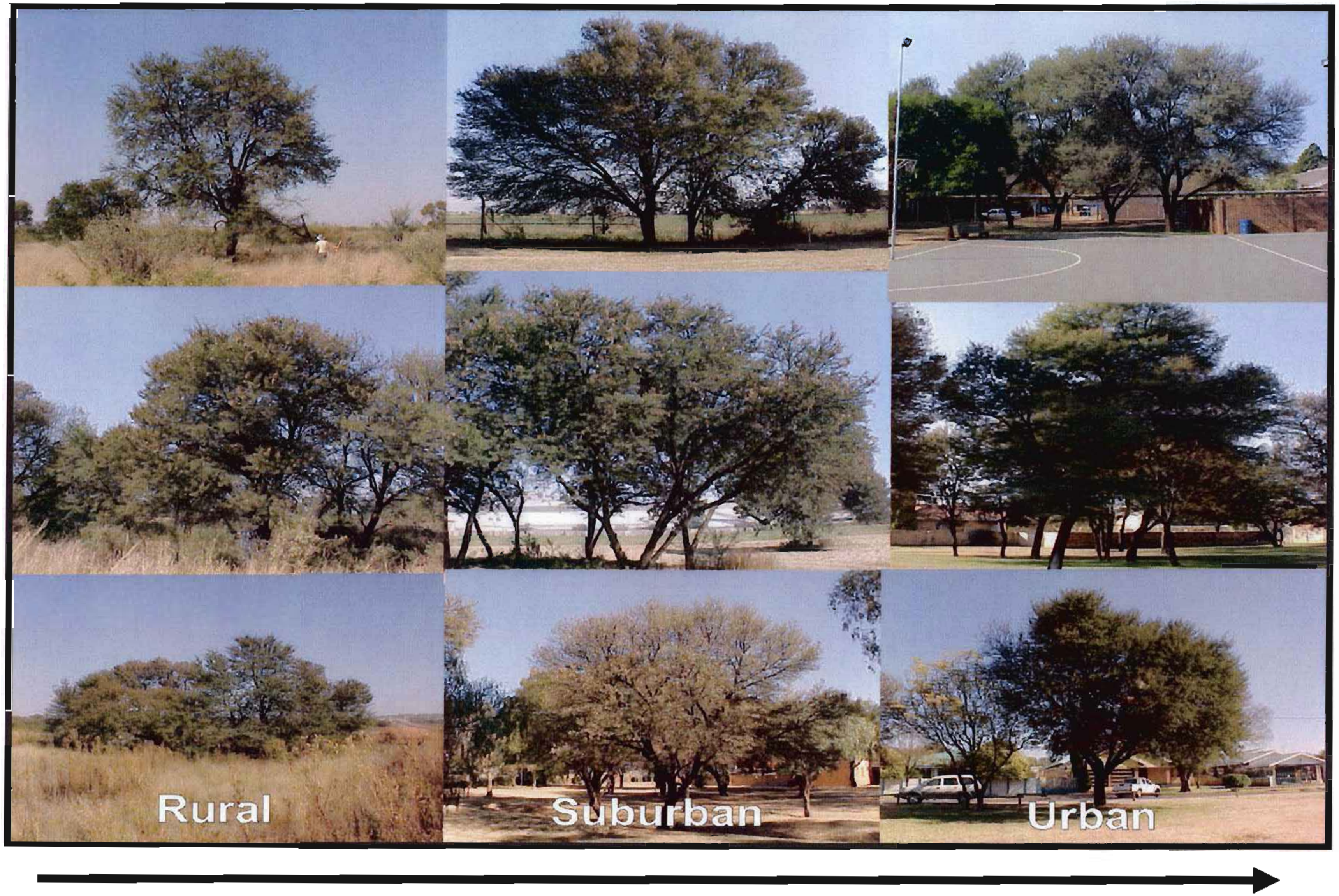

Figure 2.3. The urbanization gradient is illustrated by photographs of some of the study sites along the gradient, in the Potchefstroom Municipal Area

2.3 Quantification of urban-rural gradient

Forman and Godron (1986) divided landscapes into five broad types spanning across an urban-rural gradient. At the pristine end of the gradient are the natural landscapes that are without significant human impact. The next type is managed landscapes, which consist of planted and/or managed native or non-native species. In the middle are cultivated landscapes with villages and patches of natural and managed ecosystems scattered within the predominant cultivation. Suburban landscapes are town and country areas with a heterogeneous patchy mixture of residential areas, commercial centres, cropland, managed vegetation and natural areas. The urban end of the gradient represents remnant managed park areas scattered in a densely built up matrix several kilometres across.

According to McDonnell and Pickett (1990:1232), the gradient paradigm can be summarized as the view that environmental variation is ordered in space, and that spatial environmental patterns govern the corresponding structure and function of ecological systems, be they populations, communities, or ecosystems. The urban-rural gradient is only one of the approaches that can be used to investigate how urbanization is changing the ecological patterns and processes across the landscape (McDonnell & Pickett, 1990:1233). According to Hahs and McDonnell (2005:435), the urbanization gradient has been used in many studies to determine the impacts of urbanization on different biota and processes such as bird community composition and reproductive biology, plant community composition, leaf litter composition and nutrient cycling, pollution and water quality.

Many urban areas consist of a dense, highly developed core with irregular circles surrounding it. For this reason the gradient paradigm can be a powerful organizing tool for ecological research on urban influences on ecosystems (McDonnell, 1990:1232; Hahs & McDonnell, 2006:446). According to Weeks *et al.* (2003), the urban/rural distinction is a continuum rather than a dichotomy and the word "urbanness" can be used to describe this continuum. Transects can be used to represent changes along the gradient as a cross-section, but is highly dependent upon placement of the transect (Hahs & McDonnell, 2006:436). Urbanization therefore creates complex non-linear gradients and multi-dimensional non-linear methods should be used to ensure a more accurate representation of gradients in the urban landscape (Hahs and McDonnell, 2006:435).

Although the urban-rural gradient is a powerful tool for ecological research, it is necessary to define or quantify the urban-rural gradient for the purpose of comparing different ecological studies. According to Weeks *et al.* (2003), this urbanness continuum describes how urbanized a certain area is. Hahs and McDonnell (2006:435) described several different measures of urbanization, which can be classified in three major groups, namely 1) demographic variables, such as density of people, density of dwellings or number of people per unit urban land-cover; 2) physical variables such as density of roads, fraction of impervious surface or distance to central Business district; 3) landscape metrics, such as mean patch size, dominant land-cover or number of patches. Hahs and McDonnell (2006:435) objectively selected a subset of measures to represent urbanization from a larger group of commonly used measures, but mentioned that the applicability of those measures in other cities still needs to be tested. Due to time constraints and unavailability of some of the measures, the method of Hahs and McDonnell was not tested in this study.

We decided to use physical measures to determine the urbanization component of the gradient in this study. The Vegetation – Impervious surface – Soil model (V-I-S model) of Ridd (1995:2166) was used to quantify the urban-rural gradient (see Figure 2.4).

2.3.1 V-I-S model (Vegetation, Impervious surface and Soil)

The method that was used for the quantification of the urban-rural gradient in this study is the V-I-S model of Ridd (1995:2166). According to Ridd (1995:2166), the combination of impervious surface material, green vegetation and exposed soil are the most fundamental components of the urban ecosystem, in terms of contrast to the surrounding environment as well as contrast within the city. For this study, water surfaces were ignored but they could be added to the model (Rashed *et al.*, 2001:9; Weeks *et al.*,. 2003). Ridd (1995:2172) also explained that the objective of this model is to identify and characterize variable land cover patterns and not to identify land-use. For this method of quantification, remote sensing is used to classify different study sites into urban or rural areas. Remote sensing divides the earth's surface into remote sensing pixels/ image pixels. By classifying these image pixels into vegetation, impervious surface or soil, the degree of urbanness could be determined. This means that a subdivision of urban areas may be made based on the percentage of the image pixel (spatial unit) occupied by vegetation, impervious surface or soil (Ridd, 1995:2173).

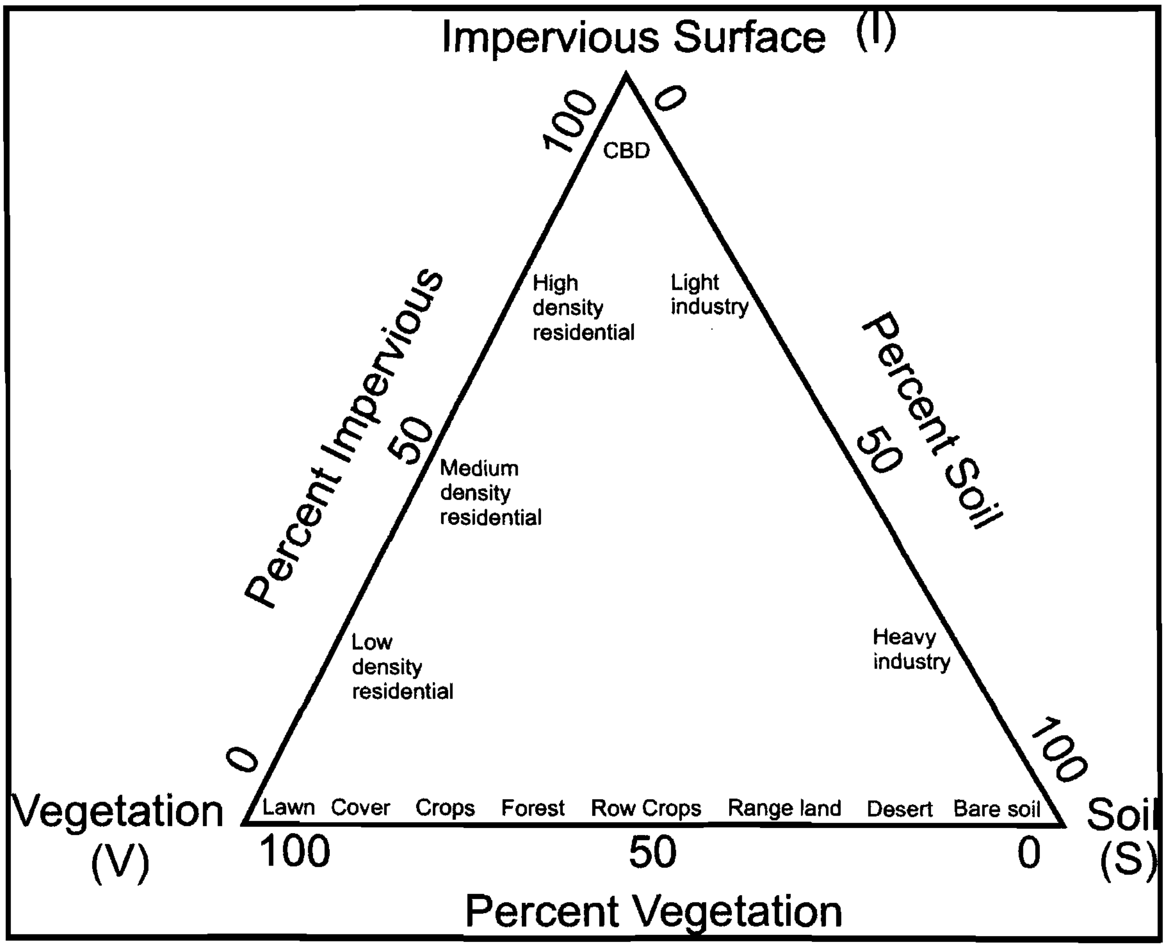

Figure 2.4: VIS (Vegetation-impervious surface- soil) model of Ridd (1995,2173) that was used to characterize the urbanization gradient in the Potchefstroom Municipal Area.

In the V-I-S model (Ridd, 1995:2173), the S-V axis represents land that is not yet urbanized, or urban land undergoing change. There are few or no impervious surfaces in non-urban/pre-urban environments. The V-I axis represents a typical residential sequence, while the traditional commercial and industrial areas lie on the I-S axis.

For this study, aerial photographs were used to determine the degree of urbanness of the different study sites (Phinn *et al.*, 2002:4131). An area of 0.5 km x 0.5 km around each study site was used to determine the urbanness (Figure 2.5). Using the aerial photograph of Potchefstroom and ArcView 9 (ESRI, 2006), each 0.5 km x 0.5 km block was divided into vegetation, impervious surfaces and soil (See table 2.1 for the different classifications of vegetation, impervious surfaces and soil and Figure 2.5 for an example of the method). The terms that were used to classify the percentage vegetation, impervious surfaces and soil are terms used by Giscoe (Botha, 2006). For each of the 0.5 km x 0.5 km blocks, the percentage vegetation, impervious surface and soil were determined and according to the percentage vegetation and impervious surface the urban-rural gradient was quantified.

According to the percentage impervious surface and vegetation cover, the urban and the rural study sites were easily distinguished. There was a gradual transition from the urban to the suburban study sites with respect to the percentage impervious surface and vegetation cover. We decided to subjectively use 50% impervious surface (50% vegetation cover) as the distinguishing line between urban and suburban study sites. The rural study sites were the study sites with a vegetation cover of 96-100% and a impervious surface of 0-2%, the suburban study sites were represented by a vegetation cover of 50-66% and an impervious surface cover of 30-49%, the urban study sites were represented by sites with a vegetation cover of 5-46% and an impervious surface cover of 52-95%. See table 2.3 for the quantification of the urban-rural gradient according to percentage vegetation and impervious surfaces. Table 2.2 is a summary of all the study sites.

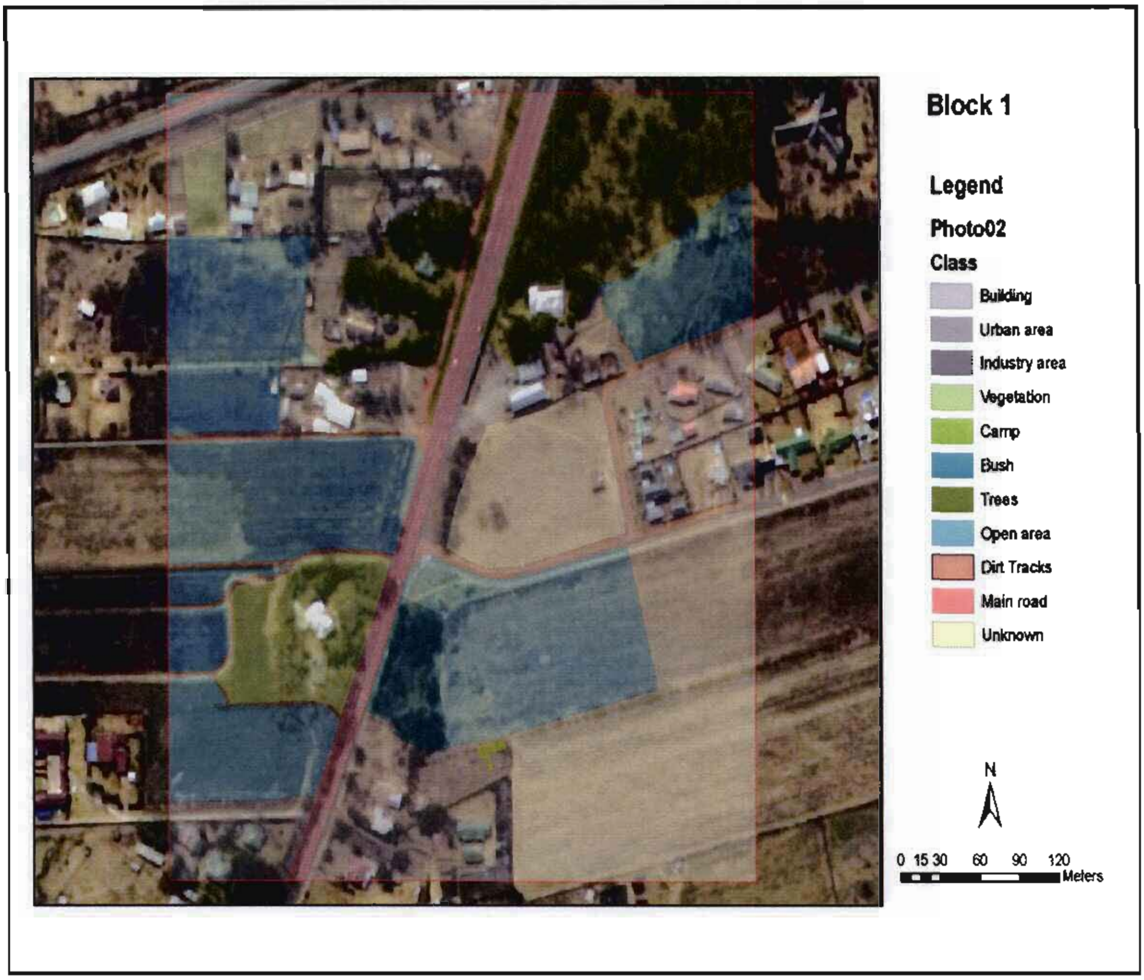

Figure 2.5 Example of how the urbanness of the different study sites was determined in Potchefstroom, by using one of the suburban study sites, Mooivallei Park. Mooivallei Park was classified as a suburban study site with 30% impervious surface, 66% vegetation cover and 4% soil.

Table 2.1 Classification of Impervious surfaces, Vegetation and Soil that were used to quantify the urbanization gradient in Potchefstoom.

Impervious surface	Vegetation	Soil
Buildings	Bush	Dirt tracks
Canal	Camp area	
Cemetery	Cricket area	
Clubhouse	Cultivated land	
Court	Open area	
Industry area	Park	
Main roads	Recreation	
Parking	Sport area	
Pool	Trees	
Railway	Vegetation	
Secondary roads		
Tennis court		
Train road		
Urban		
Water tank		

Table 2.2 Quantification of the urbanization gradient using % impervious surface (%I) and % vegetation (%V) using the V-I-S model (Ridd, 1995) of the study sites in Potchefstroom.

	VIS-MODEL %		
Study sites	**% I**	**% V**	**% S**
uC	95%	5%	0%
uO	67%	32%	1%
uG	65%	33%	2%
uH	63%	37%	0%
uW	61%	36%	3%
uV	58%	40%	2%
uS	52%	46%	2%
sM	49%	50%	1%
sG	49%	50%	1%
sK	48%	48%	4%
sV	46%	52%	2%
sC	42%	57%	1%
sT	36%	61%	3%
sP	30%	66%	4%
rD	2%	96%	2%
rA	0%	100%	0%
rO	0%	100%	0%
rP	0%	100%	0%
rV	0%	100%	0%
rF	0%	100%	0%

Table 2.3 Summary of the study sites in the Potchefstroom Municipal Area.

Study site (Keywords are underlined)	Study site nr.	Position along urbanization gradient	GPS co-ordinates	Type of disturbance	Other Information
Church garden in a residential area	uC	Urban	26° 43, 948' S 27° 05,743' O	Trees and lawn were used for parking area. Soil is compacted; the lawn receives a lot of water through irrigation.	Situated in a residential area.
Garden inside a residential area Opkoms	uO	Urban	26° 43, 084' S 27° 05, 276' O	Trees and lawn are used for parking area. Soil is compacted with sparse vegetation under trees.	Situated in a residential area.
Potchefstroom Gimnasium High School garden	uG	Urban	26° 39, 280' S 27° 06, 207' O	Walkway for scholars. Soil is compacted with sparse vegetation under the trees.	Trees are on school ground between class rooms.
Volkskool High School sports fields	uH	Urban	26° 43, 495' S 27° 05, 023' O	Root damage caused by lawn mowers.	Situated on school grounds next to a tennis court
Urban open Space, Wasgoedspruit	uW	Urban	26° 35, 275' S 27° 06, 813' O	Lawn mowed often.	Trees form part of a municipally managed open area
Trees along Viljoen Street	uV	Urban	26° 44, 453' S 27° 05, 145' O	Trampling occurs	On periphery of city, situated on agricultural land.
Study site on open space in Station Road	uS	Urban	26° 42, 33' S 27° 05, 51' O		Zone between residential area and industrial area

Study site (Keywords are underlined)	Study site nr.	Position along urbanization gradient	GPS co-ordinates	Type of disturbance	Other Information
Study site in Municipal garden along Meadow Street	sM	Suburban	26° 43, 396' S 27° 06, 159' O	Lawn is mowed often.	Municipally managed garden next to road.
Residential garden in Grimbeek Park	sG	Suburban	26° 43, 426' S 27° 06, 920' O	Lawn is mowed often and receives a lot of water through irrigation.	In residential area on periphery of city.
Industrial study site in Kynoch	sK	Suburban	26° 42, 829' S 27° 04, 170' O	Site is used as a picnic spot. Trampling and soil compaction.	Situated in industrial area.
Open space in Van der Hoff Park	sV	Suburban	26° 41, 949'S; 27° 06, 995'O	Trees are part of a field being used for horse grazing. Soil is compacted with sparse or no vegetation. Trampling	In a residential area
Suburban study site in a Historical Cemetery	sC	Suburban	26° 42,834' S; 27° 05, 260'O	Stripping of branches, homeless people sleep under the trees.	Zone between CBD and industrial area
Technical High School garden	sT	Suburban	26° 42, 354' S 27° 07, 305' O	Trees are next to N12 to Johannes burg and exposed to air pollution.	Situated on school grounds on periphery of city
Open Space, Mooivallei Park	sP	Suburban	26° 40, 838' S 27° 06, 172' O	Lawn is mowed often.	Municipally managed open area on periphery of city.
Dassierand	rD	Rural	26° 41, 898' S	This site is an illegal	On periphery of

Study site (Keywords are underlined)	**Study site nr.**	**Position along urbanization gradient**	**GPS co-ordinates**	**Type of disturbance**	**Other Information**
			27° 03, 147' O	dumping ground for garden waste	city
Agricultural Research Council	**rA**	Rural	26° 44, 559' S 27° 03, 238' O	Grazing, trampling, soil compaction under trees. Sparse vegetation/ bare soil under trees.	On periphery of city
Oudedorp Farms	**rO**	Rural	26° 42, 072' S 27° 05, 547' O	Dust from dirt road.	In rural area next to dirt road.
Pienaarskamp Farm	**rP**	Rural	26° 41, 263' S 27° 05, 852' O	Grazing, soil compaction, trampling, sparse vegetation under trees	Grazing field
Vyfhoek Farm	**rV**	Rural	26° 40, 889' S 27° 08, 981' O	Trees are exposed to air pollution.	Close to the N12 road to Johannesburg.
Farm on the way to Viljoenskroon	**rF**	Rural	26° 46, 30' S 27° 06, 12' O	Soil compaction, trampling	Grazing field

2.4 Description of *Acacia karroo* Hayne

Acacia karroo was chosen as the focal point of this study because of its distribution over the entire Potchefstroom, including the rural areas around Potchefstroom. *Acacia karroo* shows a wide habitat tolerance and thus a wide distribution range. *Acacia karroo* grows on most soil types, but is often found on soils with a relatively high fertility such as clay and loam soils. Of all the South African *Acacia* species it is the most tolerant to cold (Smit, 1999:65).

2.4.1 General description of *Acacia karroo*

Acacia karroo is a medium-sized tree of 5-12m in height, but can reach heights of 25m. It is usually a single stemmed tree but can also be a multi-stemmed shrub of 2m. The crown is somewhat rounded or flattened; the foliage is dark green and can be fairly dense. The bark on the main stem of mature trees is coarse, longitudinally fissured and can be reddish-brown to dark-brown or black. Young shoots are smooth and usually hairless. They are green to reddish-brown and covered with small inconspicuous reddish sessile glands as well as numerous light-coloured lenticels. Older shoots are covered with a thin layer of light-coloured bark, which splits longitudinally to reveal a smooth green under-surface (Barnes et. al., 1996:3; Smit, 1999:65).

The stipules are modified into hardened spines. They are straight and occur in pairs at nodes. The spines are greyish-white, hairless with reddened or darkened tips. The spines can be 40mm to 250mm in length. The leaves are bipinnately compound and typically glabrous with pinna pairs that vary between 2-6 and pinnule pairs that vary from 8-16 per pinna. The pinnules are green in colour and are the same colour above and below with a main vein that is clearly visible on the underside but indistinct above. The petiole has a slight swelling at the base and both the petiole and the rachis are hairless (Barnes *et al.*, 1996:3; Smit, 1999:65).

Globose flowering heads are borne on the new season's shoots, commencing some distance down from the tips and extending up to the tips to form a panicle, which is usually leafless. The flowers are bright yellow and scented. Pods occur in clusters along the old panicle positions, sometimes in such profusion that they form a tangled mass. They are sickle-shaped and linear. The younger pods are green and hairless while the dried pods are dark brown in colour and with thin brittle waves. The seeds are olive green to light brown in colour and are compressed with an elliptic outline (Barnes *et al.*, 1996:3; Smit, 1999).

2.4.2 Habitat description of *Acacia karroo*

According to Barnes *et al.* (1996:16) and Smit (1999:64), *Acacia karroo* is one of the most widespread trees in southern Africa and has a wide habitat tolerance. *Acacia karroo* occurs naturally over an extraordinary range of climates (12°C - 40°C) with rainfall distribution ranging from summer maximum, through evenly distributed, to winter maximum. The mean annual rainfall can vary from 200 to over 1500mm. The species will survive all, but the most severe frost (-12°C).

Acacia karroo grows on most soil types, but over much of its inland range it tends to be restricted to the heavier soils and it is one of the few species that grow on the heavy, black, hydromorphic, cracking vertisols with high pH. It will also thrive on deep alluvial clay-loam soils in river valleys, on shales and even on acid soils. At the other extreme, it thrives on unconsolidated bare drift sands of the coastal dunes and is tolerant of extremely saline conditions. Tolerance of this wide range of edaphic conditions may be in part due to the extremely dense and robust rooting habit (Barnes *et al.*, 1996:16; Smit, 1999:64).

Acacia karroo is present in all seven the Biomes of South Africa and is listed as a typical constituent in five of the seven main veld types of South Africa, particularly in the savanna, karoo and coastal dune forest. It occupies a successional position between the tropical forest and the bushveld but it grows in riverine communities and even in very arid environments, provided there is an assured supply of underground water. Large specimens of *Acacia karroo* are reputed to be indicators of underground water (Barnes *et al.*, 1996:17).

According to Barnes *et al.* (1996:17), *Acacia karroo* is an adaptable species that is expanding its range, particularly under disturbed ecological conditions, which resulted from human activities. These expansions are usually associated with poor veld grazing management practices and could be due to climatic deterioration.

Acacia karroo is a pioneer plant with a maximum life span of about 40 years. It is well adapted to establishing itself with no shade, shelter or protection from grass fires. Despite it being a pioneer, some environmental conditions allow *Acacia karroo* stands to regenerate themselves. These may be natural (soil or climatic conditions), or they may be the result of human interference (over-grazing or forest clearance). Under these circumstances, there is often the development of an understory of perennial, palatable and nutritious grasses, which thrive on the environmental benefits that stem from the species' ability to use water and nutrients from deep down and to fix nitrogen. Shading by the *Acacia karroo* canopy may also reduce soil surface temperature and evaporation, making conditions more suitable for drought susceptible grasses (Barnes et. al., 1996:23).

2.5 Chlorophyll *a* fluorescence

2.5.1 Photosynthetic vitality of trees

For this study, chlorophyll *a* fluorescence was used as a tool for determining the photosynthetic vitality of trees (Force *et al.*, 2003:17). The kinetics of the polyphasic chlorophyll fluorescence transient OJIP (Strasser & Govindjee, 1992:423) are indicative of the overall performance and functioning of the photosynthetic apparatus, especially photosystem II (PSII) This has become one of the most powerful and widely used techniques available to ecophysiologists (Maxwell & Johnson, 2000:659; Richardson *et al.*, 2004:52).

2.5.2 Theoretical principles

Light energy utilized in photosynthesis is absorbed by a number of photosynthetic pigments, with absorption spectra covering a large range of available light energy. The most prominent pigments that absorb this energy are chlorophylls *a* and *b*. The light energy absorbed by the chloroplast first excites pigment molecules of the light harvesting complex (LHC). The LHC-proteins transfer their energy to either Photosystem I (PSI) or Photosystem II (PSII). These photosystems contain the reaction centre (RC) pigments for the conversion of absorbed light energy to oxidation and reduction potential to drive electron transport. Light energy absorbed by the LHC is transferred to the reaction centres and can be lost in several different ways: it can be used to drive photosynthesis (photochemistry), excess energy can be dissipated as heat or it can be re-emitted from the first excited state as light – chlorophyll fluorescence (Maxwell & Johnson, 2000:659). These three processes are in competition with each other, thus the increase in the efficiency of the one will result in a decrease in the yield of the other two. By measuring chlorophyll *a* fluorescence, information about changes in the efficiency of photochemistry and heat dissipation can be gained (Maxwell & Johnson, 2000:659; Percival & Sherffs, 2002:215).

Kautsky and co-workers first observed the changes in the yield of chlorophyll *a* fluorescence in 1931 (Kautsky and Hirsch, 1931; reviewed by Lazár, 2006:9). They found that when photosynthetic material is transferred from the dark into the light, an increase in the yield of chlorophyll *a* fluorescence occurs over a time period of 1 s. These characteristic changes in Chl *a* fluorescence intensity is known as the Kautsky effect (Kautsky and Hirsch, 1931:964). This rise has been explained as a consequence of a reduction of electron acceptors in the photosynthetic pathway, downstream of PSII, notably plastoquinone, and in particular, Q_A. Once PSII absorbs light and Q_A has accepted an electron, it is not able to accept another until it has passed the first on to a subsequent electron carrier (Q_B). During this period, the reaction centre is closed. If, at any point in time, a percentage of the reaction centres are closed, it leads to an overall reduction in the efficiency of photochemistry and so to a corresponding increase in the yield of chlorophyll *a* fluorescence (Maxwell & Johnson, 2000:664).

Recording the fast chlorophyll *a* fluorescence rise with a high time resolution instrument permits a precise detection of F_0, the fluorescence value at the onset of illumination when all RCs are open. The fast rise in the chlorophyll *a* fluorescence transient can clearly be seen when the fluorescence values are plotted on a logarithmic time scale. The fluorescence values from F_0 (O) to the maximal F_M (P) show a typical polyphasic rise with two intermediate steps, denoted as J and I (Strasser & Govindjee, 1992:423), hence the notation O-J-I-P. The shape of the O-J-I-P chlorophyll *a* fluorescence transient has been found to be very sensitive to stress caused by environmental conditions (Krüger *et al.*, 1997:265) and thus forms an excellent tool to determine the photosynthetic vitality of trees (Tsimilli-Michael & Strasser, 2001:229; Hermans *et al.*, 2003:82).

2.5.3 The JIP-test:

A test has been developed which can be used as a tool for rapid screening of many samples, providing adequate information about the structure, conformation and function of their photosynthetic apparatus (Strasser & Strasser, 1995:977; Strasser *et al.*, 2000:445). The JIP-test, a procedure for the quantification of O-J-I-P transients, represents a translation of stress induced alteration in the O-J-I-P chlorophyll *a* fluorescence transients to changes in biophysical parameters quantifying the energy flow through PSII. By employing the JIP test, several biophysical parameters, in addition to the F_V/F_M ratio, which quantifies PSII-function, are obtained. One of these parameters, the performance index (PI_{ABS}), combines the three main functional steps (light energy absorption, excitation energy trapping, and conversion of excitation energy to electron transport) of photosynthetic activity by a PSII-reaction centre complex into a single multiparametric expression. A typical polyphasic chlorophyll *a* fluorescence transient O-J-I-P, plotted on a logarithmic time scale (so that the intermediate steps are clearly revealed) is shown in Figure 2.6.

For the quantification of the fluorescence transient, i.e. for the calculation of the energy fluxes, quantum efficiencies, density of reaction centres and vitality indices, the following original data are utilised:

- The maximal measured fluorescence intensity, F_P, equal here to F_M since the excitation intensity is high enough to ensure the closure of all RC's of PS II.
- The fluorescence intensity at 50 μs, considered to be the intensity F_0 when all RC's are open.
- The fluorescence intensity at 150 μs ($F_{150\mu s}$) and 300 μs ($F_{300\mu s}$)

- The fluorescence intensities at 2 ms (J step) denoted as F_J, and at 30 ms (I step) denoted as F_I.

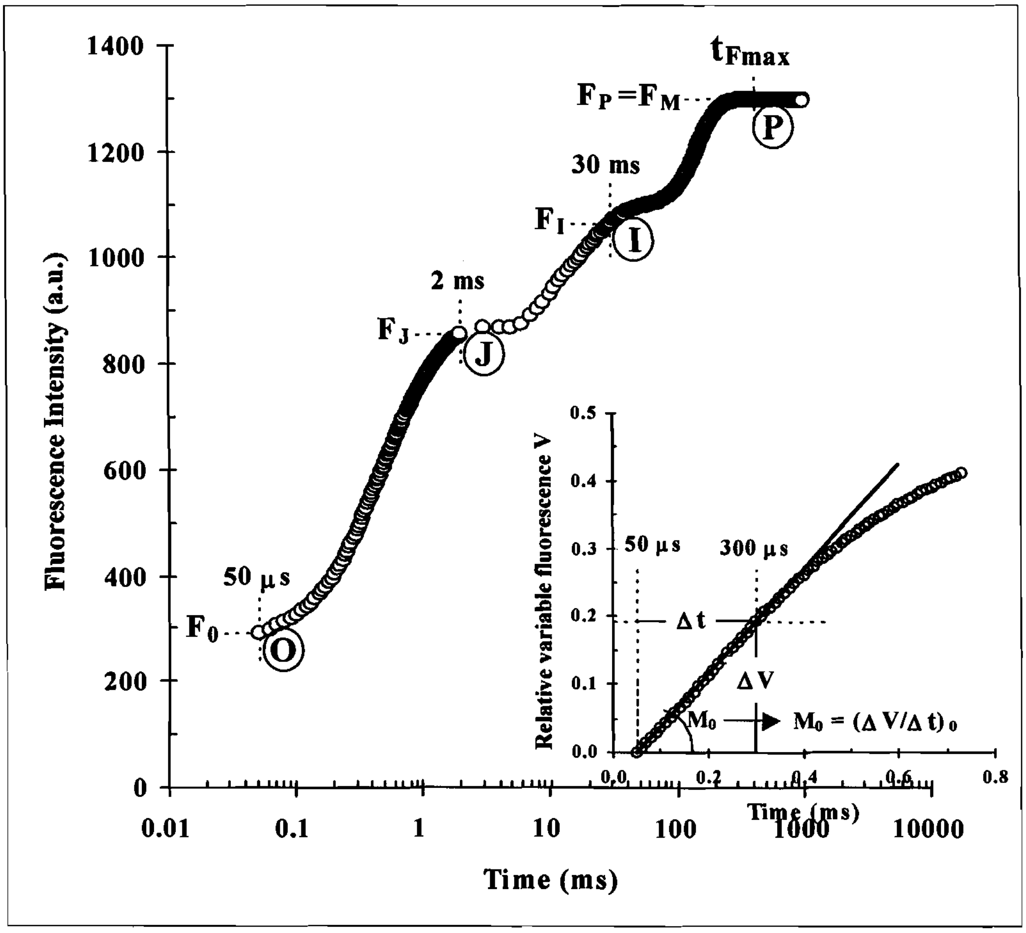

Figure 2.6 Typical chlorophyll *a* polyphasic fluorescence rise O-J-I-P, exhibited by higher plants, plotted on a logarithmic time scale from 50 µs to 1 s. The labels refer to the selected fluorescence data used by the JIP-test for calculation of structural and functional parameters. The labels are: the fluorescence intensity F_0 (at 50 µs); the fluorescence intensities F_J (at 2 ms) and F_I (at 30 ms); the maximal fluorescence intensity, $F_P = F_M$ (at t_{Fmax}). The insert presents the transient expressed as the relative variable fluorescence $V = (F - F_0)/(F_M - F_0)$ vs. time, from 50 µs to 1 ms on a linear time scale, demonstrating how the initial slope, also used by the JIP-test, is calculated (from Strasser & Tsimilli-Michael, 2001:3321).

The JIP–test represents a translation of the original data, through the formulae shown in Table 2.4, to the following biophysical parameters, which quantify PS II behaviour:

(a) The specific energy fluxes (per reaction centre) for absorption (ABS/RC), trapping (TR_0/RC), dissipation (DI_0/RC), electron transport (ET_0/RC);

(b) The flux ratios or yields, i.e. the maximum quantum yield of primary photochemistry ($\varphi_{P0} = TR_0/ABS$), the efficiency ($\psi_0 = ET_0/TR_0$) with which a trapped exciton can move an electron into the electron transport chain further than Q_A^-, the quantum yield of electron transport ($\varphi_{E0} = ET_0/ABS = \varphi_{P0} * \psi_0$);

(c) The phenomenological energy fluxes (per excited cross section, CS) for absorption (ABS/CS), trapping (TR_0/CS), dissipation (DI_0/CS) and electron transport (ET_0/CS).

The fraction of active PS II-reaction centres per excited cross section (RC/CS) is also calculated. See Table 2.4 for the set of formulae used in the JIP-test (Strasser & Tsimilli-Michael, 2001:3321).

Based on the Theory of Energy Fluxes in Biomembranes, (Strasser, 1978:513), formulae for the specific energy fluxes (per excited cross section CS, i.e. per active measured leaf area), as well as for the flux ratios or yields, have been derived using the experimental values provided by the JIP-test (Strasser & Tsimilli-Michael, 2000:445) ABS refers to the photons absorbed by the antenna pigments Chl*. Part of this excitation energy is dissipated mainly as heat and less as fluorescence emission (F), while another part is channelled as trapping flux (TR) to the reaction centre RC. There the excitation energy is converted to redox energy by reducing the electron acceptor Q_A to Q_A^-, which is then reoxidised to Q_A, thus creating electron transport (ET), which ultimately leads to CO_2 fixation.

Table 2.4 Summary of the JIP-test formulae, using data extracted from the fast phase fluorescence transient (Strasser *et al.*, 2000).

	Extracted and technical fluorescence parameters	
F_o	=	$F_{50\mu s}$, fluorescence intensity at 50μs
F_{150}	=	fluorescence intensity at 150μs
F_{300}	=	fluorescence intensity at 300μs
F_J	=	fluorescence intensity at the J-step (at 2 ms)
F_M	=	Maximal fluorescence intensity
tr_{max}	=	Time to reach F_M, ms
V_J	=	$(F_{2mx} - F_o) / (F_M - F_o)$
Area	=	Area between fluorescence curve and F_M
$(dV/dt)_o$ or M_o	=	$4. (F_{300} - F_o) / (F_M - F_o)$
S_m	=	Area / $(F_M - F_o)$
B_{ov}	=	$1- (S_m / tr_{max})$
N	=	$S_m . M_o . (1/ V_J)$ turnover number of Q_A
	Quantum efficiencies or flux ratios	
φ_{Po} or TR_0/ABS	=	$1 - (F_M - F_o)$ or F_V/F_M
φ_{Eo} or ET_0/ABS	=	$[1 - (F_M - F_o)] . \Psi_o$
Ψ_o or ET_0/TR_0	=	$1 - V_J$
	Specific fluxes or specific activities	
ABS/RC	=	$M_o . (1/ V_J) . (1/ \varphi_{Po})$
TR_0/RC	=	$M_o . (1/ V_J)$
ET_0/RC	=	$M_o . (1/ V_J) . \Psi_o$
DI_o/RC	=	$(ABS/RC) - (TR_0/RS_o)$
	Phenomenological fluxes or phenomenological activities	
ABS/ CS_o	=	F_o or another useful expression*
TR_0/CS_o	=	$\varphi_{Po} . (ABS/ CS_o)$
ET_0/CS_o	=	$\varphi_{Po} . \Psi_o (ABS/ CS_o)$
DI_o/CS_o	=	$(ABS/RC) - (TR_0/RS_o)$
	Density of reaction centers	
RC/ CS_o	=	$\varphi_{Po} . (V_J/ M_o) . F_o$*
	Performance Index	
PI_{ABS}	=	$(RC/ABS) . [\varphi_{Po}/ (1- \varphi_{Po})] . [\Psi_o/ (1- \Psi_o)]$

* When expressed per CS_M, F_0 is replaced by F_M

The maximum quantum yield of primary photochemistry $TR_0/ABS \equiv \varphi_{P0}$, the efficiency by which a trapped excision can move an electron into the electron transport chain $ET_0/TR_0 \equiv \psi_0$, or the probability that an absorbed photon will move an electron into the electron transport chain $ET_0/ABS \equiv \varphi_{E0}$, are directly related to the three fluxes, as the ratios of any two of them. TR/RC expresses the rate by which an exciton is trapped by the RC, resulting in the reduction of Q_A to Q_A^-. The maximal value of this rate is given by TR_0/RC, because at time zero, all RC's are open. The link of TR_0/RC with the experimental data is derived as follows: If the reoxidation of Q_A^- would be blocked, as happens in DCMU-treated samples, TR_0/RC would be given by the normalisation of the initial slope of the fluorescence induction curve (between 50 and 300 µs or 50 and 150 µs) on the maximal variable fluorescence, $F_V = F_M - F_0$. This normalised value is denoted as M_0, DCMU (3-(3,4-dichlorophenyl)-1,1-dimethylurea). However, if the reoxidation of Q_A^- is not blocked, the normalised value of the initial slope, M_0, indicates the net rate of closure of the RC's, where trapping increases the number of closed centres and electron transport decreases it: $M_0 = TR_0/RC - ET_0/RC$.

The JIP-test reveals changes in the behaviour of PS II that cannot be detected by the commonly used $\varphi_{P0} = F_V/F_M$, which is the least sensitive of all parameters. The performance index (PI_{ABS}, see below), however is a multi-parametric expression taking into account the independent parameters of Absorption (RC/ABS), Quantum efficiency of trapping ($\varphi_{P0}/1-\varphi_{P0}$), and Quantum efficiency of electron transport ($\psi_0/1-\psi_0$).

The initial stage of photosynthetic activity of RC-complex is regulated by three functional steps, namely absorption events of light energy (ABS), trapping of excitation energy (TR) and conversion of excitation energy to electron transport (ET). Recently, a multi-parametric expression of these independent steps contributing to photosynthesis, the performance index (PI_{ABS}), was introduced (Tsimilli-Michael & Strasser, 2001:229):

$$PI_{ABS} = \frac{\gamma}{1-\gamma} \bullet \frac{\varphi_{Po}}{1-\varphi_{Po}} \bullet \frac{\psi_o}{1-\psi_o}$$

where γ is the fraction of reaction centre chlorophyll (Chl_{RC}) per total chlorophyll ($Chl_{RC+Antenna}$). Therefore $\gamma/(1-\gamma) = Chl_{RC}/Chl_{Antenna}$ = RC/ABS. This expression can be deconvoluted into two JIP-test parameters and estimated from the original fluorescence signals as RC/ABS = $RC/TR_0 \bullet TR_0/ABS = [(F_{2ms} - F_{50\mu s})/4(F_{300\mu s} - F_{50\mu s})] \bullet F_V/F_M$. The factor 4 is used to express the initial fluorescence rise per 1 ms. The expression RC/ABS shows the contribution to the PI_{ABS} due to the RC density on a chlorophyll basis. The contribution of the light reactions for primary photochemistry are estimated according to the JIP-test as $(\varphi_{Po}/(1-\varphi_{Po})) = TR_0/DI_0 = k_P/k_N = F_V/F_M$. The contribution of the dark reactions are derived as $(\psi_0/1-\psi_0)) = ET_0/(TR_0 - ET_0) = (F_M-F_{2ms})/(F_{2ms} - F_{50\mu s})$.

In this study, the PI_{ABS} was used as a sensitive indicator of tree vitality.

2.5.4 Measurement of chlorophyll fluorescence in *Acacia karroo*

Measurements were performed with a fluorimeter (Plant Efficiency Analyser, Hansatech Instruments Ltd., U.K.). Samples were collected predawn and therefore it was easier to cut a twig and measure it later, than to take measurements while the twig is still attached to the tree. The samples were closed in brown paper bags and then stored in a dark cupboard. A sample consisted of an *Acacia karroo* twig with leaves. Four samples were collected per tree. Chlorophyll *a* fluorescence measurements were conducted at approximately 09h00 in the morning. All measurements were conducted on dark-adapted leaves (pinnules). For each session, the chlorophyll *a* fluorescence transients were measured by recording five measurements per sample. Thus 20 measurements were recorded for each tree. There were 20 sites and twigs were collected from four trees at each site. Measurements were conducted once a month over a three-month period (February-March 2005). The samples for the chlorophyll *a* fluorescence were collected at the same time the water potential was measured (pre-dawn). The chlorophyll *a* fluorescence measurements of the 20 study sites could thus not be measured on the same day because it was collected pre-dawn and there was not enough time to collect all the samples and do all the water potential measurements of all 20 study sites in one evening before sunrise.

2.6 Leaf water potential

For this study, we used Scholander pressure chamber to measure the pre-dawn water potential (Ψ_{PD}) of the trees. The pressure chamber method is simple and quick and the most suited for field studies of plant water relations (Hall *et al.*, 1993:121, Taiz & Zeiger 2002).

2.6.1 Theoretical principle

Water potential (Ψ) can be defined as the potential energy (joules) per unit mass of water (m^3) with reference to pure water at zero potential (Hall *et al.*, 1993:121), or it can be defined as the chemical potential of water in a system (Hopkins, 1999:31). Thus water potential can be seen as the chemical potential or the amount of energy contributed by one mole of water in a system at constant temperature and pressure (Hall *et al.*, 1993:121).

The water potential of a plant consists of three components: a) solute potential or osmotic potential (Ψ_π), b) pressure potential or hydrostatic pressure (Ψ_p) and c) matric potential (Ψ_m).

$$\Psi = \Psi_\pi + \Psi_p + \Psi_m$$

Osmotic potential is the effect of dissolved solutes on water potential. If solutes are added to water, the free energy of the water is reduced and thereby the water potential is also reduced. Osmotic potential is always negative because the osmotic potential of pure water is zero and by adding solutes the osmotic potential decreases below that of pure water (Moore et. al., 1998:78; Salisbury & Ross, 1992:45; Taiz & Zeiger, 2002). Pressure potential may be negative or positive. Negative pressure is tension that develops within the xylem or between adjacent cells and thus reduces the water potential. Positive pressure refers to the turgor pressure in cells and this pressure increases the water potential of the cells (Moore et. al., 1998, Taiz & Zeiger, 2002).

The matric potential results from the adhesion of water to wettable surfaces such as cell walls and the cytoplasmic matrix and is the force required to remove water from these surfaces. The adhesion decreases the potential energy of the interacting molecules and the matric potential value is thus always negative (Moore et. al., 1998:78).

The Scholander pressure chamber is an instrument used to estimate the water potential of plant tissue by measuring the negative hydrostatic pressure (tension) that exists in the xylem of plants. The water potential of the xylem is assumed to be fairly close to the average water potential of the whole plant - an assumption that is probably valid, because 1) in many cases the osmotic potential of the xylem solution is negligible (close to zero), so the major component of the water potential in the xylem is the (negative) hydrostatic pressure in the xylem column, and 2) the xylem is in intimate contact with most cells in the plant. (Taiz & Zeiger, 2002)

The tension in the xylem vessels is directly measured as follows: the organ to be measured is excised from the plant and is partly sealed in a pressure chamber. Before excision, the water column in the xylem is under some tension and when the water column is broken by excision of the organ, the water is pulled into the xylem capillaries. To make a measurement, the chamber is pressurized with compressed nitrogen gas until the water in the xylem is brought back to the cut surface. The pressure needed to bring the water to the surface is called the balance pressure and is readily detected by the change in the appearance of the cut surface, which becomes wet and shiny when this pressure is attained (Figure 2.7). The balance pressure is equal in magnitude to the negative pressure that existed in the xylem before the plant material was excised (Taiz & Zeiger, 2002; Hopkins & Hüner, 2004:543).

2.6.2 Measurement of water potential in *Acacia karroo*

Measurements were conducted pre-dawn (between 02:00 and 06:00 in the morning) when the water potential of the trees has reached a steady state. The steady state of water potential is a period where the transpiration factors have a minimum effect on the water potential of the tree. Pre-dawn water potential was measured in four trees at each site. For each tree one twig was collected and measured immediately. Measurements were conducted once a month over a three-month period (February-March 2005). The water potential measurements of the 20 study sites could not be measured on the same day because it was done pre-dawn and there was not enough time to do all the water potential measurements of all 20 study sites in one evening before sunrise.

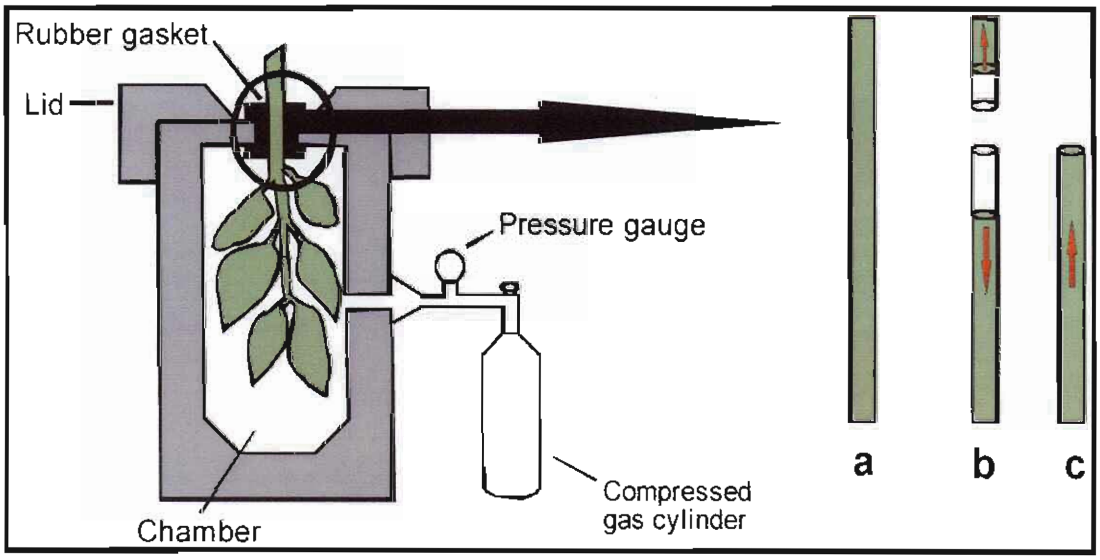

Figure 2.7 The pressure chamber method for measuring xylem tension. The diagram on the left shows a shoot sealed into a chamber. The diagrams on the right show the state of the water columns within the xylem at three points in time: a) the uncut xylem is under negative pressure. b) Cutting the shoot causes the water to pull back into the tissue in response to the tension in the xylem. c) The chamber is pressurized, and the xylem sap comes back to the cut surface (Adapted from Taiz & Zeiger, 2002).

2.7 Tree appraisal

2.7.1 General information on tree appraisal

In the fast growing urban environment, land-use areas such as residential areas, shopping malls, parking areas, industries and other types of impervious surfaces are replacing trees. Trees are beneficial for the health and well-being of the urban dwellers as clearly indicated in the Introduction of this dissertation. The removal or presence of trees in urban environments has increasingly become the cause of disputes, also in South Africa (Marx, 2005). The monetary value of trees could be determined and this understanding of the value of an urban forest could give municipalities a basis for managing urban forests and can be used for insurance compensation and litigation (Nowak, 1993:173; Marx, 2005).

Two types of formulas are used for tree appraisal methods. The first establishes an initial value based primarily on size, and then adjusts this value for condition, location, species quality and special situation factors. The second formula uses a point rating system for the factors mentioned above and a monetary factor is introduced at the end (Watson, 2002:11). There are several different tree appraisal methods. Most countries develop their own tree appraisal method that best suites each country, for example: Council of Tree and Landscape Appraisers (CTLA, United States), Standard Tree Evaluation Method (STEM, New Zealand), Helliwell method – (Amenity Valuation of Trees and Woodlands, Great Britain) and Revised Burnley Method – Australia (Watson, 2002:11).

Each of the different appraisal methods has a different approach to tree appraisal. Only two of these examples will be briefly discussed. The Guide for Plant Appraisal, 9th edition (CTLA) is based on a measurement of the cross-sectional area of the tree trunk at a height of 1.4 m, multiplied by a monetary value per square inch. The maximum value is then reduced by factors for species quality, condition and location in the landscape. The value per square inch is based on the cost of the largest commonly available trees at regional nurseries (Mooter *et al.*, 2000; Watson, 2002:11). The second example is the Amenity Valuation of Trees and Woodlands (Great Britain). This method focuses on visual amenity and rates seven factors at 1 to 4 points each. The factor points are multiplied together and then by an assigned monetary value per point.

Not only can we determine the monetary value of individual trees in an urban environment, but we can also determine the value of the urban ecosystem services (Costanza, 1997:253; Bolund & Hunhammar, 1999:293; Roberts *et al.*, 2005). According to Bolund & Hunhammar (1999:293), people are not just dependent on the urban ecosystems but also benefit from the urban ecosystems which include street trees, lawns, parks, urban forests, cultivated land, wetlands, lakes, the sea and streams. Bolund & Hunhammar (1999: 295) and Costanza *et al.* (1997:253) referred to these urban ecosystem benefits as the urban ecosystem services. According to Costanza *et al.* (1997:253), the ecosystem benefits can be divided into ecosystem goods (such as food) and ecosystem services (such as waste assimilation), but both are referred to as ecosystem services. According to the study done by Costanza *et al.* (1997:253), the ecosystem services can be divided into 17 major groups (see Table 2.5). The MA (Millennium Ecosystem Assessment, 2003:5), however, divides the ecosystem services into four major groups, namely supporting services, provisioning services, regulation services and cultural services and also focuses on the importance of these services to aspects of human well-being such as security, basic material for a good life, health and good social relations (see Figure 2.7).

The valuation of the urban ecosystem services are, however, very complex and there are several different ways in which the value of the services are determined. According to Farber *et al.* (2002:388), there are two basic methods for determining the ecosystem services based on social values: 1) What a society will be willing and able to pay for services (WTP) or 2) what it would be willing to accept to forego the services (WTA). Farber *et al.* (2002:389) also distinguished six major ecosystem service economic valuation techniques when market valuations do not adequately capture social values: 1) Avoided Cost (AC), services allow society to avoid costs that would have incurred in the absence of those services, 2) Replacement Costs (RC), services could be replaced with man-made systems, 3) Factor Income (FI), services provide for the enhancement of incomes, 4) Travel Costs (TC), service demand may require travel, 5) Hedonic Pricing (HP), service demand may be reflected in the prices people will pay for associated goods and 6) Contingent Valuation (CV), service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives.

Another method that could be used is the five valuation approaches by Wolf (2004), of which some correspond with the approaches used by Farber *et al.* (2002:389). Wolf (2004) described five valuation approaches that are used for economically valuing urban nature, associated issues of social perception and public values of urban green spaces: 1) Direct use values, which measures the value by tallying all the expenses incurred by parks system visitors and users, 2) Environmental benefits and costs, where the benefits and the costs of the ecosystems are determined, 3) Hedonic pricing, which acknowledges that both property values and people's spending behaviours can be affected by the presence of parks and green spaces, 4) Human health, which determines the medical costs an individual will save when using ecosystem services and 5) Mental health, which determines the psychosocial benefits of urban ecosystems.

Roberts *et al.* (2005) used a system that was developed by Constanza *et al.* (1997:256), which quantifies the financial value of goods and services provided by the world's ecosystems to determine the value of ecosystem services in Durban, South Africa. Roberts *et al.* (2005) estimated that the replacement value of the environmental services delivered by open spaces in Durban is approximately R3.1 billion per annum.

For the current study, we used a tree appraisal method that is based on the CTLA method and was adapted to suit the South African urban environments. This method, the South African Tree Appraisal Method (SATAM), was developed by Marx (2005) as a tool to determine the monetary value of trees in urban environments. SATAM is also an example of two of the five valuation approaches used by Wolf (2004). SATAM includes the a) Environmental benefits and costs valuation, where the benefits and costs of ecosystems are determined and b) Hedonic pricing, where both property values and people's spending behaviours can be affected by the presence of parks and green spaces.

Table 2.5 Ecosystem services, functions and examples (adapted from Costanza *et al.*, 1997).

Ecosystem service	Ecosystem functions	Examples
Gas regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance
Climate regulation	Regulation of global temperature, precipitation and other biologically mediated climatic processes	Greenhouse gas regulation
Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Flood control
Water regulation	Regulation of hydrological flows	Provisioning water for agricultural or industrial processes or transportation
Water supply	Storage and retention of water	Provisioning of water by water sheds
Erosion control and sediment retention	Retention of soil within an ecosystem	Prevention of loss of soil by wind
Soil formation	Soil formation processes	Weathering of rock and organic material
Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients	Nitrogen fixation
Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess nutrients and compounds	Waste treatment
Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations
Biological control	Trophic-dynamic regulations of populations	Keystone predator control of prey species
Refuge	Habitat for resident and transient populations	Nurseries
Food production	That portion of gross primary production extractable as food	Production of game
Raw materials	The portion of gross primary production extractable as raw material	Production of lumber
Genetic resources	Sources of unique biological materials and products	Medicine
Recreation	Providing opportunities for recreational activities	Eco-tourism
Cultural	Providing opportunities for non-commercial uses	Aesthetic

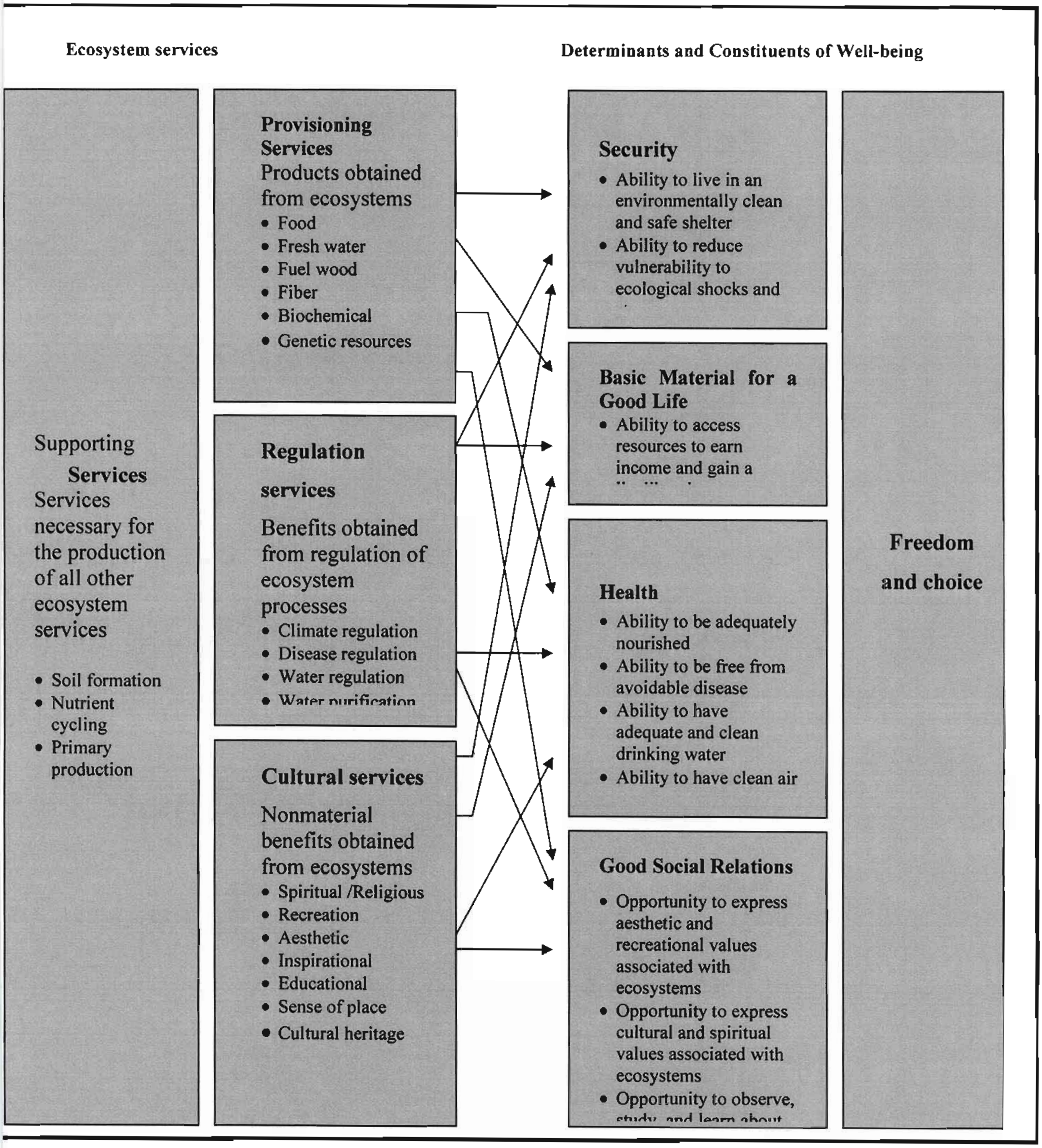

Figure 2.8 Ecosystem services (adapted from the Millennium Ecosystem Assessment, 2003)

2.7.2 SATAM

A tree-appraisal process is a systematic approach that includes an investigation of a tree, data collection about the tree and its environment, as well as the determination of why an appraisal is necessary to derive a reasonable conclusion and recommendation. To be valid and reliable, the appraisal should be an unbiased estimate of the nature, quality, and value of the tree in question (Marx, 2005).

SATAM is in the format of a dendogram with closed questions. The appraiser only needs to determine whether the answers are true (YES) or false (NO). This minimizes the personal judgement of the appraiser. To determine the degree of the defect of a tree, a question is repeated and elaborated and an option of 'not applicable' (N/A) is given (Marx, 2005). See Appendix A for the questionnaire used for the appraisal of *Acacia karroo.*

SATAM consists of six sections:

- General information
- Section A – Species, Origin appraised
- Section B – Whether the tree has any historical, cultural or genetic conservation value. This section is optional and will only be completed when the information is available.
- Section C – Condition appraisal, Environmental condition, and Amenity appraisal.
- Visual tree defect assessment. This section is optional and will only be completed when a tree may seem to be hazardous.
- Section E – Impairment factor

- **General information**

This section includes general information about the client, landowner, address and global position of the tree that is being appraised (Marx, 2005).

- **Section A – Species appraised**

This section refers to the genus and species name of the specific tree being appraised. In this section the trees are classified into six different categories based on their origin.

- Protected and Historical Monument
- Indigenous (Species that originated in South Africa, Namibia, Mozambique, Zimbabwe, and Angola)
- Exotic
- Invader Category 3
- Invader Category 2
- Invader Category 1 (Declared weeds)

- **Section B – Historical, cultural or genetic conservation value**

This section asks questions related to trees with cultural, historical, or genetic conservation values. The section is optional and will have no influence on the appraised value of trees.

- **Section C – Condition appraisal, Environmental condition, and Amenity appraisal**

a) Condition appraisal

The condition of a tree is determined by appraising its present structural integrity and state of health (Marx, 2005). The condition appraisal is divided into six categories:

- Size: The height, trunk diameter/ circumference and canopy size express the size of the tree and are measured for this section.
- General: The vigour, health and maintenance of the tree are discussed. Vigour refers to the health of the tree. If the tree has a history of failure it could be that a tree that shows loss in vigour could fail. Maintenance of the tree includes pruning, topping, bracing and cabling of the tree. Good maintenance includes cleaning out of trees by primarily removing broken/dead limbs and that preventive maintenance repair measures are still relevant and in good repair.

- Root system: The root system of a tree is crucial for the survival and the health of the tree and disturbance of the roots could lead to a loss in vigour (Marx 2005). Most of the tree's small absorption roots occur in the first 15 mm of growth medium around the tree and the larger roots extend to the edge of the tree crown/ drip line. This category includes questions about the root zone and root health of the trees. To determine the state of the root zone we should determine whether the root zone is compacted and if compacted, what percentage is compacted and whether there is enough space available for the roots to grow and expand. Root health includes questions about the visibility of root flairs and injury to the root flairs, as well as the presence of any pests/ pathogens. Another important aspect when it comes to roots is the presence of kinked/girdling roots – circling or bending of roots around each other.
- Trunk or stem: This category includes the description of the stem/trunk. The stem is the woody framework of the tree and includes the trunk that begins just above the root flairs up to the branches (Marx, 2005). This category describes the form of the trunk, for example does it taper, does the tree only have one trunk and whether the trunk developed a lean. It also describes the type of injury to the trunk and whether any pathogens are present.
- Scaffold branches: This category describes the condition of the scaffold branches (branches that support the smaller branches and twigs). The questions that are asked in this category determine whether the branches are properly attached and whether they can hold the rest of the tree's branches.
- Smaller branches and twigs: This category gives an overall description of the twigs. It describes the distribution, attachments and condition of the twigs, as well as the presence of pathogens.
- Leaves: Leaves are a good indicator of stress in trees and thus reflect the health condition of the tree. This category describes the health of the tree

by gaining information from the leaf condition for example whether the leaves are equally distributed and whether pathogens are present.

b) Environmental condition

Trees contribute to the comfort and the well being of humans in several different ways as was discussed in Chapter 1. Some of the major influences are: improvement of air quality (Beckett *et al.*, 1998:347; McPherson, 1998:215), reduce storm water runoff (Xiao *et al.*, 1998), energy conservation (Simpson, 2002:1067) and their influence on the microclimate of the surrounding environment (Simpson, 2002:1067). This category describes the contributions trees have to the environment and humans.

c) Amenity appraisal

This section describes the amenity value of trees in an urban environment. The trees in these urban environments create a beautiful view against the built environment. This section has more to do with the value or contribution the trees have to the overall landscape of the area in which they are situated.

- **Section D – Visual tree defect assessment**

This section is optional and only necessary to complete when a tree seems to be hazardous. A hazard appraisal of a tree is done to determine whether the tree, or a part thereof, will fail and what the damage of this failure will be. If a tree is hazardous, the appraiser can alert its owner to the possibility of failure and to what the damage could be.

- **Section E – Impairment factor**

This section is only included when the appraisal was a result of a complaint, either from the appraiser's client or from the owner or neighbour of the property on which the tree may be standing. This section will not influence the value of the tree at this stage.

The monetary value of the trees at each study site was determined by appraising al four the studied trees and then using the average appraisal of the four trees for the SATAM program from UNISA (Marx, 2006). The SATAM program was then used to calculate the monetary value of each study site based on the average appraisal of the four trees.

2.7.3 Calculation of SATAM

The CTLA mathematical method was used to calculate the SATAM monetary values. As previously mentioned, this method included the calculation of the tree size as well as the replacement tree size (Marx, 2006).

2.7.3.1 Calculation of size

The area size is calculated by using either its radius (r), diameter (d), or circumference (c). In the case of the current study the circumference of the trees were measured.

$r = d \div 2 = c \div 2\pi$

$\text{Area} = \pi r^2 = 3{,}14\ r^2$

$= \pi d^2 \div 2^2 = 3{,}14 d^2 \div 4 = 0{,}785\ d^2$

$= \pi c^2 \div (2\pi)^2 = 3{,}14\ c^2 \div 4(3{,}14)^2 = 0{,}080\ c^2$

2.7.3.2 Calculation of Section C

To calculate section C, each percentage of each of the different categories being appraised in the SATAM appraisal questionnaire, are calculated separately. The percentage of all the categories in Section C is then used in SATAM's worksheet to determine the monetary values.

- Calculation of the condition appraisal (Questions 8.6 - 8.11)

The condition rating is calculated by adding all the correct answers together and then determining the percentage for each subdivision. The blue coloured blocks (Table 2.6 – 2.9) represent all the correct answers as would be expected for a normal healthy tree in excellent condition.

Table 2.6 Blue coloured blocks indicate correct answers, as would be expected for a normal healthy tree in excellent condition, to the condition appraisal for SATAM (adapted from Marx, 2006).

8.6 Condition Appraisal: GENERAL			
8.6.1 Does the tree show a loss in vigour?	Yes	No	
8.6.2 Has this tree recently became a risk for failure due to a sudden exposure to wind? (Previously part of a large group of trees that was removed.)	Yes	No	
8.6.3 Does the tree that is been evaluated, have a significant history of failure?	Yes	No	
8.6.4 Have any of the adjacent trees failed?	Yes	No	
8.6.5 Is the tree properly maintained?	Yes	No	
8.6.6 Is the shedding of branches due to bad maintenance?	Yes	No	
8.6.7 Has the tree been topped or otherwise overly pruned?	Yes	No	
8.6.8 Are there large amounts of creepers in the upper canopy of the tree?	Yes	No	
8.6.9 Does the tree threaten any overhead power, electric, water pipes or telephone lines? (If any other underground servitudes are visible, the same question should be asked.)	Yes	No	N/A
8.6.10 Are previously implemented preventive repair and maintenance procedures (if any) still effective?	Yes	No	N/A
8.7 Condition Appraisal: ROOTS			
8.7.1 Is there any significant mechanical injury to the root-zone within the tree's drip-line?	Yes	No	
8.7.2 Is more than 30 % of the drip-area of the tree permanently compacted or water-logged? (Trees that naturally grow in waterlogged soils should receive "No" for an answer.)	Yes	No	
8.7.3 Are the root flairs visible?	Yes	No	
8.7.4 Is there any visible damage to the root flairs?	Yes	No	
8.7.5 Are any tree fungus, "mushrooms", conks or brackets, visible at the root flairs of the tree or within the drip-line around the tree? (If nothing is seen, ask the owner.) Take samples if unsure if they are an indication of a root problem. Compare to pictures in literature.	Yes	No	
8.7.6 Is the tree free of girdling and/or kinked roots?	Yes	No	
8.7.7 Is the root space available to the tree in proportion to the size of the tree? (i.e. does the tree have enough soil space in the plant box it is standing in?)	Yes	No	
8.7.8 Have any roots been broken off, injured or damaged, within the last six years,			

by lowering the grade, installing or removal of paving, digging trenches or compacting within the drip line? (May need to ask the client.)	Yes	No	
8.7.9 Has the site recently been changed by construction, raising the grade, installing lawn, gardening? (Recently in tree terms is within the last 6 years.)	Yes	No	
8.8 Condition Appraisal: TRUNK or STEM			
8.8.1 Does the tree have only one trunk? (The absence of co-dominant stems.)	Yes	No	
8.8.2 Has the trunk of the tree developed a lean? If the answer is no, question 8.8.3 to 8.8.5 should be answered N/A.	Yes	No	
8.8.3 Is the lean natural? (Did the lean happen due to recent upheaval, e.g. heavy rains, or strong winds, the answer should be "yes".)	Yes	No	N/A
8.8.4 Did the tree all of a sudden started leaning to one side?	Yes	No	N/A
8.8.5 Is this lean combined with soil heaving or bulging, cavities, excessive end-weight, or large amounts of creepers, or any other complicating factors? (i.e. root damage)	Yes	No	N/A
8.8.6 Does the tree's trunk taper? (Does the trunk decrease in diameter with height?)	Yes	No	
8.8.7 Is the bark and wood sound? (visual assessment)	Yes	No	
8.8.8 Are there any swollen or sunken areas visible on the bark?	Yes	No	
8.8.9 Are there any significant injuries on the trunk / stem?	Yes	No	
8.8.10 Does this tree have any significant cavities, wounds, lightning injuries, vertical cracks or decay on the trunk or branches? (Look out for beehives, nesting holes, borers, termites, etc.)	Yes	No	
8.8.11 Is there any wound/damage on the tree due to severe staking?	Yes	No	
8.8.12 If there is a wound (not including a cavity) on the stem, does it span more than 30 % or 120° of the tree circumference?	Yes	No	
8.8.13 Is there a significant indication of the presence of pathogenic pests, which may cause the decline of the tree?	Yes	No	
8.8.13.1 Name the pathogen if you can.			
8.8.14 Does this tree have any weak crotches, included bark unions/forks and/or multiple attachments in the main trunk?	Yes	No	
8.8.15 Is there any bark on the stem missing off the stem that may have come off in an unnatural way?	Yes	No	

8.9 Condition Appraisal: SCAFFOLD BRANCHES (Only to evaluate dicotyledons ignore when monocots are evaluated)		
8.9.1 Are there any large dead branches visible?	Yes	No
8.9.2 Is the live crown ratio (LCR) more than 60%? (Live crown in relation to dead branches)	Yes	No
8.9.3 Is there good callus wood development?	Yes	No
8.9.4 Do too many/all major branches originates at one point on the stem?	Yes	No
8.9.5 Are the scaffold branches properly attached to the stem? (Good stem to branch ratio = 3:1 – the diameter of the trunk in relation to the scaffold branch diameter)	Yes	No
8.9.6 Are there any seams, or cracks on the scaffold branches? (Especially look at the base of the scaffold branches.)	Yes	No
8.9.7 Do any scaffold branches have included bark in their attachments?	Yes	No
8.9.8 Is there any unnatural bow or sweep branches present? (Trees that naturally grow bow branches will receive a "No" for an answer.)	Yes	No
8.9.9 Is there any significant die-back (stag-horning) visible?	Yes	No
8.9.10 Is there a significant indication of the presence of pathogenic pests on the scaffold branches, which may cause the decline of the tree?	Yes	No
8.9.10.1 Name the pathogen if you can.		
8.10 Condition Appraisal: SMALLER BRANCHES AND TWIGS (Only to evaluate dicotyledons)		
8.10.1 Is the shoot elongation the same year on year?	Yes	No
8.10.2 Is there an even distribution of healthy twigs?	Yes	No
8.10.3 Is there any poorly attached side-growth from previous topping or other heavy pruning?	Yes	No
8.10.4 Are there any branches with excessive end-weight and little or no taper?	Yes	No
8.10.5 Are there any loose hanging branches in the tree?	Yes	No
8.10.6 Are there narrow branch attachments with included bark?	Yes	No
8.10.7 Is there a significant indication of the presence of pathogenic pests on the smaller branches and twigs, which may cause the decline of the tree?	Yes	No
8.10.7.1 Name the pathogen or insect if you can.		

8.11 Condition Appraisal: FOLIAGE / FRONDS		
8.11.1 Does the tree have any leaves on at present. (If the answer is no the rest of this section should be ignored.)	Yes	No
8.11.2 Is the canopy excessively dense for the species in comparison to other species in the area? (To be determined by the tree species.)	Yes	No
8.11.3 Is there a significant indication of scorching, chlorosis, necrosis, deformity (e.g. mistletoe) or other abnormalities of leaves present on the tree?	Yes	No
8.11.4 Do the leaves have a normal size and shape?	Yes	No
8.11.5 Is the density of the foliage normal and evenly distributed?	Yes	No
8.11.6 Is there any un-seasonal leaf drop or wilted leaves present, especially after heavy rains or wind?	Yes	No
8.11.7 Is there a significant indication of the presence of pathogenic pests on the small branches and twigs, which my case the decline of the tree?	Yes	No

The number of questions in each of the subdivisions will represent the total mark of that subdivision from which the percentage is then determined. For example:

- ✓ General = 10 points (answer multiplied by 10 = percentage)
- ✓ Roots = 9 points (answer multiplied by 100, divided by 9 = percentage)
- ✓ Trunk/stem = 15 points (answer multiplied by 100, divided by 15 = percentage)
- ✓ Scaffold branches = 10 points (answer multiplied by 10 = percentage)
- ✓ Smaller branches and twigs = 7 points (answer multiplied by 100, divided by 7 = percentage)
- ✓ Leaves/Fronds = 7 points (answer multiplied by 100, divided by 7 = percentage)

The percentage of all the subdivisions are then added together and divided by 6 to obtain the average condition appraisal rating of the tree.

- Calculation of the environmental contribution (Questions 9.1 - 9.12)

In Figure 2.7, the blue blocks represent the correct answers as would be expected for a healthy normal tree with a 100% environmental contribution.

Table 2.7 Blue coloured blocks indicate correct answers, as would be expected for a normal healthy tree in excellent condition, to the environmental contribution rating for SATAM (adapted from Marx, 2006).

9. Environmental contribution (Please answer all the questions.)			
9.1 Does this tree provide shade?	Yes	No	
9.2 Does this tree have a big influence on the utilisation of the area? (e.g. parking area, home, patio, picnic site, pedestrians, and so on.)	Yes	No	
9.3 Does this tree significantly influence the micro-climate of the surrounded environment?	Yes	No	N/A
9.4 If the tree is removed will it have a negative impact on the micro-climate of the surrounded environment?	Yes	No	
9.5 Does this tree act as a wind barrier/break?	Yes	No	
9.6 If the tree is removed will it create a opening in the windbreak that will tunnel the wind and increase the wind velocity?	Yes	No	N/A
9.7 Does this tree act as sound and visual buffer to noisy streets, factories, school or any other unsightly views?	Yes	No	
9.8 If the tree is removed will it significantly influence soil erosion?	Yes	No	
9.9 Is this tree stabilizing a slope, river bank, embankment, and so on?	Yes	No	
9.10 Are there any visible bird nests in the tree?	Yes	No	
9.11 Are there any signs of frequent visiting (roosting or feeding – feathers and droppings will be visible)	Yes	No	
9.12 Does this tree provide food (fruit or nectar) to small animals, birds, butterflies, bees or bats?	Yes	No	

The environmental contribution rating is calculated by adding all the correct answers together and then calculating the percentage thereof. The correct answer are then divided by the total number of questions, namely 12 and multiplied by 100 to obtain the percentage.

Although it is not always possible to determine the environmental contribution of trees, it is a known fact that trees do contribute to the environment. Because of this fact, the environmental contribution of trees starts at 25% (Marx, 2006). The percentage of the environmental contribution is then calculated by dividing the percentage by 4 (4 times

25%) multiplied by 3 (to obtain 75% of the environmental contribution) and added to 25% (the given environmental contribution value) to calculate the percentage of the environmental contribution rating.

For example:

A tree scored 8 out of 12. The environmental contribution calculation will be done as follow:

8 (correct answers) ÷ 12 (total questions) = 0.67

0.67 x 100 = 67%

67 ÷ 4 = 16.75 x 3 = 50.25 (to calculate 75%)

50.25 + 25% = 75.25% (the approximate environmental contribution of the tree).

- Calculation of the amenity appraisal

The amenity appraisal rating is determined by calculating all the correct answers together and calculating the percentage thereof. As with the environmental contribution, it is not always possible to determine the aesthetic values of trees. It is a known fact that trees do contribute beauty of an area. Because of this fact, the aesthetical contribution will also start with 25% (Marx, 2006).

Table 2.8 Blue coloured blocks indicate correct answers, as would be expected for a normal healthy tree in excellent condition, to the aesthetical appraisal for SATAM (adapted from Marx, 2006).

10. Amenity Appraisal (Please answer all the questions) Only for urban areas			
10.1 Is this tree the focal point (accent) of this area?		Yes	No
10.2 Has the tree a specific seasonal value that makes it a focal plant?	Foliage	Yes	No
	Flowers	Yes	No
	Berries	Yes	No
	Bark	Yes	No
	Growth habit	Yes	No
	Fragrance	Yes	No
	Other	Yes	No

10.3 Does the tree has a specific contribution to the setting in the landscape? e.g. colour of the bark, flowers, etc. that is part of the overall design theme.		Yes	No
10.4 If the tree is removed will it negatively influence the design of the garden, park, and so on?		Yes	No
10.5 If this tree is removed will it negatively influence the background of the rest of the garden or park?		Yes	No
10.6 Was this tree planted / or is it currently used to:	Screen unsightly views	Yes	No
	Define a space	Yes	No
	Create a vista or frame a view	Yes	No
	Direct traffic	Yes	No
10.7 If the tree is removed will it negatively influence the:	Design theme	Yes	No
	Vista or view that was created	Yes	No
10.8 Is this tree too big or too small in proportion (scale) to the area it is standing? (e.g. *Celtis africana* in a townhouse garden or *Alberta magna* next to a double story home.)		Yes	No
10.9 Is this tree been planted to attract fauna to the garden or area?		Yes	No
10.10 Was this tree been planted to establish a eco-friendly garden?		Yes	No
10.11 If this tree is removed will it influence the rhythm of the garden, street scape? (e.g. A row of *Jacaranda mimosifolia* as street trees.)		Yes	No
10.12 Was this tree planted to supplement the owner's income? (e.g. fruit trees, vines, timber, fire wood – not on a commercial scale)		Yes	No
10.13 Was the tree planted to provide the family with fresh fruit?		Yes	No

The correct answer are divided by the total number of questions, namely 23 and multiplied by 100 to obtain the percentage. The percentage of the aesthetic contribution is then calculated by dividing the percentage by 4 (4 times 25%) multiplied by 3 (to obtain 75% of the environmental contribution) and added to 25% (the given environmental contribution value) to calculate the percentage of the aesthetical appraisal rating.

For example:

A tree scored 15 out of 23. The environmental contribution calculation will be done as follow:

15 (correct answers) ÷ 23 (total questions) = 0.67

0.65 x 100 = 65%

65 ÷ 4 = 16.25 x 3 = 48.75 (to calculate 75%)

48.75 + 25% = 73.75% (the approximate environmental contribution of the tree).

2.7.4 Detail explanation of the mathematical operation for the SATAM

The SATAM program from UNISA calculates all the data collected by the appraiser according to the method discussed above. The SATAM program calculates the monetary value as follow:

- The appraiser will choose the tree species that has been appraised from the tree list on the program.
- The measurement of the height of the tree (information transferred from Section C – question 8.1)
- Measurement of the circumference of the tree at 1,4 metres above ground level (information transferred from Section C – question 8.2)
- The calculation of condition rating percentage as discussed above.
- The calculation of environmental contribution rating percentage as discussed above.
- The calculation of aesthetic appraisal percentage as discussed above.
- The tree species will determine the rating of the species or origin appraisal according to Section A of the SATAM questionnaire
- The replacement tree area (TA_R) is then calculated according to the information completed by the appraiser.
- The replacement tree cost is the retail cost of the largest replacement tree (#8) as supplied by the appraiser.
- The installation cost refers to the cost of installing of the replacement tree This cost include the site preparation, transport and planting costs and has been established as 30% of the replacement tree retail cost.
- The installed tree cost is the sum of the replacement tree (#9) and the installation cost (#10) of the replacement tree

- The unit tree cost is then determined by dividing the retail replacement tree cost (#9) by the replacement tree size (#8)
- The cross-sectional trunk area (TA_A) of the appraised tree is then automatically calculated by using the trunk circumference supplied in section C.
- The next step will be for the program to subtract the trunk area of the replacement tree (TA_R) (#8) from the trunk area (TA_A) of the appraised tree (#13) to obtain the appraised area increase
- The increase in the size of the appraised tree (TA_{INCR}) (#14) is then multiplied with the unit tree cost (#12), after which the installed tree cost (#11) will be added to obtain the basic tree cost of the appraised tree.
- The basic tree cost (#15) is then multiplied by the percentage condition rating (#4), the percentage environmental contribution rating (#5), the percentage aesthetical appraisal rating (#6) and the species or origin rating (#7) to obtain the monetary value of the tree that is being appraised.
- The monetary value is then rounded off to the nearest R100.

2.8 Soil Analysis

Soil analyses were done for each of the 20 study sites. Three samples were collected per site and mixed to form one sample that was more or less representative of the whole site. A 1:2 water extract was used and the soil was analysed for the following: micro-elements (Fe, Mn, Cu, Zn, B), macro-elements (Ca, Mg, K, Na, P, SO_4, NO_3, NH_4, Cl, HNO_3), heavy metals (Pb, Cr, Cd, Se, As, Al, Ni, Co), pH, CEC (Cation Exchange Capacity), EC (electrical conductivity) and % carbon. The particle size distribution of the soil was also analysed.

2.9 Study of vegetation associated with *Acacia karroo*

At each of the study sites, only the plant species that are associated with the *Acacia karroo* trees were recorded. We regarded all the plant species that were found within the drip-line of the trees to be associated with *Acacia karroo*. After the plant species were recorded, a cover-abundance value was estimated for the recorded plant species according to the Braun-Blanquet scale (Table 2.5; Kent & Coker, 1992:45). For each of the groups of plants described in this study, the total number of species, number of native and exotic species and the number of declared weeds (DW) and declared invaders (DI) were determined. Identification of DW and DI was based on Henderson (2001).

Table 2.9 The Braun-Blanquet cover-abundance scale used in this study (Kent & Coker, 1992:45).

Scale	**Description**
r	One or few individuals with less than 1% cover of total sample plot area
+	Occasional and less than 1% of total sample plot area
1	Abundant and with very low cover, or less abundant but higher cover, 1-5% cover of total sample plot
2	Abundant with > 5-25% cover of total sample plot area, irrespective of the number of individuals
2a	> 5-12,5% cover, irrespective of the number of individuals
2b	> 12,5-25% cover, irrespective of the number of individuals
3	> 25-50% cover of total sample plot area, irrespective of the number of individuals
4	> 50-70% cover of total sample plot area, irrespective of the number of individuals
5	> 75% cover of total sample plot area, irrespective of the number of individuals

2.10 Data processing:

The following methods and/or programs were used for the data processing:

The urban-rural gradient was analysed using a GIS program, Arcview9 (ESRI, 2006).

Measurements that were taken with the PEA (Plant Efficiency Analyser) apparatus were converted into usable data through Biotrans. The data were analysed in Excel and Sigma Plot was used to draw the graphs.

The water potential data was summarized in Sigma Plot and this program was also used to draw the graphs.

The tree appraisal data were analysed by the SATAM program from UNISA (Marx 2005).

The vegetation is analysed using a database, TURBOVEG (Hennekens, 1996a) and a visual editor for constructing phytosociological tables, MEGATAB (Hennekens, 1996b).

Two indirect multivariate analysis techniques were used, i.e. PCA (Principal Component Analysis) to illustrate the soil characteristics at each study site, and a DCA (Detrended Correspondence Analysis) to determine the correlation between the tree vitality data and the water potential, soil, vegetation and tree appraisal data. The CANOCO software program (Ter Braak, 1988) was used for multivariate statistics.

To determine whether there was a statistical correlation between the urbanization gradient and the tree appraisal values, Spearman's rank correlation test was used (STATISTICA, 2005).

Chapter 3

Soil characteristics and Vegetation composition

3.1 Soil characteristics

3.1.1 Introduction

Soils have several functions in urban ecosystems, of which the most important is to serve as a medium for plant growth, foundation for buildings and a source and sink for water and pollutants (Bullock & Gregory, 1991:1). According to Craul (1992:2), the growth medium for trees should ideally be typified by a sufficient amount of soil, with a minimum moisture holding capacity, have adequate drainage properties, be aerated to a certain degree, as well as be able to address some nutrient requirements. In an urban environment these are not the typical soil characteristics.

According to Mullins (1991:87), urban soil can be seen as artificial material that has some of the physical properties of soils in their natural or agricultural environment. Craul (1992:86) refers to urban soil as material that has a non-agricultural, man-made surface layer more than 50 cm thick. This layer is produced by human activities such as mixing and filling, or by contamination of land surfaces in urban and suburban areas. The Soil Classification Working Group (1991:49) classified urban soils in South Africa as the Witbank soil form. The Witbank soil form consists of an orthic A-horizon and a layer of man-made soil deposit beneath the A-horizon. The A-horizon does not qualify as organic, humic, vertic or melanic topsoil, although organic matter may darken it (Soil Classification Working Group, 1991:17). The man-made layer may consist of rock fragments or man-made materials (Soil Classification Working Group, 1991:38). Effland and Pouyat (1997:217) used 'anthropedogenesis' to refer to the role of human activities in changing the natural direction of soil formation. For this study the definition of urban soil will refer to a growth medium consisting of a layer of material that has some of the properties of soil in a natural environment (forest, agricultural land) and which is impacted on by human activities, a definition that is proposed by Sheyer and Hipple (2005).

The general characteristics of soils in natural environments are as follows: 1) a high degree of aggregation and the presence of many macropores, allowing deep rooting and ease of root penetration 2) sufficient water because of a large available water-holding capacity, 3) optimal gaseous diffusion due to the high degree of aggregation, 4) adequate amounts of nutrients in an available and reserved form and in the proper ratio coupled with a large cation-exchange capacity, and 5) rich soil micro-flora and microfauna that decompose organic matter rapidly, bring about nutrient transformations into available form, and provide a highly developed soil structure (Craul, 1992:88). In contrast, urban soil (Craul, 1992:88) is characterized by having: 1) great vertical and spatial variability, 2) modified soil structure leading to compaction, 3) presence of surface crust on bare soil, 4) modified soil reaction, 5) restricted aeration and drainage of water, 6) interrupted nutrient cycling and a modified soil organism population and activity, 7) presence of anthropogenic materials and other contaminants and 8) highly modified soil temperature.

Some of the characteristics of urban soils, as well as their influence on trees, will be discussed in more detail in the following section. These soil characteristics could be divided into two groups, namely the characteristics that were measured for the current study and those that were not measured for the current study.

The following soil characteristics were measured either directly or indirectly:

3.1.1.1 Compaction

Soil compaction is the process of reduction of the specific volume or porosity of the soil and thus results in an increase in the bulk density of the soil (Mullins, 1991:97; Craul, 1992:211). Porosity refers to the volume of voids per unit volume of soil, while bulk density is a measure of how closely the soil particles are packed together (Mullins, 1991:97). Compaction is caused by several factors such as 1) low organic matter, 2) variable moisture content, 3) settling and slumping, 4) foot and vehicle traffic and 5) poaching/trampling by grazing animals (Mullins, 1991:99; Craul, 1992:215).

Organic matter acts as a cementing agent and enhances soil aggregation/structure. These aggregates are usually water-stable and tend to persist and prevent soil self-compaction (Craul, 1992:216). Soils with inherently high water holding capacities, as well as soils with a dominant sand fraction and associated high internal friction level are not prone to compaction. However, there is critical moisture content where the compaction potential of soils is the greatest; this critical point differs for different soil types (Craul, 1992:217). Soils can also undergo compaction as a result of settling and slumping. Settling occurs as a result of cycles of drying and wetting (shrinkage and swelling), which cause aggregates to pack more closely together (Mullins, 1991:98; Craul, 1992:218). Slumping occurs when soil aggregates weaken as a result of wetting. This leads to partial disintegration of the aggregates, which causes the soil to pack closer together (Craul, 1992:218). One of the more obvious causes of soil compaction within an urban environment is the load of humans and traffic on soil. According to Mullins (1991:99), the typical static ground pressure exerted by a human, tractor and cow are 30, 100 and 200 kPa, respectively. The repeated application of foot traffic on bare soil results in soil compaction and crust formation. Grass absorbs much of the initial impact, but the soil may be compacted to nearly the same degree as bare soil. The loading of vehicles or other heavy machinery is much more than foot traffic and the compaction is deeper into the soil layers (Craul, 1992:220). Compaction caused by the hooves of grazing animals is called poaching (Mullins, 1991:99).

The reduction in pore space increases the potential mechanical resistance to root penetration (Craul, 1992:225). This also results in a decrease in water-holding capacity and air-filled pore spaces. Because of the compaction of soil the infiltration ability of water is decreased, which causes runoff and erosion. Compaction results in a reduction in soil aeration and thus soil oxygen is decreased and the CO_2-concentration is increased. The soil temperature increases because soil particles are closer together and heat can be conducted much easier (Craul, 1992:226). Compaction results in two types of nutrient unavailability. The first type is a mechanical obstruction that prohibits root penetration and prevents the roots to reach the nutrients that are available in the soil. To fully understand this it should be realised that nutrients can only be transported by means of mass flow and diffusion, both of which are severely restricted in compacted soil. The second type is because of a reduction in soil aeration and thus a reduction in soil oxygen, which helps with the absorption of water and nutrients (Craul, 1992:228). In this regard it is important to note that although the roots cannot sense where the nutrients are, they grow and proliferate in areas typified by an acceptable oxygen to water ratio.

In the present study, the soil compaction was not measured directly but indirectly determined by utilizing the urbanization gradient (VIS-model from Ridd, 1995:2173). The study sites with a higher percentage impervious surface have a higher percentage compacted soil because of the high percentage soil that is covered and the low percentage vegetation cover. The soil in the rural areas has a higher percentage vegetation but might have soil compaction due to trampling by grazing animals.

3.1.1.2 Surface crusting

Urban soils are prone to surface crust formation (Craul, 1992:92). This is caused by several factors of which compaction is probably the most dominant. Compaction influences the vegetation groundcover negatively and because of the absence of this cover there is less organic matter on the soil surface and raindrop splash disintegrates soil aggregates. A second factor is chemical dispersion and this depends on the soil exchangeable sodium percentage and electrolyte concentration in the precipitation. These surface crusts decrease the permeability and the aeration of soils.

In the current study, surface crusting was not measured directly but by using the vegetation cover as an indirect tool to determine the probability of surface crusting. According to Craul (1992:92), one of the causes of soil surface crusting has been ascribed to a low organic content of soil that might have resulted from a low percentage vegetation cover. The urbanization gradient could, however, not be used as an indirect tool to measure the soil surface crusting as this could lead to inaccuracies. Some of the study sites, such as rC (Church, see Table 2.3) for example, have a high percentage impervious surface and the rest of the area is covered by vegetation, as opposed to some other urban study sites, such as rG (Gimnasium, see Table 2.3), which is a High School where the specific site is used as a walk through. The latter study site has a high percentage of soil, which is not covered by vegetation.

3.1.1.3 Nutrient cycling and organic matter

Urban soils generally lack the organic matter cycle and its associated nutrient cycles. Some urban soils do not rest on parent material or bedrock, and do not receive the benefits of nutrients released from inorganic mineral weathering (Craul, 1992:97). In a natural environment, biomass is cycled in the form of leaves, litter, and animal remains. These contribute to the favourable physical, chemical and biological characteristics of the natural soil. In an urban area there is little or no other vegetation present. The organic matter is too small an amount to accumulate, and if it does, it is removed as a nuisance (Craul, 1992:97). Individual trees in sidewalk pits or containers suffer maximum effects of the interrupted organic and nutrient cycles. Turf areas may have some organic matter returned to the soil, but the amount is significantly reduced by the raking or sweeping away of the excess material (Craul, 1992:98).

Plants require certain elements to ensure good health, these include macro-elements such as C, N, P, K, Ca, Na, Mg and S and microelements such as Fe, Mn, B, Cu, Zn and Cl. Table 3.1 provides a summary of some of the functions ascribed to macro-elements in the plants.

Table 3.1 The role of the macronutrients in plants, adapted from Craul (1992:161).

Macronutrients	**Role**
Nitrogen (N)	Essential component of proteins, chlorophyll, nucleic acid, and enzymes. Performs a critical role in assimilation and metabolic processes of growth such as stem and shoot elongation.
Phosphorus (P)	Essential to the energy transfer and photosynthetic systems as phosphorylated sugars; component of nucleoproteins, phytin, etc.; important to flowering and seed production, protein metabolism, respiration, and enzyme synthesis.
Potassium (K)	Needed for carbohydrate formation, photosynthesis, protein synthesis; increases osmotic pressure, aids water absorption and frost resistance.
Magnesium (Mg)	Part of the chlorophyll molecule; needed for enzyme activity, formation of carbohydrates, protein, etc., and cell division.
Calcium (Ca)	Controls physiological processes in the cells, root growth and elongation. Calcium is a component of the middle lamella of the cell wall.
Sulphur (S)	Needed as a constituent of proteins, amino acids and vitamins.

Plant growth is limited by the nutrient that is present in the most limiting concentration, the law of minimum. Micro-elements are available in very small amounts, even when sufficient for plant growth. Excess or toxic levels are very quickly attained (Craul, 1992:162). Plants that are under nutrient stress are more susceptible to insect and disease attack as well as to moisture stress (Craul, 1992:98).

Nitrogen (N) provides the most universal response to plant growth, primarily because it is the most limiting nutrient in most soils (Craul, 1992:159). Most plants take up nitrogen as either NH_4^+ or NO_3^- and a continual supply is necessary to meet their requirements. The small amounts of nitrogen in soils are quickly exhausted by plant uptake (Pulford, 1991:120; Craul, 1992:160). Because of the nature of the environment in degraded soils, contaminated soils or substrates, it is often the case that mineralization is inhibited or that immobilisation, denitrification and volatilisation are increased, resulting in a shortage of nitrogen available for plants (Pulford, 1991:120). Consequently, plants more often than not show a positive response to applied nitrogen.

Phosphorus (P) is not usually a limiting nutrient to woody shrubs and trees, even though it is present in low amounts in most soils. The major reason for this phenomenon is the fact that many woody species support various mycorrhizae, which greatly increase the surface area of the absorbing surfaces of roots (Craul, 1992:160).

Potassium (K) is easily recycled in the ecosystem and its high solubility creates few deficiency problems for woody shrubs and tree species. Deficiencies primarily occur in soils that are acid, sandy, and low in organic matter content.

Calcium is rarely found to be deficient for plant growth and usually the deficiency evolves from excesses of other elements that may cause ion antagonisms, or as many occur in acid soils, manganese, copper and aluminium may replace the calcium, which reduces the availability of other nutrients (Craul, 1992:162).

The occurrence of many of the elements in soil is due to natural soil forming processes from the parent material. Potchefstroom forms part of the Black Reef series, Dolomite series as well as the Pretoria series (Nel *et al.,* 1939:67). The Black Reef series consists of conglomerates, quartzite and shale. The shale in the Black Reef series is dark grey with a ferrogineous (Fe and Mn oxides and hydroxides) and carbonaceous characteristic (Nel *et al.*, 1939:68). The dolomite series consists of dolomitic limestone, chert and shale whereas the Pretoria series consists of quartzite and shale, which is ferrogineous in character (Nel *et al.*, 1939:72).

In the present investigation we opted to determine the soil nutrient content by collecting soil samples and testing it for, amongst others, the water soluble macro-elemental and micro-elemental fractions rather than studying the respective nutrient cycles or organic material accumulation. The results of the soil elemental composition will be discussed in Chapter 3 and Chapter 6. The soil elemental concentrations and organic matter content of the soil could be determined by using the urbanization gradient as an indirect tool. According to Craul (1992:97), urban soils lack nutrients and organic matter because there is little or no release of nutrients through inorganic weathering and organic decomposing. Study sites in urban areas usually have a high level of maintenance and thus lack most of the nutrients that are released through the decomposition of organic matter such as leaves. In the current study, we observed that the more rural study sites had little maintenance or no maintenance at all and thus had a higher percentage of organic matter that could decompose or inorganic matter that could release nutrients through weathering.

3.1.1.4 Contamination by heavy metals

Soil contamination describes a condition where the content of a natural or synthetic substance is above that of the background, natural content (Craul, 1992:185). Urban soils differ from rural soils because of the more pronounced influence of anthropogenic activities that usually leads to soil contamination. The main sources of soil contamination in an urban area are industrial emissions, traffic, burning of fossil fuels and waste from industrial and residential activities (Thornton, 1991:48). The typical contaminants from these sources are heavy metals (HM), polyaromatic hydrocarbon (PAH), chlororganic compounds and radionuclides (Craul, 1992:186; Lee *et al.*, 2005:45; Biasioli *et al.*, 2006:155). For this study the soil was tested for the presence of HM and thus only contamination by HM will be discussed. HM are compounds that contain the elements of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) (Craul, 1992:186). HM are absorbed by the soil colloids and organic matter, and absorbed by the plants growing in these soils. Metals are toxic to plants because they affect the permeability of cell membranes and disrupt the energy-producing functions of the cell. In soils, high concentrations of metals can replace essential nutrients held on soil exchange sites (Ashman & Puri, 2002). HM are not biodegradable and have a long residence time in soil and thus the leaching of HM from the soil is very slow (Craul, 1992:186;

Lee *et al.*, 2005:46; Biasioli, 2006:155). These HM can be toxic to humans and because of the HM characteristics the contamination of soil by HM forms a great concern in urban areas.

For the current study the contamination of the soil by heavy metals was measured by collecting soil samples from each study site and testing them for the heavy metals mentioned above. The results will be discussed in Chapter 3 and Chapter 6.

3.1.1.5 Effect of soil pH

Generally, most plant roots can tolerate a wide range of soil or solution pH-values. The pH-range of 4 to 8 appears to negligibly influence root growth. If the pH drops below 3 it can inhibit root growth of plants. Maximum absorption rates of both cation and anion elements occur at pH values from 5 to 7. Below pH 4, H^+ ions cause a loss of previously absorbed ions such as potassium, organic and inorganic phosphorus and soluble nitrogen. Another effect of pH is the distribution of nitrogen between the ammonium (NH^+) and ammonia (NH_3) forms; the latter is toxic to plants. The pH of soil also has a significant effect on, but not limited to, the aluminium solubility. Root growth is very sensitive for incorrect aluminium concentrations (Craul, 1992:146) due to its antagonistic effect on calcium sequestration.

Sampling and analysis to determine the soil pH and the concentrations of the macro-elements, micro-elements and heavy metals occurred concurrently at each of the study sites.

The following soil characteristics were not measured during the current study:

3.1.1.6 Soil temperature

Heat loading of urban soils is greater than that of rural soils. Although the incoming radiation in cities is less, because of cloudiness and increased haze, building and street surfaces absorb and reradiate a greater amount of heat than vegetation (Craul, 1992:144). Because there is no continuous vegetative cover/ canopy in urban environments or in built up areas, the soil generally lacks the insulating property of organic horizons. This results in a great amount of radiation reaching the soil surface (Craul, 1992:144). Heat and moisture are transferred in soils and on the soil surface. This can affect tree water stress by changing the distribution of soil water and the water demand of trees. These heat extremes could be lethal for the trees/ vegetation in urban environments (Halverson & Heisler, 1981:1).

3.1.1.7 Restricted aeration and water drainage

Urban soils are usually covered with a crust, compacted or covered with a nonporous material that restricts gaseous diffusion and water movement in the soil. Buildings, curbs, streets and sidewalks cover soils and thus urban soils also lack the horizontal continuity between soil bodies. This disrupted continuity of the soil may cause damming and ponding of water within the soil. Gaseous diffusion is restricted, reducing the oxygen concentrations and increasing the CO_2 concentrations until the soil begins to drain (Glinski & Stepniewski, 1983:137; Craul, 1992:95). For the current study the aeration and water drainage of the soil were not measured, but the % impervious surface (V-I-S model) can be used as an indirect indicator of restricted soil aeration and water drainage of the soil.

3.1.2 Results and discussion

Principal Component Analysis (PCA) was used to analyse some of the communalities in response to some of the soil analysis results because this technique is regarded as one of the most effective multivariate analysis methods to analyse environmental data (Kent & Coker, 1998:186). Figure 3.1 is a PCA ordination of the different soil macro-elements per study site (Figure 3.1), which clearly indicates that most of the sites are clustered into one group (Group A), but there are study sites (sK-Kynoch, uC-Church, sG-Grimbeeck Park, sV-Van der Hoff Park, rD-Dassierand, uV-Viljoen Street) that deviate from this group (outliers). SO_4, K and HCO_3 are strongly associated with ordination axis 1 (E = 0.38), whilst the association with the micro-elements Mg and NO_3 is less pronounced. NH_4, P, Na and Ca are strongly associated with ordination axis 2 (E = 0.23). The study sites of group A represent a combination of urban, suburban and rural sites and are closely associated with high levels of NO_3 in the soil. NO_3 is chemically available to plants and is produced through the mineralization (a process carried out by heterotrophic decay organisms) of N stored in organic matter. Nitrifying organisms in the soil are responsible for the production of NO_3 from N (Hausenbuiller, 1978:278). The study site rD (Dassierand) is associated with NH_4, Ca, P and Na while uV (Viljoen Street) is strongly associated with NH_4, P and Ca. Both N and P are derived from the mineralization of organic matter or added to the soil through fertilizers (Hausenbuiller, 1978:275,307). The minerals Ca and Na occur naturally in the soils or could be added to the soil through irrigation water (Anon, 2003).

The study site uV (Viljoen Street) is situated next to cultivated land and the nutrients NH_4, P and Ca could result from fertilization and irrigation of the soil. The study site rD (Dassierand) lies in a rural area and the minerals found there could be from parent material. The macro-elements NH_4 and P are associated with the study site sK (Kynoch). This site is located next to a liquid fertilizer blending plant and this could be the explanation for the high NH_4 and P values. N is one of the most important macro-elements for plants and promotes plant growth and therefore increases the biomass of trees. N-fertilizers have been used to increase wood production and forest growth (Kontunene-Soppela, 2001). The study site uC (Church) is strongly associated with SO_4, K and HCO_3. K occurs as a natural element in soil and could be added to soil through fertilizers (Hausenbuiller, 1978:331). SO_4 is formed when S stored in soil organic matter is released by mineralization (Hausenbuiller, 1978:341). SO_4 can also be derived from minerals and fertilizers. The main minerals in irrigation water are Cl, SO_4, HCO_3, Na, Ca and Mg (Anon, 2003). uC (Church) represents a sampling site close to a church situated in a residential area of which the trees are irrigated regularly and the lawn receives fertilizer that could explain the strong association with SO_4, K, Cl and HCO_3. The study site sG (Grimbeek Park), which is a garden in a residential area, is strongly associated with Mg. Mg is supplied to the soil by means of fertilizer as well as being generated by parent minerals such as ferromagnesium (Hausenbuiller, 1978:323). Ferromagnesium is one of the minerals that occur in the soil of natural areas of Potchefstroom (Nel *et al.*, 1939: 77).

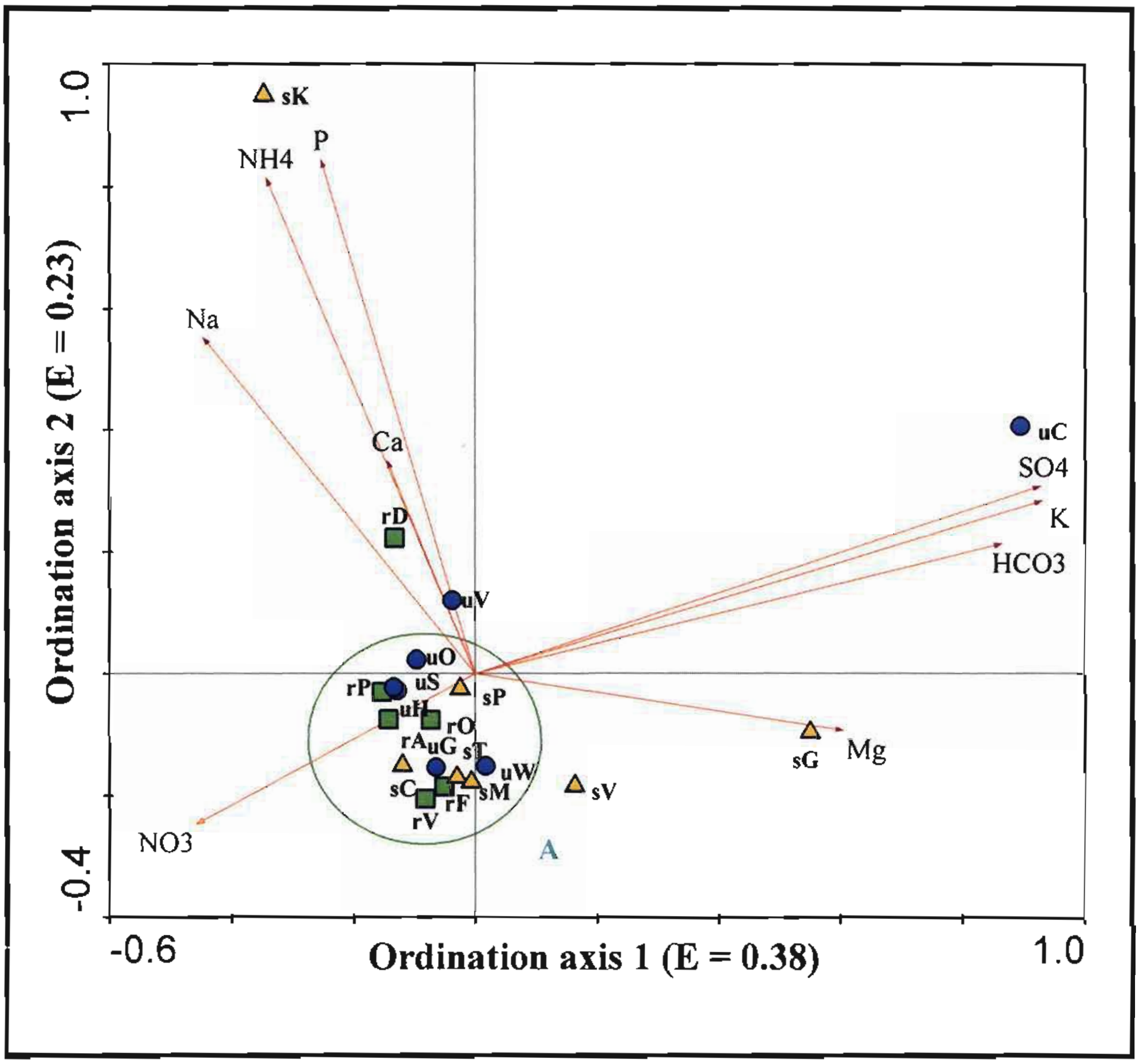

Figure 3.1 Principal Component Analysis (PCA) of the macro-elements of the twenty study sites in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

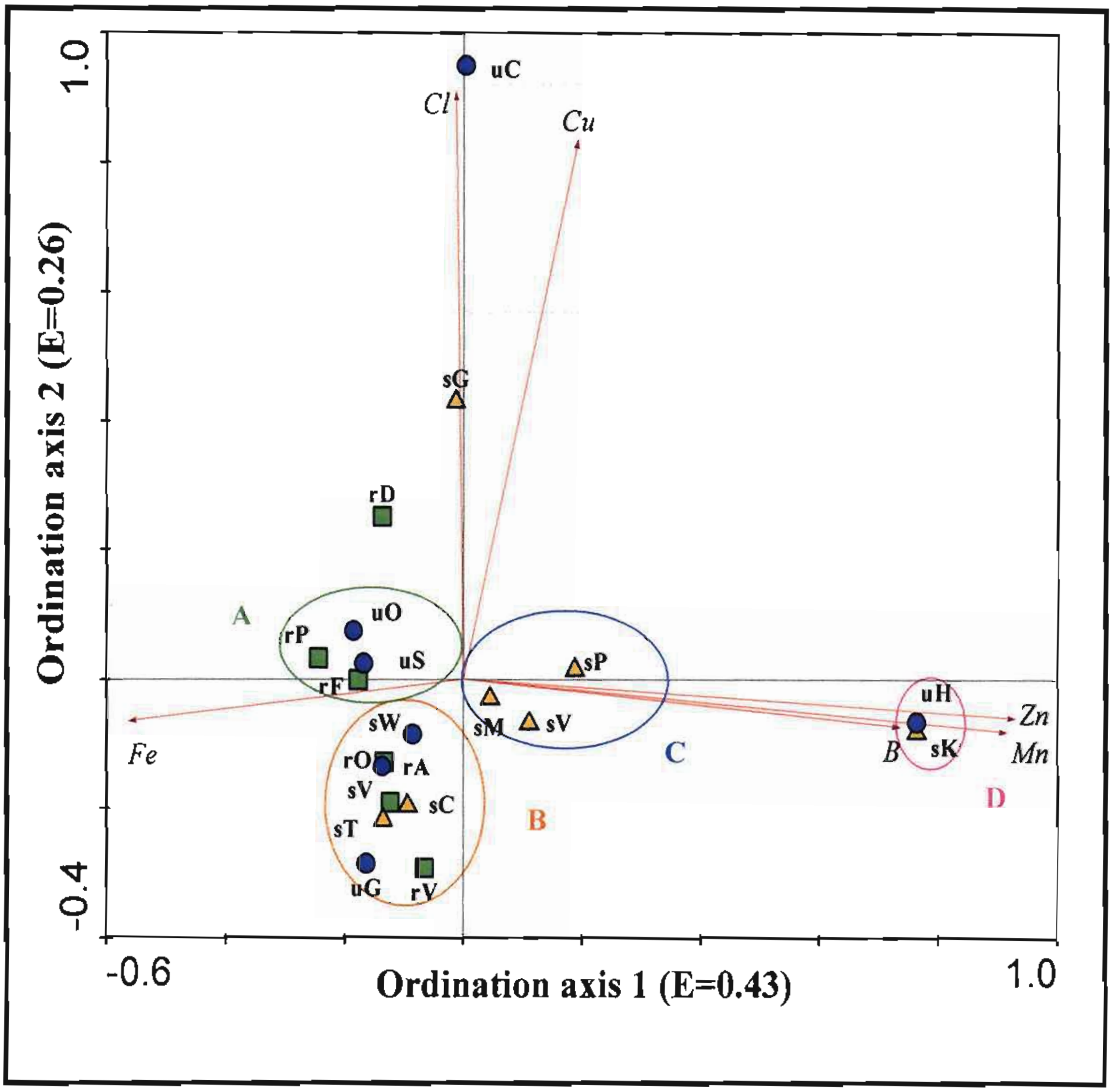

Figure 3.2 Principal Component Analysis (PCA) of the micro elements found in the soil from the twenty study sites in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

From the PCA ordination results (Figure 3.2) of the micro-elemental concentrations per study site, four clear groupings (A, B, C, D) and three individual sites (rD-Dassierand, sG-Grimbeek Park, uC-Church) arise. The micro-elements Fe, Zn, Mn and B are associated with ordination axis 1 (E = 0.43) and the micro-elements Cl and Cu are associated with ordination axis 2 (E = 0.26). Group A consists of urban, suburban and rural study sites and is strongly associated with Fe. Fe is one of the most abundant elements on earth and occurs as ferromagnesium silicates and as ferrogineous shale, which forms part of the geology of Potchefstroom (Nel *et al.*, 1939:70 & Schulte, 1999). According to Nel *et al.* (1939:68), Potchefstroom forms part of the Black Reef series as well as the Pretoria series, which is rich in Fe and this could be a reason why the soil from most of the different study sites has a relatively high Fe content (see Table 2, Appendix A).

Group B represents a combination of urban, suburban and rural sites and is not really associated with any of the micro-elements. Group D (uH – High School, sK-Kynoch) is strongly associated with B, Zn and Mn while Group C, (sM-Meadow Street, sV-Van der Hoff Park, sP-Mooivallei Park) is associated to a lesser degree with the same elements. According to Kelling (1999), most of the B found in soils form part of the soil organic matter. Mn occurs as a natural element in soil in concentrations higher than those of other micronutrients (Smith & Paterson, 1995:228; Schulte & Kelling, 1999). Mn can also be applied to soils as an addition to macronutrient fertilizers (Schulte & Kelling, 1999). According to Kiekens (1995:285) the Zn-content of soils is largely dependent on the composition of the parent materials. Zn can also be added to the soil through atmospheric fall-out through the burning of coal and other fossil fuels as well as the melting of non-ferrous metals (Kiekens, 1995:285). The study sites uV (Viljoen Street) and sK (Kynoch) are within two kilometres of each other and this could be a reason for the high association with each other. These two sites are close to the industrial area of Potchefstroom and the strong association with Zn could be due to atmospheric fall-out (Schulte, 2004). The high association with Mn could be due to the fact that sK (Kynoch) is a fertilizer plant and that Mn is used in the manufacturing process of fertilizer and deposited in the soil through atmospheric deposition. The study sites sM (Meadow Street), sV (Van der Hoff Park) and sP (Mooivallei Park) are not close to the industrial area of Potchefstroom and the association with B, Zn and Mn could be because these elements occur naturally in the soil. The individual sites rD (Dassierand), sG (Grimbeek Park) and uC (Church) are associated with Cl. sG (Grimbeek Park) and uC (Church) are strongly associated with Cl, while As is associated to a lesser degree. uC (Church) and sG (Grimbeek Park) are sites in a residential area and receive water on a regular basis. The high association with Cl could be due to the irrigation water. According to Anon (2003), Cl is one of the main components of irrigation water.

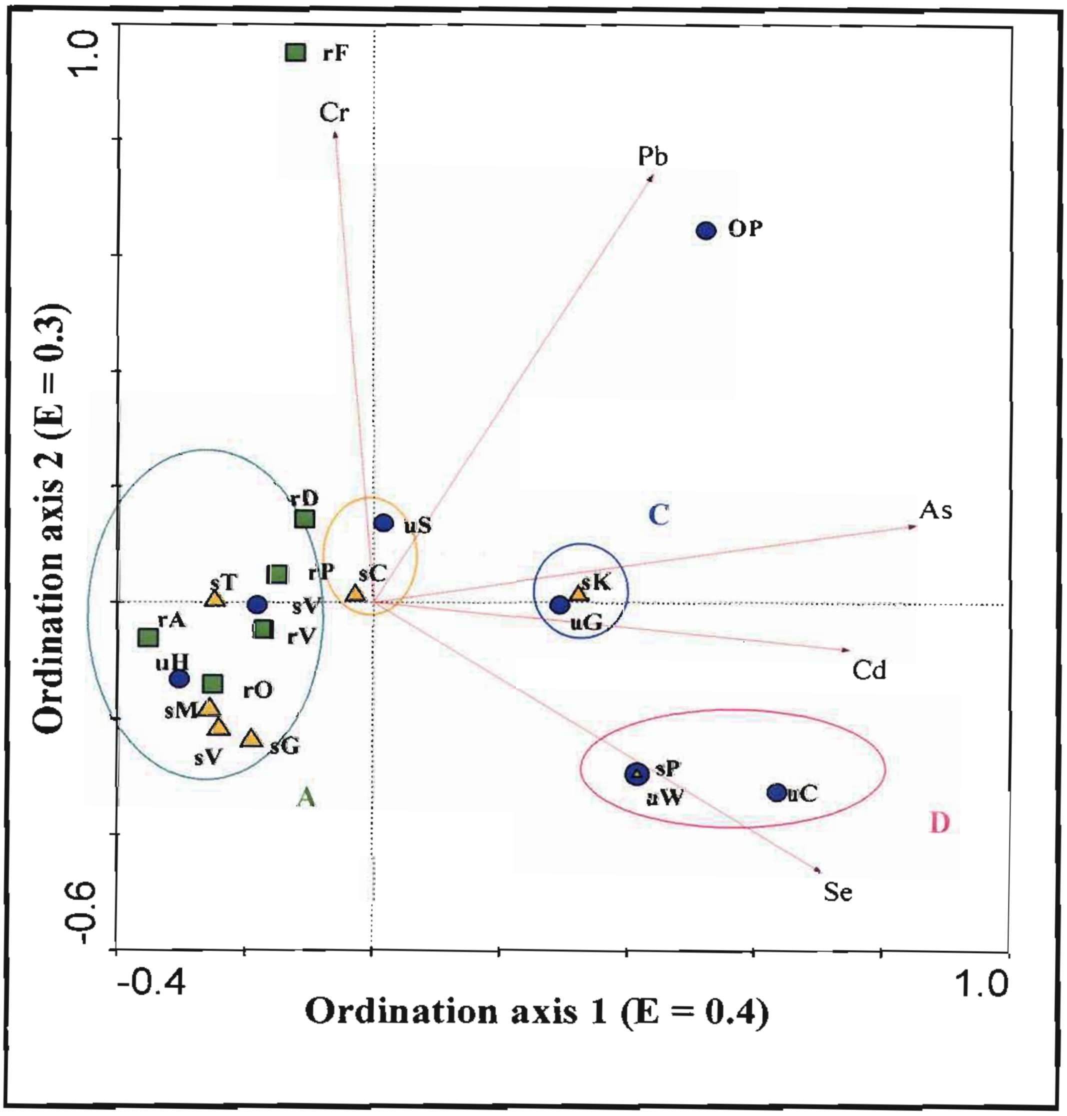

Figure 3.3 Principal Component Analysis (PCA) of the heavy metals found in the soil from the twenty study sites in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

The heavy metal concentrations that were found in the soil samples collected for the respective study sites are presented in Figure 3.3. Most of the heavy metals found in soil are minerals from parent materials and are not necessarily a contaminant of the soil (Alloway, 1995:3). Most of the study sites are grouped together into one group (A) with three smaller groups (B, C, D) and two outliers (rF-Farm, uO-Opkoms). As and Cd are strongly associated with ordination axis 1 (E = 0.4) while Se is associated to a lesser degree with this axis. Cr is strongly associated with ordination axis 2 (E = 0.3), while Pb is associated to a lesser degree with this axis.

Group A represents a combination of urban, suburban and rural study sites. Most of the rural sites, except rF (Farm), are included in group A. Group A is not highly associated with any of the heavy metals. It could be that the heavy metals are only present in small quantities and that they are derived from parent material and do not form a contaminant in the soil. Group B (uS-Station Road, sC-Cemetery) and especially the individual study site (rF-Farm) are strongly associated with Cr. Cr is found in the crustal rocks of the earth and is a natural element in soil (McGrath, 1995:155). Cr could also be added to the soil through fertilizers and atmospheric deposition through combustion of coal (McGrath, 1995:158). Other smaller sources of Cr include wear of Cr-containing asbestos brake linings in vehicles and aerosols produced from catalysts used in emission reduction systems for treating exhaust fumes (McGrath, 1995:163). All three the study sites are close to a railway line or a road and it could be that the Cr in the soil is as a result of atmospheric deposition. Group C (sK-Kynoch, uG-Gimnasium) is associated with As and Cd. Both As and Cd occur naturally in soils and are derived from shales (Alloway, 1995:123; O'Neill, 1995:107). Shale is one of the rock types found in Potchefstroom and thus the study sites could be associated with As and Cd that occur naturally in soils. Cd is also used in phosphatic fertilizer, which can lead to high levels of Cd in the soil (Alloway, 1995:126). The reason for the higher levels of Cd (see Table 3, appendix A) at study site sK (Kynoch) could be due to the fact that sK (Kynoch) is a fertilizer plant and Cd could be deposited in the atmosphere from this plant. Group D (sP-Mooivallei Park, uW-Wasgoedspruit, uC-Church) is strongly associated with Se.

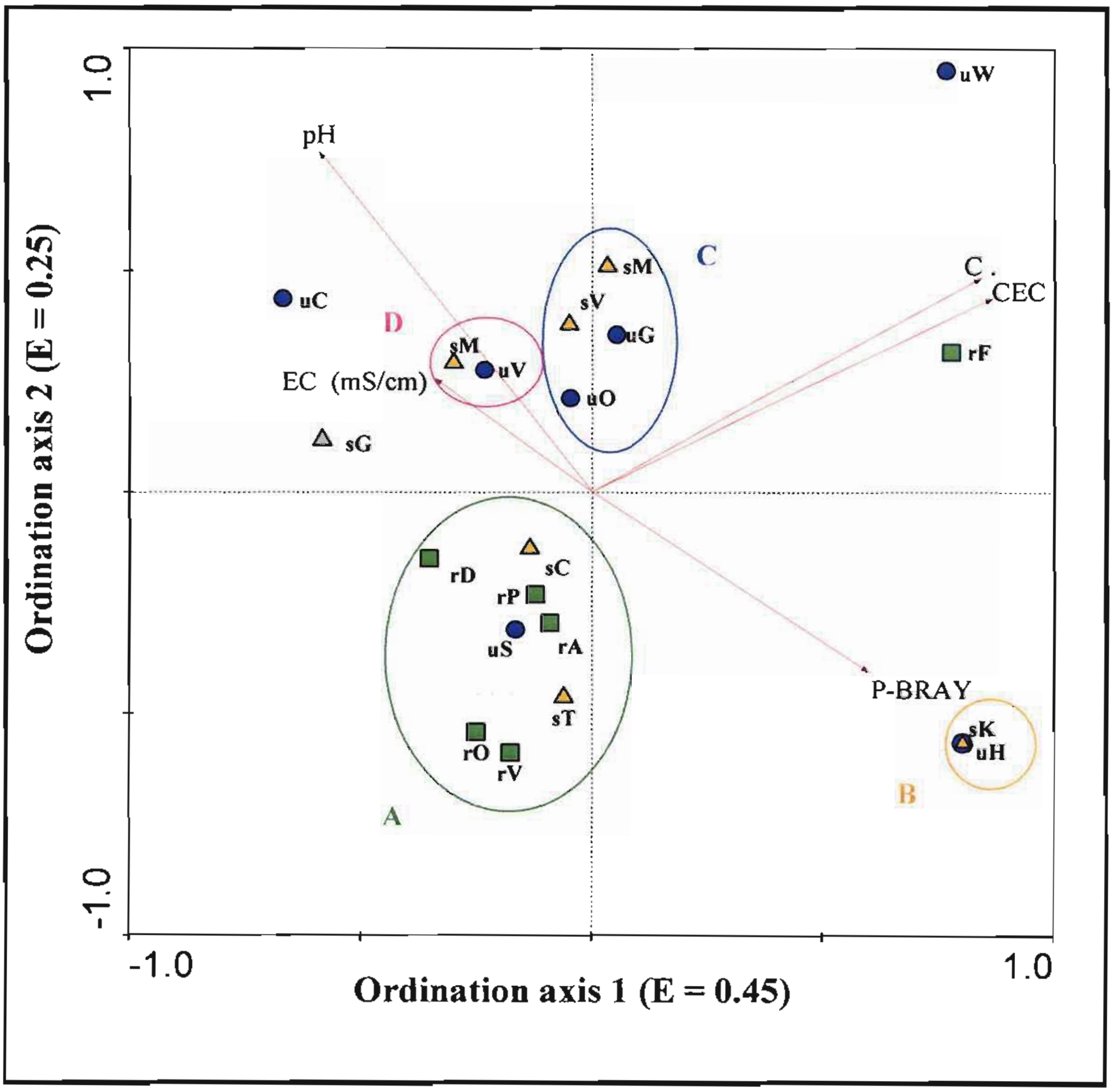

Figure 3.4 Principal Component Analysis (PCA) of the chemical characteristics of the soil from the twenty study sites in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

Se is a naturally occurring trace element found in most soils (Nakamaru *et al.*, 2005:109) and is formed by weathering of parent material such as shale (Black shale). Se can also be derived from the combustion of coal in electric power plants and in industrial, commercial and residential burners (Neal, 1995:264). The study site uO (Opkoms) is highly associated with Pb. One of the most important sources for Pb is vehicle emission (Sezgin *et al.*, 2003:979; Davydova, 2005:134; Leung & Jiao, 2006:753). This site is used as parking space for cars because of the shade of the trees and this could contribute to the high Pb levels in the soil.

The study sites and their associated broad chemical soil properties are presented in Figure 3.4 The study sites formed four groups (A, B, C, D) and four individual sites (uW-Wasgoedspruit, rF-Farm, uC-Church, sG-Grimbeek Park). Group A is a combination of urban, rural and suburban study sites. The group is not clearly associated with any of the chemical characteristics. Group B only includes two study sites (uH – High School, sK-Kynoch) and these sites are highly associated with P-BRAY. P-BRAY is a test used to determine the level of phosphorus in soil. The high levels of phosphorus in the soil could be from the fertilizer plant that is found in the same area as these two study sites. Group C is a combination of urban and suburban study sites and is not really associated with any the chemical characteristics of the soil. Group D includes two suburban study sites (sM-Meadow Street, uV-Viljoen Street) that are associated with pH and the EC (electrical conductivity, ms/cm). EC is the capacity of a substance to conduct and transmit electrical current. In soil, the EC is related to dissolved solutes (salinity), which is an indirect indicator of salt in the soil (Brady & Weil, 2002:426). The salts in soil are usually Cl and SO_4 of Ca, Mg, K and Na (Brady & Weil, 2002:426). Study site uV (Viljoen Street) lies on the border of a cultivated land and the high association with EC could be due to irrigation of the cultivated land (Anon, 2003). The study site sM (Meadow Street) is part of a municipal garden and the high association with EC could be from irrigation water (Anon, 2003). The main minerals in irrigation water are Cl, SO_4, HCO_3, Na, Ca and Mg (Anon, 2003). The pH of the study sites range between 4.22 and 7.60 and shows a wide range in the pH of the soil from the different study sites. The study site rF (Farm) is associated with C (carbon content) and CEC (Cation Exchange Capacity). The CEC is defined as the sum total of the exchangeable cations that a soil can absorb (Hausenbuiller, 1978:177; Brady & Weil, 2002:345). According to Brady & Weil (2002:348) clay soils are associated with high CEC. The study site rF (Farm) has a high clay content (see Table 4.4, Appendix A) and this could be the reason for the high association with CEC. A high

C-level is associated with high organic matter in the soil and the organic matter is usually associated with clay soils (Brady & Weil, 2002:20). The study site uW (Wasgoedspruit) is not clearly associated with any of the chemical properties, but uC (Church) and sG (Grimbeek Park) are to a certain extent associated with pH and EC, respectively.

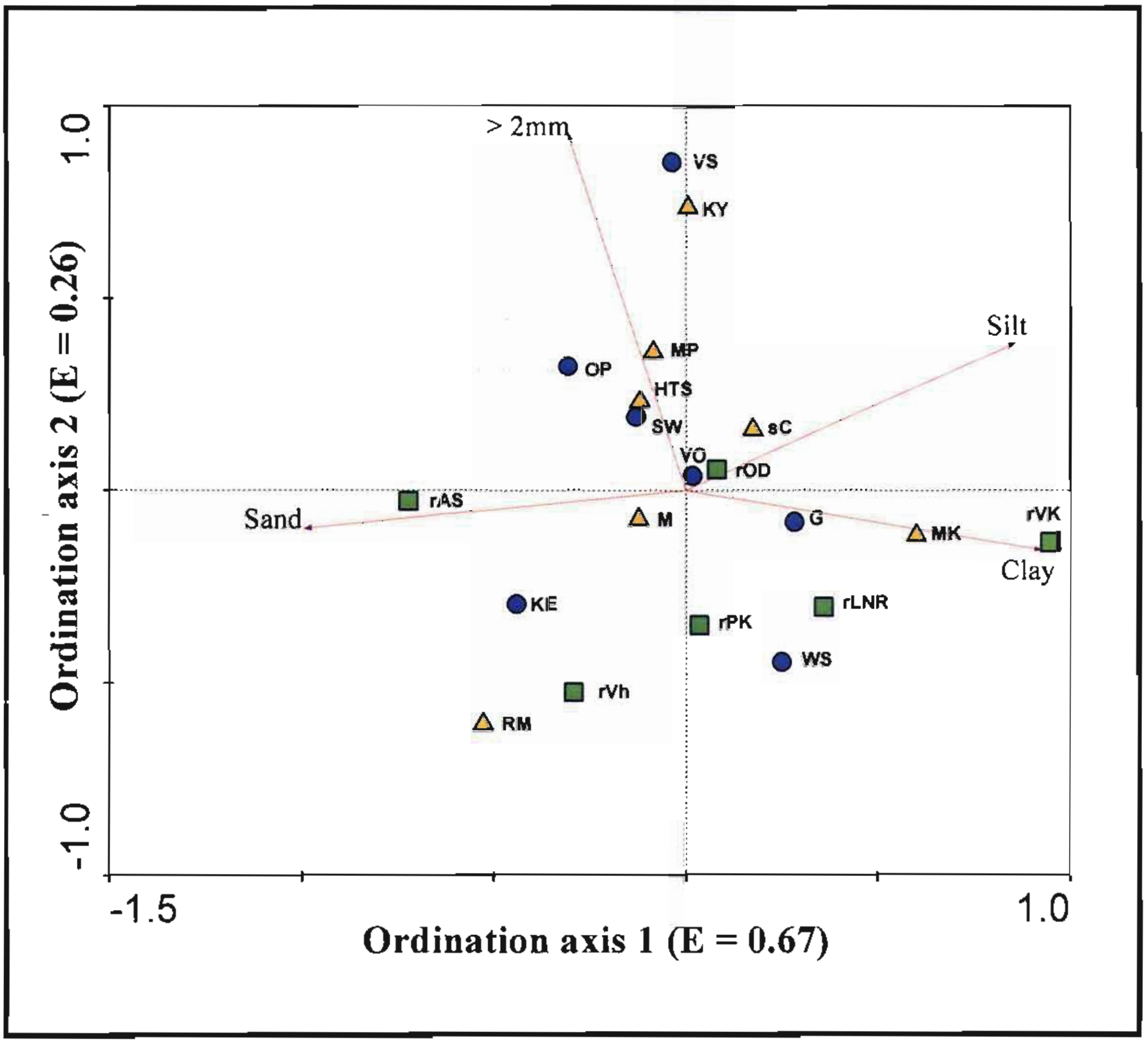

Figure 3.5 Principal Component Analysis (PCA) of the soil particle size distribution of the soil samples from the twenty study sites in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

The PCA ordination conducted for the soil particle size distribution that was found at each study site (Figure 3.5) indicated that the variables clay (particles smaller than 0.002 mm) and sand (Particles smaller than 2mm but bigger than 0.05 mm) are strongly associated with ordination axis 1 (E = 0.67), while silt (particles smaller than 0.05 mm) is associated to a lesser degree with this axis. A soil particle size greater than 2 mm (> 2 mm) is strongly associated with ordination axis 2 (E = 0.26). The study sites are scattered and no distinctive group was formed. This finding, i.e. the heterogeneity within the data, corroborates the statement made by Mullins (1991:87), that urban soil can be seen as artificial material that has some of the physical properties of soils in their natural or agricultural environment. The rural study site rD (Dassierand) is strongly associated with sandy soils while the study sites uG (Gimnasium), sV (Van der Hoff Park) and rF (Farm) are strongly associated with clay soils. The study sites uG (Gimnasium), sV (Van der Hoff Park), rF (Farm), rO (Oudedorp), uH (High School) and sC (Cemetery) have high silt contents (see Table 4, Appendix A), which give these soils a much greater compressibility (Brady & Weil, 2002:169). In the case of study sites uG (Gimnasium), sV (Van der Hoff Park) and rF (Farm), the elevated clay contents will be more prone to compaction than the other sites. The study sites uO (Opkoms), sP (Mooivallei Park), sT (Technical High School) and uS (Station Road) are associated with a soil particle size greater than 2 mm.

3.1.3 Conclusion

None of the soil characteristics studied was clearly associated with the urban-rural gradient. In other words, urbanization in general does not seem to affect the measured soil characteristics directly. Specific human influences, which are not necessarily, associated with either urban or rural areas, such as the fertilizer plant, irrigation, soil compaction and vehicle emission are highly localized and influence the soil contents directly.

3.2 Vegetation composition

3.2.1 Results and discussion

For each study site the vegetation that is associated with the *Acacia karroo* trees along the urbanization gradient was identified, classified and described. The associated vegetation was regarded as the plants which occur within the drip line of the tree crowns. The associated vegetation represented the main biotic component of the habitat of *Acacia karroo*. A Destrended Correspondence Analysis ordination (DCA) of the study sites according to their vegetation composition show a definite urbanization gradient along ordination axis 1with the rural sites situated on the left and the urban sites more to the right along ordination axis 1, while the suburban study sites are situated more or less in between the two groups (Figure 3.6).

According to the classification of the vegetation, the study sites could be divided into three groups, which can be regarded as three main groups, which are shown clearly in a dendogram (Figure 3.7). Community 1 represents the rural study sites, Community 2 included most of the suburban study sites and Community 3 included most of the urban study sites. The results from the TWINSPAN classification was also used to construct a phytosociological table (Table 3.2).

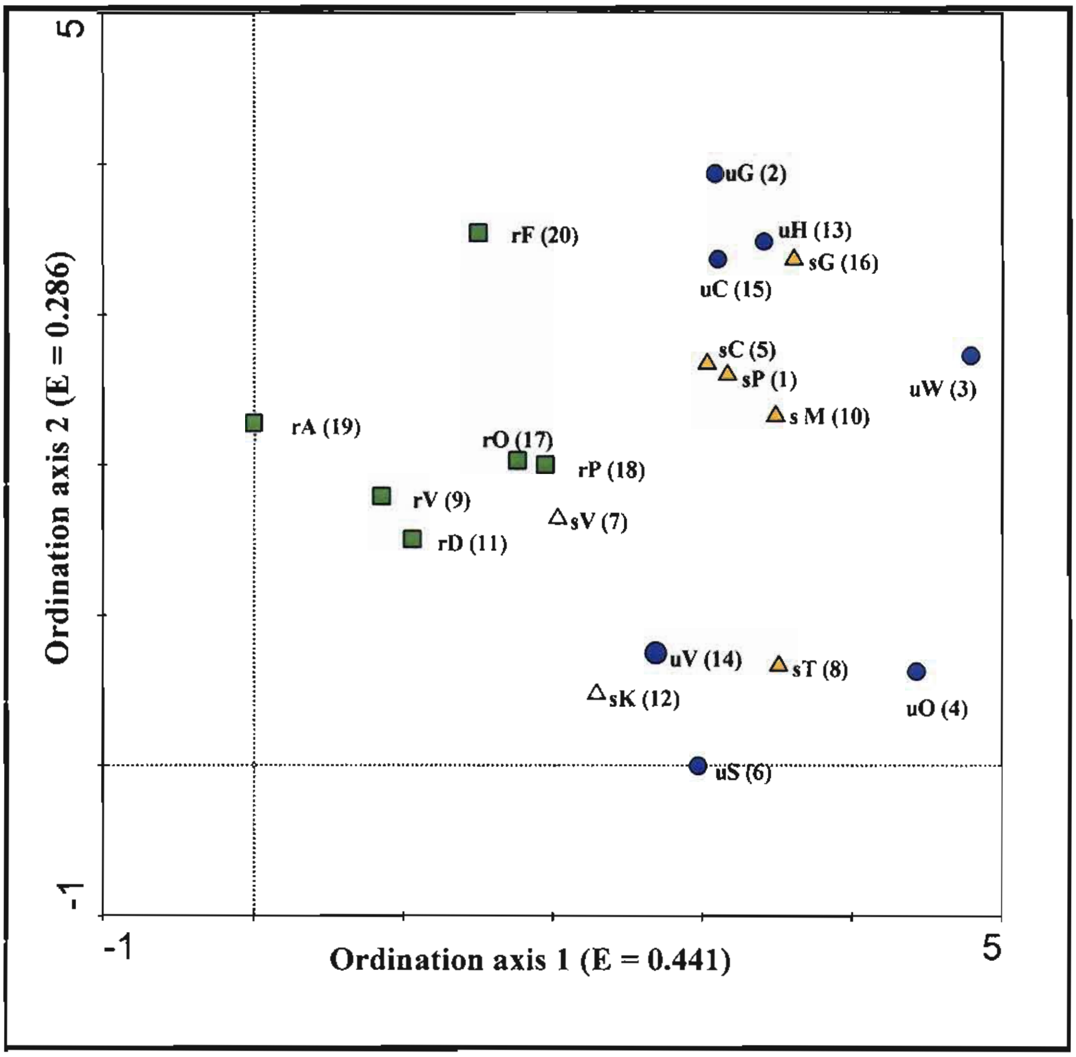

Figure 3.6 Detrended Correspondence Analysis (DCA) that illustrates the grouping of the study sites according to the vegetation composition of the different study sites in the Potchefstroom Municipal Area. The green squares represent the rural study sites, the orange triangles represent the suburban study sites and the blue circles represent the urban study sites (according to the V-I-S model). Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

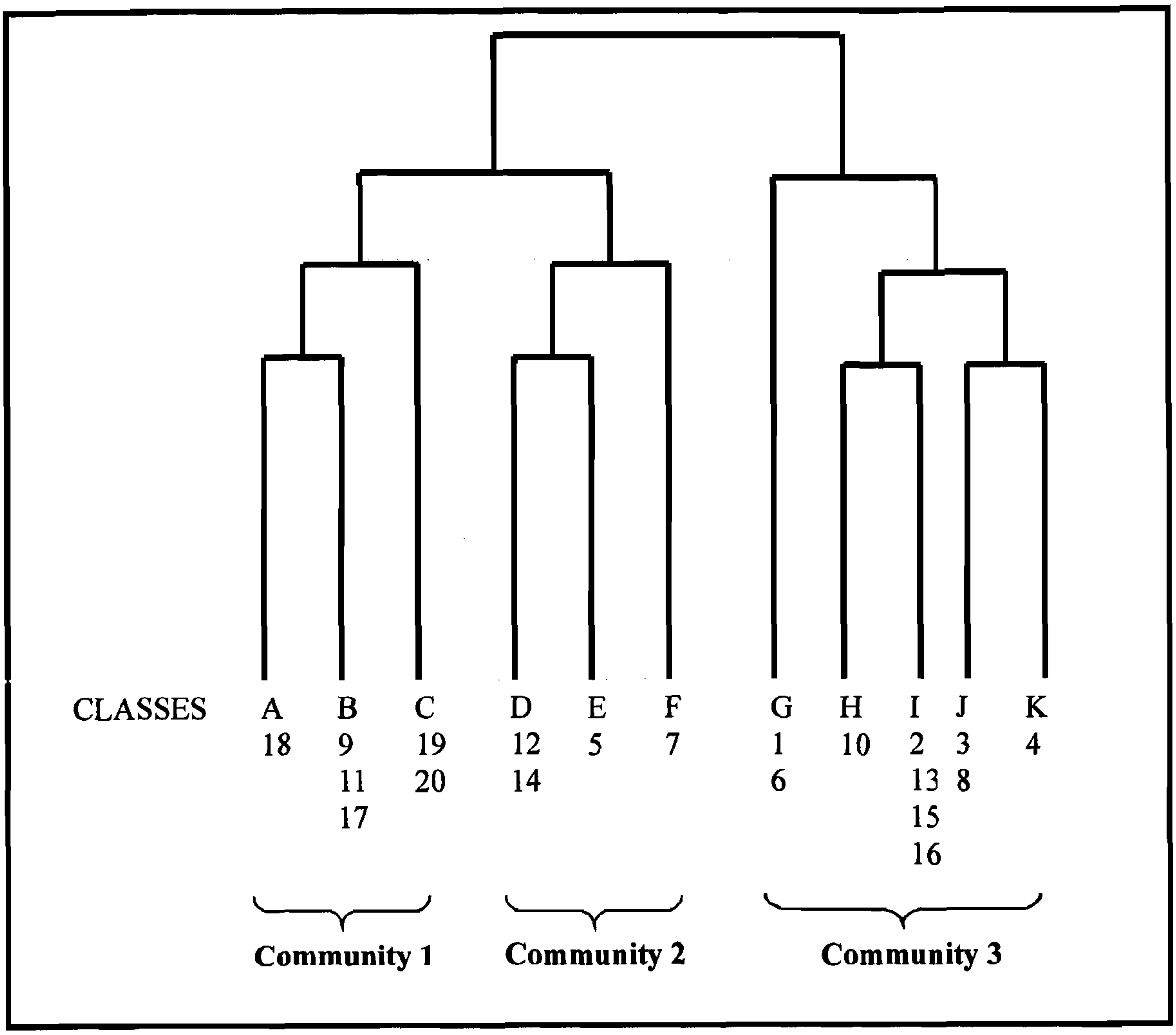

Figure 3.7. Dendogram following TWINSPAN classification that illustrates the grouping of the study sites according to their vegetation composition for *Acacia karroo* in the Potchefstroom Municipal Area.

Table 3.2 Phytosociological table of all the *Acacia karroo* study sites in the Potchefstroom Municipal Area.

Relevé numbers	18	17	9	11	19	20	12	5	14	7	1	6	10	2	13	15	16	3	8	4
Site name	rP	rO	rV	rD	rA	rF	sK	sC	uV	sV	sP	uS	sM	uG	uH	uC	sG	uW	sT	uO
Number of species	32	21	36	38	23	28	25	25	29	19	34	19	23	16	19	12	7	25	30	22
Communities	**Community 1**						**Community 2**				**Community 3**									
Species group A																				
Setaria sphacelata var. *torta*	1	+	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Themeda triandra	1	.	a	1	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asparagus suaveolens	1	+	+	+	1	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Pavonia burchellii	+	.	1	1	1	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.
**Achyranthes aspera* [2]	+	.	.	+	b	a	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Grewia flava	+	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Clematis brachiata	.	.	.	+	b	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Eragrostis superba	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species group B																				
Cymbopogon plurinodis	1	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Antizoma angustifolia	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asparagus africanus	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cucumis zeyheri	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Turbina oblongata	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Salsola kali*	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species group C																				
Digitaria eriantha	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis plana	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crabbea acaulis	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Heteropogon contortus	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Jamesbrittenia aurantiaca*	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tephrosia species	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Ligustrum lucidum* [1]	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Cuscuta campestris* [2]	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Datura stramonium* [2]	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Solanum incanum	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Verbena tenuisecta*	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Galium spurium*	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Zinnia peruviana*	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Salvia runcinata	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Relevé numbers	18	17	9	11	19	20	12	5	14	7	1	6	10	2	13	15	16	3	8	4
Site name	rP	rO	rV	rD	rA	rF	sK	sC	uV	sV	sP	uS	sM	uG	uH	uC	sG	uW	sT	uO
Number of species	32	21	36	38	23	28	25	25	29	19	34	19	23	16	19	12	7	25	30	22
Communities	**Community 1**						**Community 2**				**Community 3**									
Species group D																				
Rhus pyroides	+	1	+	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Ziziphus zeyheriana	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hibiscus pusillus	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Vernonia oligocephala	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Teucrium trifidum	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species group E																				
Ziziphus mucronata	.	.	.	.	a	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Cosmos bipinnatus*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Panicum coloratum var. *colaratum*	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Cirsium vulgare* [2]	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Rumex crispus* [1]	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species group F																				
**Physalis viscosa*	.	.	.	+	.	+	+	+	+	+	.	1	.	.	.	.	.	.	.	.
Rhus lancea	.	.	.	.	.	.	.	+	+	r	.	.	.	.	.	.	.	.	.	.
**Cestrum laevigatum* [2]	.	.	.	.	.	.	.	.	a	1	.	.	.	.	.	.	.	.	.	.
**Araujia sericifera* [2]	.	.	.	.	.	.	.	1	.	+	+	+	.	.	.	.	.	.	.	.
Stachys hyssopoides	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.
**Ambrosia psilostachya*	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	.	.
**Atriplex semibaccata*	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
**Sorghum bicolour*	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
**Sisymbrium orientale*	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Sida rhombifolia	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
**Morus alba* [1]	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.
Species group G																				
**Chenopodium album*	+	.	.	.	1	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
**Galinsoga parviflora*	.	.	.	.	.	a	1	.	+	.	.	.	.	.	.	.	.	.	.	.
Species group H																				
**Amaranthus hybridus*	.	.	+	+	.	+	.	.	+	+	.	.	.	.	.	.	.	r	.	+
Celtis africana	.	+	.	+	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
**Ipomoea purpurea* [1]	.	.	+	+	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.
Hyparrhenia hirta	.	+	+	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.
**Pseudognaphalium undulatum*	.	.	1	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.

Relevé numbers	18	17	9	11	19	20	12	5	14	7	1	6	10	2	13	15	16	3	8	4
Site name	rP	rO	rV	rD	rA	rF	sK	sC	uV	sV	sP	uS	sM	uG	uH	uC	sG	uW	sT	uO
Number of species	32	21	36	38	23	28	25	25	29	19	34	19	23	16	19	12	7	25	30	22
Communities	**Community 1**						**Community 2**				**Community 3**									
Pentarrhinum insipidum	.	.	+	1	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Convolvulus sagittatus	.	+	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
**Commelina benghalensis*	.	.	+	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
**Solanum elaeagnifolium* [2]	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Species group I																				
Setaria verticillata	b	+	+	.	+	+	1	+	+	+	.	.	.	.	.	.	.	.	+	.
**Tagetes minuta*	1	1	+	+	1	1	.	1	.	+	+	.	.	.	.	.	.	.	.	.
Eragrostis chloromelas	+	.	1	+	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	a
Panicum maximum	+	.	.	1	.	.	+	1	+	.	.	a	.	.	.	.	.	.	.	1
Sida spinosa	1	+	+	+	.	.	.	.	+	.	+	.	.	.	.	.	.	.	+	.
Species group J																				
Oxalis corniculata	.	.	+	+	.	a	.	.	.	.	+	.	+	+	1	+	+	1	+	.
Chloris pycnothrix	.	.	.	.	.	.	.	.	.	.	1	a	+	+	.	.	.	b	1	b
**Modiola caroliniana*	.	.	.	+	.	+	.	.	.	.	+	1	.	+	a	.	+	1	+	.
Cotula australis	.	.	.	.	.	.	.	.	.	.	+	.	.	+	a	+	.	+	+	+
**Taraxacum officinale*	.	.	.	.	.	.	.	.	.	+	+	.	+	.	+	.	+	1	.	+
Conyza podocephala	+	.	+	.	.	.	.	.	.	+	.	+	1	.	+	.	.	+	+	+
**Plantago lanceolata*	+	.	.	.	.	+	.	.	.	.	.	+	1	.	1	.	.	1	1	.
**Eleusine coracana*	.	.	.	.	.	.	+	.	.	.	+	.	.	+	.	+	.	.	+	+
Species group K																				
**Poa pratensis*	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Senecio consanguineus	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
**Senna* species [1]	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Falckia oblonga	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Lepidium africanum	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Species group L																				
**Celtis sinensis*	.	.	.	.	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.
**Gleditsia triacanthos* [1]	.	.	.	.	.	.	.	+	.	.	1	.	.	.	.	.	.	.	.	.
**Bidens pilosa*	.	.	.	.	.	.	+	.	.	.	1	.	.	.	.	.	.	.	.	.
**Bromus catharticus*	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.
**Medicago sativa*	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	.	.

Relevé numbers	**18**	**17**	**9**	**11**	**19**	**20**	**12**	**5**	**14**	**7**	**1**	**6**	**10**	**2**	**13**	**15**	**16**	**3**	**8**	**4**
Site name	**rP**	**rO**	**rV**	**rD**	**rA**	**rF**	**sK**	**sC**	**uV**	**sV**	**sP**	**uS**	**sM**	**uG**	**uH**	**uC**	**sG**	**uW**	**sT**	**uO**
Number of species	32	21	36	38	23	28	25	25	29	19	34	19	23	16	19	12	7	25	30	22
Communities	**Community 1**						**Community 2**				**Community 3**									
Species group M																				
Asparagus laricinus	1	b	b	b	3	3	.	.	1	b	1	+	.	.	.	.	.	.	.	.
**Bidens bipinnata*	1	a	1	a	1	+	b	.	+	.	a	+	.	.	.	.	.	.	.	.
Urochloa mosambicensis	1	1	.	+	.	.	a	.	+	+	+	b	+	.	.	.	.	.	.	.
**Verbena bonariensis*	.	+	+	.	1	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.
Sporobolus fimbriatus	.	.	.	.	+	+	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Oxalis species	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Species group N																				
**Cichorium intybus*	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
**Melia azedarach* [1]	.	.	.	.	.	.	.	.	.	.	+	.	r	.	.	.	.	.	.	.
Chloris virgata	.	.	.	.	.	.	.	.	.	.	.	a	+	.	.	.	.	.	.	.
**Malva neglecta*	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.
Species group O																				
Moraea thomsonii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
**Capsella bursa-pastoris*	.	.	.	.	.	.	.	.	+	.	.	.	.	+	+	+	.	.	.	.
Species group P																				
Urochloa panicoides	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	1	+	1
Sporobolus africanus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	a	+	.
Gazania krebsiana var. *serrulata*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.
**Ciclospermum leptophyllum*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Eragrostis lehmanniana	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	a	.
**Medicago polymorpha*	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.	.
Lotononis listii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Felicia muricata	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Cyperus obtusiflorus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
**Gomphrena celosioides*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.
**Hypochaeris glabra*	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.
Ledebouria revoluta	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
**Euphorbia peplus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.
Species group Q																				
**Poa annua*	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	a	a	.	1
**Guilleminea densa*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	1	1	a
**Chamaesyce hirta*	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	1	.	.

Relevé numbers	**18**	**17**	**9**	**11**	**19**	**20**	**12**	**5**	**14**	**7**	**1**	**6**	**10**	**2**	**13**	**15**	**16**	**3**	**8**	**4**
Site name	**rP**	**rO**	**rV**	**rD**	**rA**	**rF**	**sK**	**sC**	**uV**	**sV**	**sP**	**uS**	**sM**	**uG**	**uH**	**uC**	**sG**	**uW**	**sT**	**uO**
Number of species	32	21	36	38	23	28	25	25	29	19	34	19	23	16	19	12	7	25	30	22
Communities	**Community 1**						**Community 2**				**Community 3**									
**Coronopus didymus*	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	+	.
Species group R																				
**Pennisetum clandestinum*	.	.	.	.	.	.	+	3	+	.	3	.	b	+	b	b	4	1	.	.
**Alternanthera pungens*	.	.	.	.	.	+	+	.	+	+	+	.	+	+	.	.	.	1	+	.
**Paspalum dilatatum*	.	.	.	.	.	.	+	.	+	.	+	.	.	.	.	.	.	1	+	1
Cynodon hirsutus	.	.	.	.	.	.	a	.	a	.	.	.	1	.	+	.	.	.	a	a
**Picris echioides*	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	r	.
Species group S																				
Acacia karroo	4	4	4	4	4	3	4	4	3	3	3	3	4	3	4	4	4	3	3	3
Atriplex species	1	a	3	3	a	a	b	+	+	1	1	+	+	+	.	+	.	1	+	+
**Malvastrum coromandelinum*	+	.	.	+	1	+	b	1	a	a	+	a	1	+	.	.	.	.	+	1
**Dichondra repens*	+	.	.	.	1	3	.	+	a	1	+	1	a	3	3	b	1	b	+	1
Cynodon dactylon	.	1	.	1	.	+	.	.	1	+	.	.	b	.	+	+	.	b	1	b
**Conyza bonariensis*	.	.	+	.	.	+	+	+	.	.	+	+	.	+	.	.	.	1	.	+
**Lepidium bonariensa*	.	.	.	+	.	.	+	.	.	.	.	.	+	+	.	.	.	.	+	1

* Exotic species, [1]DI – Declared invader, [2]DW – Declared weed (Botha, 2001, Henderson, 2001)

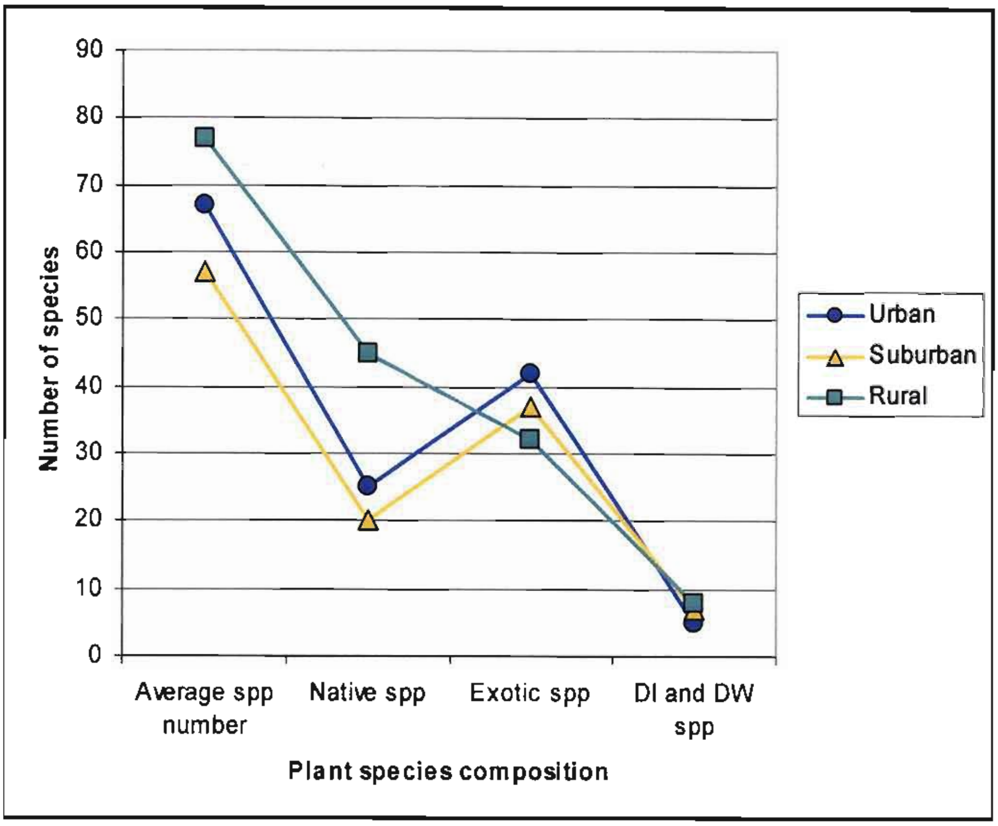

Figure 3.8 Plant species composition at the three different types of study sites for *Acacia karroo* in the Potchefstroom Municipal Area.

Community 1 represents the vegetation of all the rural study sites. These sites can be regarded as natural areas on the city margin of Potchefstroom and had 96%-100% vegetation cover and 0%-2% impervious surface cover according to the V-I-S model (Ridd, 1995:2173). The study sites in this community received no maintenance at all. This community includes 77 plant species with 45 native plant species and 32 exotic plant species of which five are declared weeds (DW) and three are declared invaders (DI) (Figure 3.8). The differential species of this community are the species from Species group A (Table 3.2). The grass *Themeda triandra* is a prominent species in this community and is usually found in grasslands of the Bc land type as previously discussed by Bezuidenhout and Bredenkamp (1991:508). The shrub-like species *Asparagus suaveolens* is also a prominent species in this community and was previously described by Bezuidenhout and Bredenkamp (1991:503) as occurring in the *Acacia karroo* Community. Species group A also included species such as the forbs *Pavonia burchellii* and *Achyranthes aspera* and the grass *Setaria sphacelata* var. *torta*. Community 1 included species that are not found in all the study sites but are specific to a site and are represented by Species groups B, C, D and E. The rural study sites also share a considerable number of species with the suburban areas (Species group G, H, I) and less species with the urban areas (Species group L). The vegetation composition of Community 1 was previously discussed by Cilliers *et al.* (1999:20) in their discussion of the vegetation of the natural and semi-natural areas in the Potchefstroom municipal area. According to their study, they classified the vegetation into six communities of which the *Acacia karroo* community best described the rural study sites in this study. Bezuidenhout and Bredenkamp (1991:100) described the same vegetation community in their study of the vegetation of the Bc-land type of the Western Transvaal. According to them the vegetation of the rural study sites can be described as the *Acacia karroo* all. nov., which consists of the woody species *Acacia karroo* and *Rhus pyroides*, the shrub-like species *Asparagus suaveolens* and *Asparagus laricinus*. As described by Cilliers *et al.* (1999:22), the *Acacia karroo* community covers large areas on the city margin and is characterised by the woody species *Celtis africana* and the shrubs *Grewia flava*, *Rhus pyroides*, *Asparagus laricinus* and *Asparagus sauveolens*. The herbaceous species include forbs such as *Bidens bipinnata* and *Tagetes minuta* as well as the grass species *Themeda triandra*. Most of the species that are described in the *Acacia karroo* community of Cilliers *et al.* (1999:22) are presented in the Species groups that distinguished the rural study sites from the more urban study sites.

Community 2 includes the study sites, which can be regarded as more suburban sites, with the exception of uV (Viljoen Street). The suburban sites are areas with 42%-58% impervious surface cover and 46%-57% vegetation cover. These sites receive low to moderate maintenance and are exposed to disturbances such as trampling. The suburban study sites included areas that form a transition zone between two types of land uses (for example between industrial area and a residential area) or it can be semi natural patches within the urban areas. The vegetation composition consists of 57 plant species with 20 native species and 37 exotic species of which four are DW and three are DI (Figure 3.8). The differential species of this community are the species from Species Group F. Species that are typically found in these suburban areas include the climber *Araujia sericifera,* which was previously discussed by Cilliers and Bredenkamp (1999b:163) and the forb *Physalis viscose,* which is a prominent species in this community and is characteristic of disturbed open places. Other species that were found in this community but which were not prominent species include species from Species group G, H and I, which are found in both the rural and the suburban study sites and differentiated these study sites from the urban study sites. These Species groups include indigenous grasses such as *Hyparrhenia hirta*, *Eragrostis chloromelas* and *Setaria verticillata,* which are commonly found in grasslands and disturbed areas (Van Oudtshoorn, 2004).

The vegetation composition in the study sites in Community 2 resembles those of the study sites that Cilliers and Bredenkamp (2000:163) described as vacant lots and roadside verges. According to Cilliers and Bredenkamp (2000:231), the *Acacia karroo* communities which are established on these study sites could be there due to the encroachment of woody plants such as *Acacia karroo* and *Asparagus laricinus*, which was described by Bezuidenhout and Bredenkamp (1991,100) as the *Acacia karroo* alliance of the Bc-land type. The study sites in Community 2 are situated mainly in residential areas and industrial areas on the city margin and according to Cilliers and Bredenkamp (2000:231), the *Acacia karroo* communities will probably not develop spontaneously on residential and commercial vacant lots closer to the city centre, because of strict maintenance policies implemented by the municipality. The vegetation composition that is associated with the *Acacia karroo* communities of the vacant lots and roadside verges, as discussed by Cilliers and Bredenkamp (2000:231), is fairly similar to the vegetation, which is included in Community 2 (Table 3.3). These species included woody species such as *Acacia karroo* and *Asparagus laricinus*, herbaceous species *Tagetes minuta*, *Amaranthus hybridus*, *Bidens bipinata* and grass species *Setaria verticillata*.

Community 3 included most of the urban study sites and four of the suburban sites. The urban study sites have sites with 58%-96% impervious surface cover and 4.6%-40% vegetation cover and the suburban sites are areas with 42%-58% impervious surface cover and 46%-57% vegetation cover. These study sites are areas that are well maintained such as gardens, parks and schoolyards. These types of sites were described by Cilliers and Bredenkamp (1999a: 59) as spontaneous vegetation of intensively managed urban open spaces. The study sites undergo high levels of disturbance such as trampling or mowing of lawns. Community 3 consists of 67 plant species, which included 25 native plant species, and 42 exotic plant species of which one is a DW and four are DI (Figure 3.8). The high number of exotic species is also an indication of high levels of disturbance and is characteristic of the urban environment. The differential species of this community are the species from Species group J. Other Species groups that are included in this community are Species group L, N, O and P. Species group J include species such as the annual grass *Chloris pycnothrix*, which is a common weed in disturbed places such as gardens and lawns (Van Oudtshoorn, 2004:232), the prostrate forb *Modiola caroliniana*, which is especially found on lawns (Botha, 2001:276) and the forb *Oxalis corniculata*, which is a common species found in disturbed areas such as lawns and sports fields (Botha, 2001:292). Although study sites sP (Mooivallei Park) and uS (Station Road) are actually more suburban study sites, based on the V-I-S model, they are included in Community 3 based on the species from Species group J. Species group Q differentiates the urban study sites from study sites sP (Mooivallei Park) and uS (Station Road). The species that differentiate the urban study sites are species such as the grass *Poa annua* and the forbs *Guilleminea densa, Chamaesyce hirta* and *Coronopus didymus.* These plant species are species with a prostate growth form and are found in disturbed areas such as lawns. The species from Species group K and L differentiate study sites sP (Mooivallei Park) and uS (Station Road) from the rest of the urban study sites in Community 3. Species groups K and L include species such as the forbs *Senecio consanguineus and Lepidium africanum.* Although these species are also found in disturbed areas they grow much taller than the species from Species group Q. This seems to be the main difference between the two sub-communities in Community 3. The study areas in the urban environment undergo maintenance and the taller weeds are, therefore, removed, but in the more suburban study sites the taller weeds are not removed because of less maintenance. The study sites 1 and 6 are not only associated with Community 3 but also have species similar to those from Community 1 and Community 2 (Species group M, Table 3.2) and included the following plant species: the shrub *Asparagus laricinus* the grasses *Urochloa mosambicensis, Sporobolus fimbriatus* and the forbs *Bidens bipinnata, Verbena bonariensis, and Oxalis* species. From the vegetation composition of study sites sP (Mooivallei Park) and uS (Station Road), it is possible that these two sites form transitional zones (ecotones) between two ecological communities. These transition zones include species that are representative of all the groups and some species that are only found in that specific zone.

Cilliers and Bredenkamp (1999a, 63) described three plant communities that are associated with disturbed or high-level maintenance urban areas, but which do not always contain *Acacia karroo*, *Alternanthera pungens –Guilleminea densa* sub-community, *Paspalum dilatatum* sub-community and *Eragrostis lehmanninana* community. The *Alternanthera pungens – Guilleminea densa* community is associated with heavy trampling and this could result in the development of bare patches. This community also included the dominant grass species *Cynodon dactylon* as well as other grass species such as *Cynodon hirsitus* and *Poa annua*. The *Paspalum dilatatum* community is situated on pavements and invade *Pennisetum clandistinum* lawns that are planted on the pavements (Cilliers & Bredenkamp, 1998:135). This community usually occurs where there is moderate trampling of the vegetation cover. The indigenous grass species *Eragtostis lehmanniana* is a grass species that is associated with disturbed areas as described by Cilliers and Bredenkamp (1998, 135).

3.2.2 Conclusion

According to the vegetation composition (Table 3.2), the study sites can be divided into three groups: Rural (Community 1), Mainly suburban (Community 2) and Mainly urban (Community 3). Although each community is differentiated from the others by a specific vegetation composition, there is a group of species that occurs in all three the communities namely Species group S. These species include the woody species *Acacia karroo*, the forbs *Atriplex* spp., *Malvastrum coromondelianum, Dichondra repens, Conyza bonariensis* and *Lepidium bonariensis*, and the grass *Cynodon dactylon*. The vegetation composition could, therefore, also be used as a parameter to further characterize the urbanization gradient. It is also evident from Figure 3.8 that the community with the highest number of exotic species was found on the urban study sites. The community with the lowest number of exotic species is community 1, the rural study sites. There are more disturbances in the urban environments that could lead to the establishment of higher numbers of exotic species. The urban study sites could, therefore, be classified as study sites with high maintenance, high levels of disturbance, more exotic species but also a relatively high number of species. The rural study sites can be classified as study sites with low maintenance or no maintenance at all, not too much disturbance and less exotic species, but with the highest number of total species. The suburban study sites are study sites that fall between these two types.

Chapter 4

Tree appraisal

4.1 Introduction

In urban areas, there is a variety of different types of green spaces e.g. parks, school yards, gardens and sport fields. These green spaces, as well as all the trees there in, contribute to the health and well-being of humans (Bolund and Hunhammar, 1999:294; McPherson *et al.,* 2001:1). The area around these green spaces, as well as the activities that are associated with these areas, can influence the contribution these spaces make to human life, as it could influence the vitality of the trees in these green spaces.

In this chapter, the general appearance of the trees at each study site is described. The appearance of the trees was described using the South African Tree Appraisal Method (SATAM).

4.2 Results and discussion

For the analysis of the tree appraisal data, Detrended Correspondence Analysis (DCA) was used. For some of the analyses all of the tree appraisal characteristics were used, but for others only specific tree appraisal characteristics were used. The study sites were divided into rural study sites (control) and the more urbanized study sites, which include suburban and urban study sites. Throughout this chapter, the rural study sites are represented by the colour green, the suburban study sites are represented by the colour orange and the colour blue represents the urban study sites. Figure 4.1 is an illustration of all the tree appraisal characteristics and the study sites. See Appendix A for a list of all the tree appraisal characteristics that were used. As can be seen from Figure 4.1, the study sites form more or less one group with the rural study sites all grouped together to the right of the group. Because there are too many tree appraisal characteristics, only some of the characteristics were subjectively chosen to illustrate the association between the study sites and the characteristics. Only the tree appraisal characteristics that are representative of a specific group (rural or more urbanized) were chosen and not those that are shared among the groups. The specific characteristics can be seen in Table 4.1. For example: the characteristic ECOF (Eco-friendliness) is only applicable to the study sites which are more urban and thus distinguish these sites from the rural sites, whereas the characteristic DBV (Dead branches) is only applicable to the rural sites and thus distinguish these sites from the more urban sites. A characteristic like FBV (Bird visiting) is applicable to all the sites and was thus not used. This technique was used to filter the tree appraisal characteristics in an attempt to better illustrate the difference between the different study sites based on the tree appraisal characteristics.

Table 4.1 Tree appraisal characteristics that distinguish the rural study sites from the urban and suburban study sites, in the Potchefstroom Municipal Area.

Rural study sites characteristics		**Urban study sites characteristics**	
DBV	Dead branches visible	**PPT**	Pathogens/pest on trunks
SOB	Seams and cracks on branches	**MB**	Missing bark
IBB	Included bark in branches	**IU**	Influence utilisation of the area (e.g. parking area, picnic site)
EDT	Even distribution of healthy twigs	**RID**	Influence design of park/garden
EFD	Even foliage distribution	**ID**	Influence design of landscape
LIV	Loss in Vigour	**IB**	Influence the background
		SUV	Screen unsightly views
		DS	Define a space
		CTL	Contribute to the landscape
		AF	Tree planted to attract fauna
		ECOF	Establish eco-friendly garden
		VRF	Visible root flairs

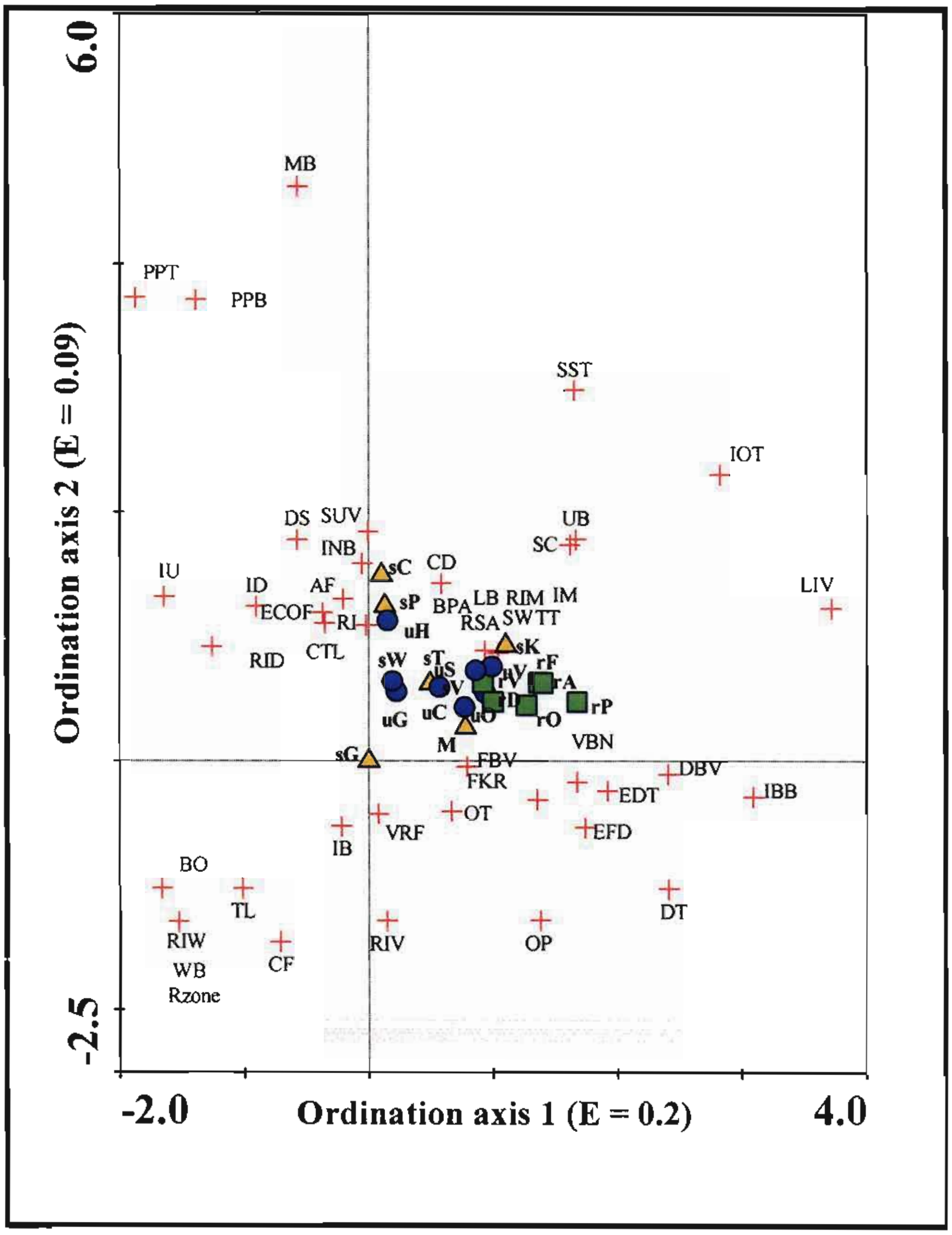

Figure 4.1 Detrended Correspondence Analysis (DCA) of the different study sites and all the tree appraisal characteristics used for *Acacia karroo* in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites, the green squares represent the rural study sites and the red crosses represent the tree appraisal characteristics. Symbols for the tree appraisal characteristics are explained in Table 5 (Appendix A). Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

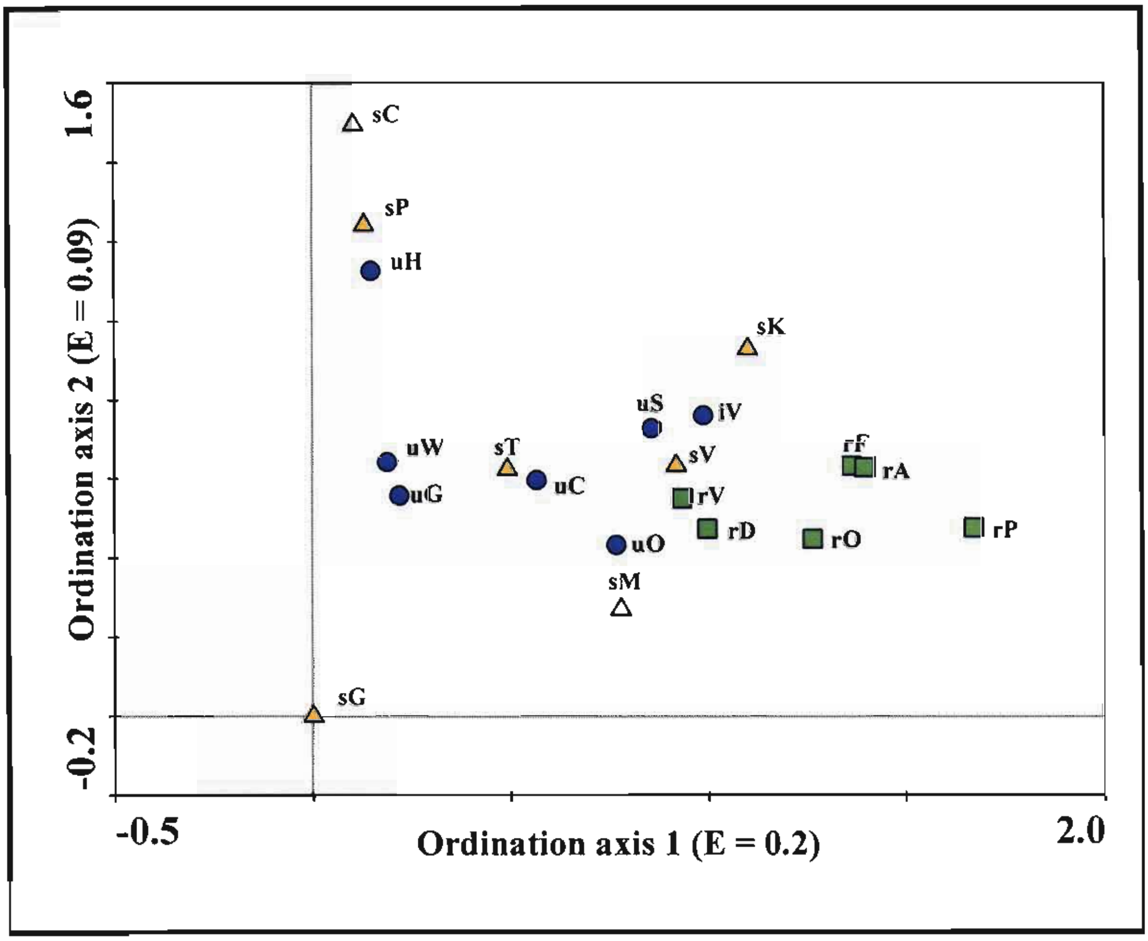

Figure 4.2 Detrended Correspondence Analysis (DCA) of the different study sites according to all the tree appraisal characteristics used for *Acacia karroo* in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

DCA was also used to group the different study sites by first using all the tree appraisal characteristics (Figure 4.2) and then according to the selected tree appraisal characteristics (Figure 4.3). It is evident from both Figures (Fig 4.2 and Fig 4.3) that the rural study sites are all grouped to the right along ordination axis 1 and the suburban and urban study sites are arranged to the left along ordination axis 1. Although the urban and suburban sites do not form distinctive groups, there is a general urbanization gradient from left to right along ordination axis 1 based upon the tree appraisal characteristics that were used. There are, therefore, specific characteristics, which are related more to trees in rural areas than to those in urban areas. It seems, however, that the trees in urban and suburban areas are quite similar with respect to the appraisal characteristics that were used.

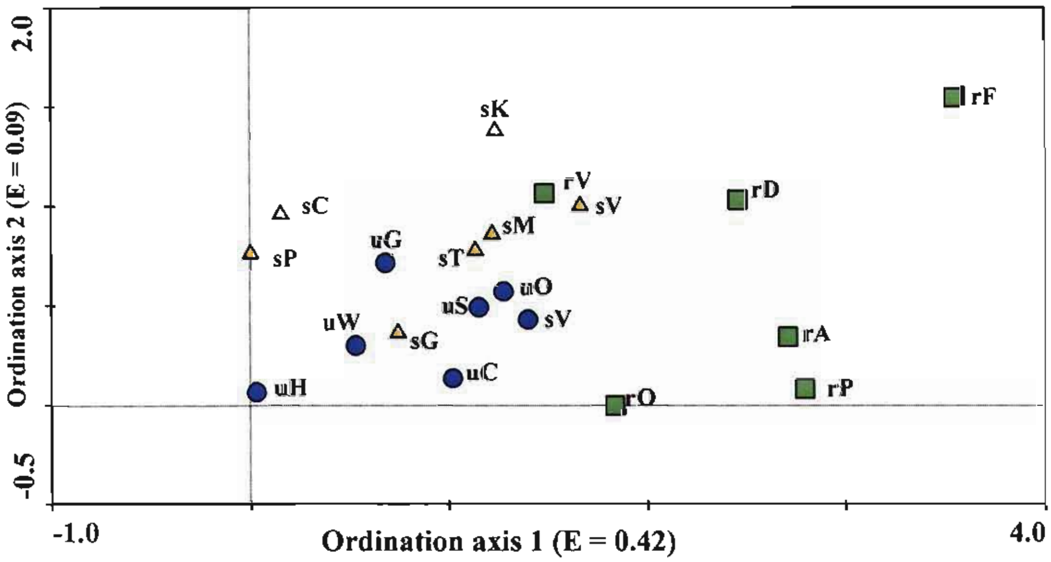

Figure 4.3 Detrended Correspondence Analysis (DCA) of the different study sites according to the selected tree appraisal characteristics used for *Acacia karroo* in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites and the green squares represent the rural study sites. Symbols for the study sites referred to more detail descriptions of the study sites in Table 2.3 in Chapter 2.

A DCA was also used to show both the study sites and the selected tree appraisal characteristics (Figure 4.4). The Figure illustrates the grouping of the study sites according to the different selected tree appraisal characteristics as indicated in Table 4.1.

The tree appraisal characteristic LIV (Loss in vigour) is strongly associated with the rural study site rF (Farm). Loss in vigour is a typical characteristic associated with rural trees because there is no maintenance and the trees have much dead wood/branches and are thus aesthetically unappealing (Figure 4.5).

The tree appraisal characteristic DBV (dead branches visible) is another indication that there is no maintenance on the trees and it may be that the trees are shedding branches, which may be an indication of maturing and a loss in vigour (Marx, 2005). The characteristics IBB (Included bark in branches) and SOB (Seams and cracks on branches) were more associated with study sites rO (Oudedorp), rA (Agricultural) and rP (Pienaarskamp). These two characteristics are also an indication of loss in vigour. The cracks/seams in the branches could lead to failure, while the included bark is an indication of a weak union, which could also lead to failure (Marx, 2005). The characteristics EFD (Even foliage distribution) and EDT (Even distribution of healthy twigs), which were also associated with the rural trees, imply that the trees have an even distribution of the crown and that there were no obstacles or maintenance that interfered with tree growth, which are quite common in urban areas (Mckenzie, 2000; Caplan, 2004). Trees that are situated in a more urban environment usually undergo some sort of pruning or the growth is disturbed by obstacles. Therefore these trees do not have an even distribution of twigs or foliage.

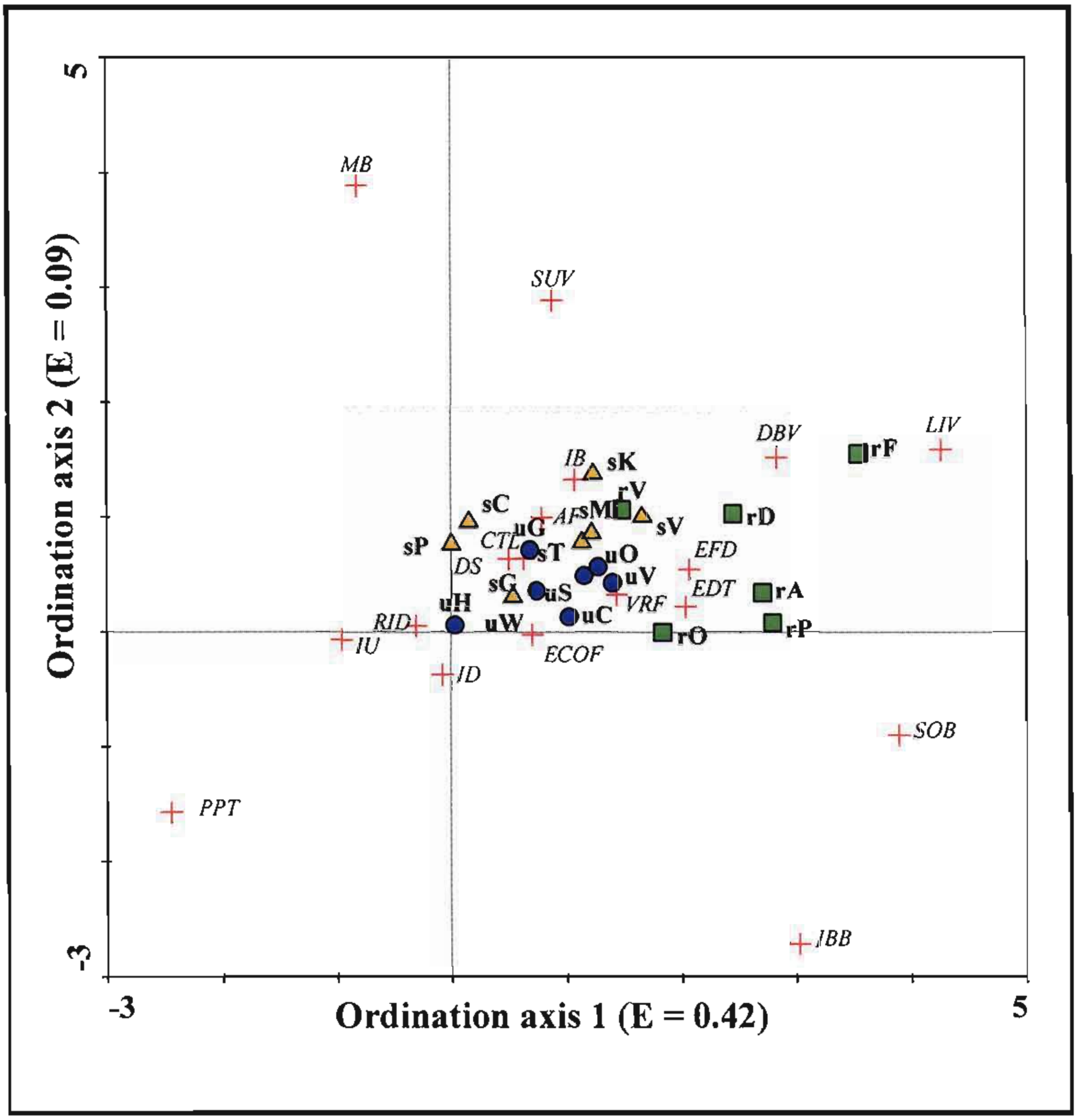

Figure 4.4 Detrended Correspondence Analysis (DCA) of the grouping of the study sites according to the tree appraisal characteristics used for *Acacia karroo* in the Potchefstroom Municipal Area. The blue circles represent the urban study sites, the orange triangles represent the suburban study sites, the green squares represent the rural study sites and the red crosses represent the tree appraisal characteristics (symbols are explained in Table 4.1). Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

Figure 4.5 *Acacia karroo* trees at the rural study site rF (Farm) in the Potchefstroom Municipal Area, which were strongly associated with the tree appraisal characteristic LIV (loss in vigour).

The tree appraisal characteristics PPT (Pathogens/pest on trunks), MB (Missing bark) and SUV (Screen unsightly views) were not strongly associated with a specific urban study site, but were typical characteristics of the sites occurring on the left along ordination axis 1. PPT, MB and SUV are typical characteristics of trees in urbanized areas. Some trees in urban areas are planted to screen unsightly views such as roads or neighbouring houses. Missing bark of trees especially occurs in urban areas where there are homeless people who use the bark and branches as firewood. This makes the trees more vulnerable to pathogens or pests (Tatter, 1980:1). The tree appraisal characteristic CTL (Contribute to the landscape) was associated with most of the urban and suburban study sites, which implies that most of the trees planted in the urban environment contribute to the landscape in some way, for example: trees are planted to form part of a specific design (ID) and if removed it could have a great influence on that design (RID). Trees are also planted to define a space (DS) and thus influence the utilisation (IU) for example trees that are planted to direct traffic (Bernatzky, 1978:87). These days more and more trees in urban areas are planted to attract fauna (AF) and to create more eco-friendly gardens (ECOF) and environments (Perkins *et al.*, 2004:297). The study site uH (High School) was associated with the tree appraisal characteristics RID, IU and ID and can be used as an example of trees that contribute to the landscape of the area in some way or another. The trees at uH (High School) were planted next to the tennis courts and form a barrier between the tennis courts and the rest of the sport fields. If one of these trees were removed it would influence the design of the landscape. These trees do not only contribute to the design of the landscape but also provide shade (Figure 4.6).

As mentioned before, specific tree appraisal characteristics are different for the rural and the more urbanized study sites, but trees in suburban and urban areas show similarities in tree appraisal characteristics. Trees in urban and suburban areas have similar functions. The trees in rural and more urbanized areas differ because trees in rural areas are not planted for a specific reason but grow naturally and the trees in urban areas are planted for a specific reason. Taking this information into consideration, we would expect that the trees in more urbanized areas would have higher monetary values than trees in rural areas, if SATAM (Marx, 2005) is applied. This could be true because most of the tree appraisal characteristics will positively influence the monetary value and are more appropriate in urbanized areas.

Figure 4.6 *Acacia karroo* trees at the urban study site uH (High School) in the Potchefstroom Municipal Area, which was associated with the tree appraisal characteristics RID (Influence design of park/garden), IU (Influence the utilisation of the area) and ID (Influence the design of the landscape).

The average monetary value of four trees in each study site was determined and can be seen in Figure 4.7 (monetary values of the study sites can be viewed in Appendix A, Table 6) . The study sites are arranged according to the urbanization gradient from high percentage impervious surface and low percentage vegetation on the left to high percentage vegetation and a low percentage impervious surface on the right. The green bars represent the rural study sites, the yellow bars represent the suburban study sites and the blue bars represent the urban study sites. According to the Spearman rank correlation tests (STATISTICA, 2005); there was no correlation between the monetary values of the trees and their specific position (Urban, suburban and rural) along the urbanization gradient. The average monetary value of trees in all the rural study sites was; however, lower than the average monetary value of the trees in more urbanized study sites. Both the highest and the lowest monetary values were for trees situated in the more urbanized study sites. For example, the trees with the highest monetary value were those of sM (Meadow Street). This study site is situated on the periphery of a residential area and forms part of a municipality garden. These trees contribute to the design of the garden and receive proper maintenance. The trees with the lowest monetary value are the trees at the study site uV (Viljoen Street). This study site is also situated on the periphery of a residential area, but the trees form part of an agricultural setting and do not really contribute to the landscape of that area and do not receive any maintenance.

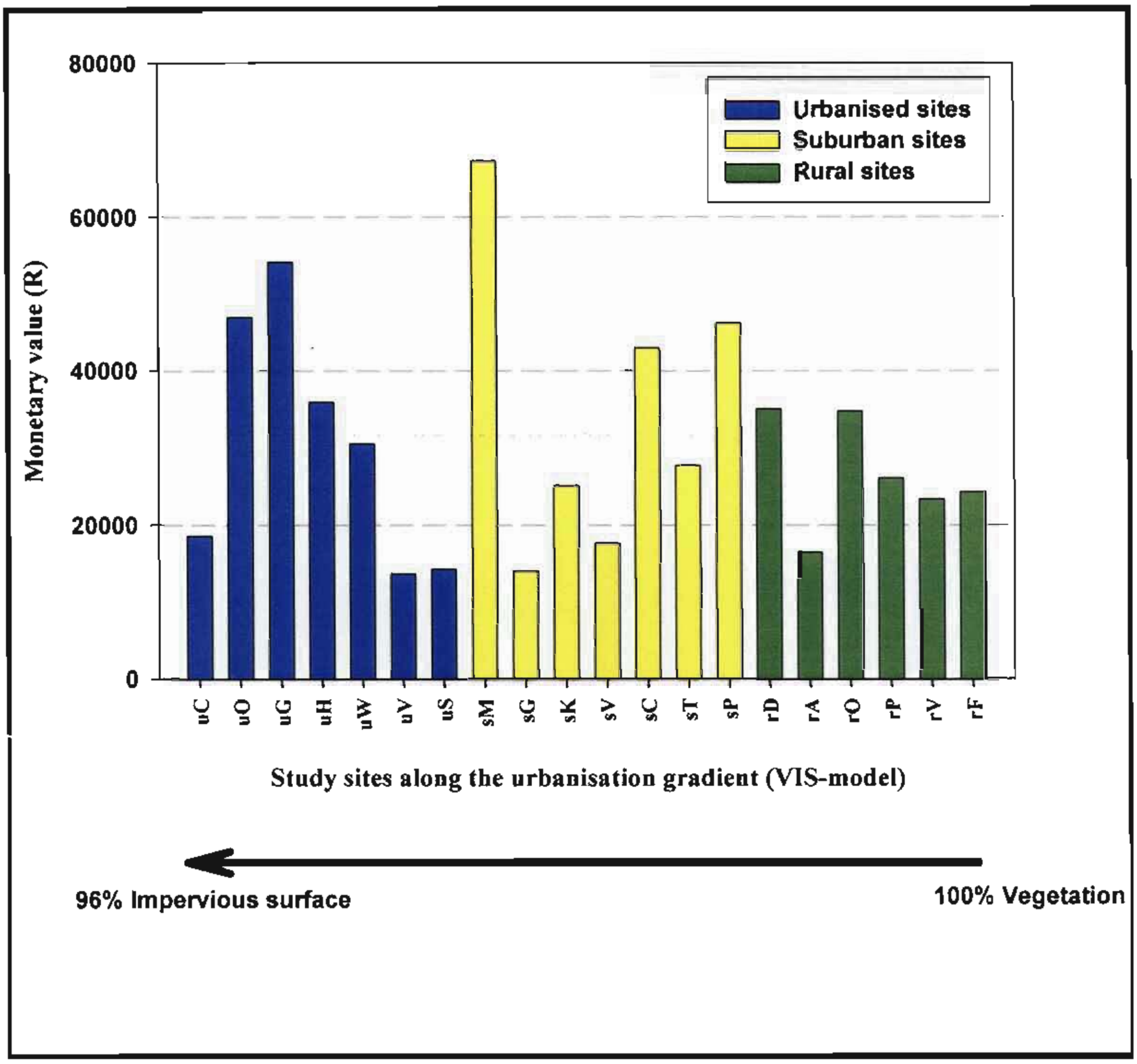

Figure 4.7 Illustration of the monetary values of *Acacia karroo* at the different study sites along an urbanization gradient (VIS-model) in Potchefstroom Municipal Area. The green bars represent the rural study sites, the blue bars represent the urban study sites and the orange bars represent the suburban study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

The monetary value of the trees could not be associated with their specific position along the urbanization gradient, but rather depended on the contribution of the specific trees to the environment, the landscape of the area as well as the visual contribution of the trees. One would argue that the size of the trees would influence the monetary value. The size of the tree trunk can be best described by the circumference of the stem at a height of 1.4m (Marx, 2005).

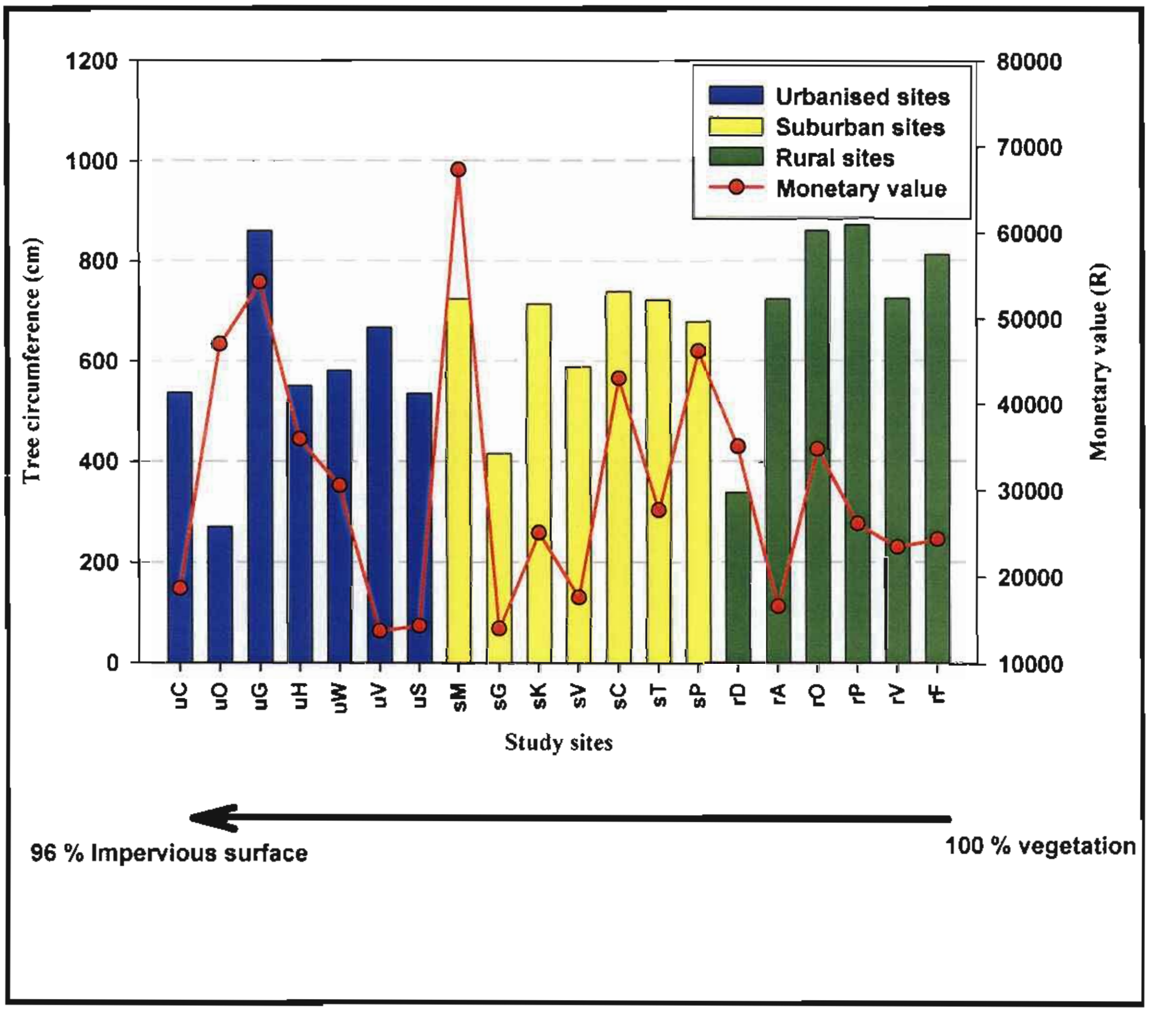

Figure 4.8 Illustration of the correlation between the monetary values of *Acacia karroo* (R) and the circumference (cm) at a height of 1.4m for each study site along the urbanization gradient in the Potchefstroom Municipal Area. The bars represent the tree circumference with the green bars that represent the rural study sites and the blue bars that represent the more urbanized study sites. The red line indicates the monetary values of the study sites and the arrow indicates the urbanization gradient. Symbols for the study sites referred to more detail descriptions of the study sites in Table 2.3 in Chapter 2.

Figure 4.8 illustrates the correlation between the monetary value and the stem circumference of the trees (at a height of 1,4 m) for each study site. In SATAM, the circumference of the tree is used to characterize the size of the tree, which is used in the calculations of the monetary values. In this graph, the bars represent the tree circumference at each study site. The study sites are arranged according to the urbanization gradient as indicated by the arrow. The red line represents the average monetary value of the trees at a specific study site. It is evident from Figure 4.8 that the monetary values of the trees and the tree circumference were not correlated. This was also indicated by the Spearman rank correlation test (STATISTICA, 2005). The study site with the highest monetary value (sM-Meadow Street) did not have the biggest trees and the study site with one of the lowest monetary values (sG-Grimbeek Park) had some of the biggest trees. There was, however, a slight correlation between the stem circumference and the percentage impervious surface (urbanization gradient) as indicated by the Spearman rank correlation tests (STATISTICA, 2005). As can be seen from Figure 4.8, there was a gradual change in the circumference of the trees from the urban to the rural study sites. With exeptions, the trees at the more urbanized study sites had a smaller circumference than the trees at the rural study sites.

4.3 Conclusion

It was evident from this study that the monetary values of *Acacia karroo* were not really influenced by the position of the trees along the urbanization gradient or by the stem circumference of the trees. This is illustrated by Figures 4.7 and 4.8 and by the Spearman rank correlations test (STATISTICA, 2005). The stem circumference of the trees was, however, slightly correlated with the urbanization gradient. The tree monetary value was influenced by the contribution of the tree to the landscape and the environment as well as the visual condition and appearance of the trees.

Chapter 5

The ecophysiology of *Acacia karroo* along the urbanization gradient

5.1 Introduction

5.1.1 Brief overview of photosynthesis

Photosynthesis involves the overall process of water oxidation (removal of electrons with release of O_2 as a by-product) and a reduction of CO_2 to form organic compounds such as carbohydrates. These processes take place within the chloroplasts and cytosol of all photosynthesising cells. The chloroplast is surrounded by a double-membrane system that controls molecular traffic into and out of it. Within the chloroplast is the stroma, which contains enzymes that convert CO_2 into carbohydrates, especially starch. Embedded in the stroma is the pigment-containing tylakoids, in which energy from light is used to oxidize H_2O and from energy rich ATP and NADPH, required by the stroma to convert CO_2 to carbohydrates (Salisbury & Ross, 1992:209). The pigments on the thylakoid membranes are largely chlorophyll a and chlorophyll b of which chlorophyll a is the most important pigment, which is responsible for the absorbtion of light (Moore *et al.*, 1998:142).

The pigments are arranged in aggregates on the thylakoids and are called antenna complexes, which as previously mentioned consists of mostly chlorophyll a. The energy absorbed by the antenna complexes flows energetically downhill to a special pair of energy-collecting molecules of chlorophyll a and associated proteins called a reaction center. There are two kinds of reaction centers namely P700 and P680. The complex containing P700 is Photosystem I (PSI) and the complex which contains P680 is photosystem II (PSII) (Moore *et al.*, 1998:146).

When light is absorbed in the antenna complexes, the energy of its photons (discrete packets of energy, each having a specific associated wavelength) is captured by the pigments and is used to boost the energy of electrons. These excited electrons can have several fates namely 1) the energy can be released as heat, 2) the energy can be released as an afterglow of light via a process called fluorescence, or 3) the energy can be passed to neighbouring molecules (Moore *et al.*, 1998:142). During photosynthesis the excited electrons are treansferred from one molecule to a neighbouring molecule and are called an electron chain. The potential energy of each electron drops at each step of the electron transport chain. Plants couple this exorgenic flow of electrons to an endergonic reaction that makes ATP, this process is called photophosphorylation and is depended on the proton gradient. The proton gradient is created by the movement of protons which is pumped from the stroma into the tylakoid space.

Photosynthesis consists of two stages namely the light-depended stage (photochemical reactions) and the temperature-dependent stage which is the biochemical reactions. During the photochemical reaction photons strike P680 of Photosystem II and excite the elctrons. The excited electrons are unstable and some of the enrgy is released as heat. The electrons ejected from P680 leave space for electrons from water. Photosystem II thus removes electrons from water, releases oxygen and uses the electrons to replace those ejected by photons absorbed by the reaction center. Splitting two molecules of water releases a molecule of O_2 and four electrons. The electrons ejected from P680 reduce pheophyton, a pigment that accepts electrons from chlorophyll. The electrons moves across the thylakoid membrane and are accepted by plastoquinone (Pq). The electrons then descend an electron transport chain of molecules in thylakoids linking Photosystem II and Photosystem I. As the electrons move down this chain, the electrons form a proton gradient that generates ATP (Moore *et al.*, 1998:146).

The final electron acceptor in the electron transport chain is P700, the reaction center of photosystem I. There, the electrons have a higher energy than when they left P680. At P700 four more photons absorbed by antennae transfer their energy to the reaction center, where the energy is used to eject electrons from P700's electron donor, located on the tylakoid membrane. These energized electrons cross the membrane and reduce ferredoxin, a small, iron-containing protein that accepts electrons from Photosystem I.

Ferredoxin then reduces $NADP^+$ to NADPH. Ferredoxin is on the outer side of the membrane, and NADPH thus forms in the stroma, where it is used in biochemical reactions to reduce carbon dioxide to carbohydrate, the basic nutrient of life (Moore *et al.*, 1998:148).

The second stage in photosynthesis is the biochemical stage where carbon dioxide is reduced to carbohydrates (Calvin cycle).

5.1.2 Chlorphyll fluorescence in relation to photosynthesis

As mentioned in Chapter 2, the fast phase of the Kautsky curve is related to the primary processes of Photosystem II. Following the illumination of dark-adapted photosynthetic tissues, there is a fast rise in fluorescence to a so-called minimal level. This is attained when light is absorbed by the chlorophyll antennae, but before the excitations has been trapped by the reaction centers of Photosystem II. Upon illimination with a sufficiently strong light, fluorescence increases from the so called minimum level via an intermediate level to a peak level (a typical polyphasic chlorophyll *a* fluorescence transient, Figure 2.6). This rise reflects a gradual increase in the yield of chlorophyll fluorescence, as the rate of photochemistry concurrently declines (Bolhàr-Nordenkampf & Öquist, 1993:196).

Fast phase chlorophyll *a* fluorescence measurements, followed by analysis according to the JIP test to quantify energy fluxes through PS II, lead to the calculation of the Performance Index (PI_{ABS}) (Strasser *et al.*, 2004). The PI_{ABS} was used as a measure of the vitality of the experimental trees in an attempt to determine whether trees in urban areas perform worse than trees in more rural areas. We also measured the leaf water potential of the trees to determine whether water status could be used as a tool to determine the effect of urbanization on trees. The VIS-model (Vegetation – Impervious surface – Soil) of Ridd (1995:2166) was used to classify the study sites in urban, suburban and rural study sites (Table 3.1).

5.2 Results and Discussion

5.2.1 Tree vitality along the urbanization gradient

The chlorophyll fluorescence based Performance Index (PI_{ABS}) is a multiparametric function which takes into account the three main steps of primary photochemistry namely 1) the efficiency of light absorption, 2) the quantum efficiency of excitation energy trapping and 3) the efficiency of converting trapped excitation energy to electron transport. Figure 5.1 shows the percentage deviation of the PI_{ABS} of each tree relative to the average PI_{ABS} value of all the trees measured over a three-month period (February-April 2005). The y-axis presents the percentage deviation from the average PI_{ABS}, where the zero-line represents the average PI_{ABS} (average PI_{ABS} value = 28) of all the trees (see Appendix A for the calculations, Calculation 1). The x-axis presents the individual trees at each study site (uC – rF, see Figure 5.1). The study sites are arranged according to the VIS-model (Figure 5.1) and show a descent in percentage impervious surface, where study site uC (church garden in a residential area) had the highest percentage impervious surface and a low percentage vegetation and study site rF (farm on the way to Viljoenskroon) had a high percentage vegetation and a low percentage impervious surface. The study sites were divided into three groups according to the deviation from the zero line over the three-month period. Group 1 (Study sites uC -uS) are the study sites where most trees had PI_{ABS} values lower than the average of all the trees ("Worse performing group"). Although Group 1 is the "Worse performing group" the trees in this group did not all show a PI_{ABS} value lower than the average PI_{ABS} value. This group of trees are classified as the "Worse performing group" because 70% of the trees in this group had a PI_{ABS} value lower than the average PI_{ABS} value. Group 2 (study sites sM - sP) consisted of more or less the same amount of trees that performed better (40% of the trees) or worse (60% of the trees) than the average PI_{ABS} value.

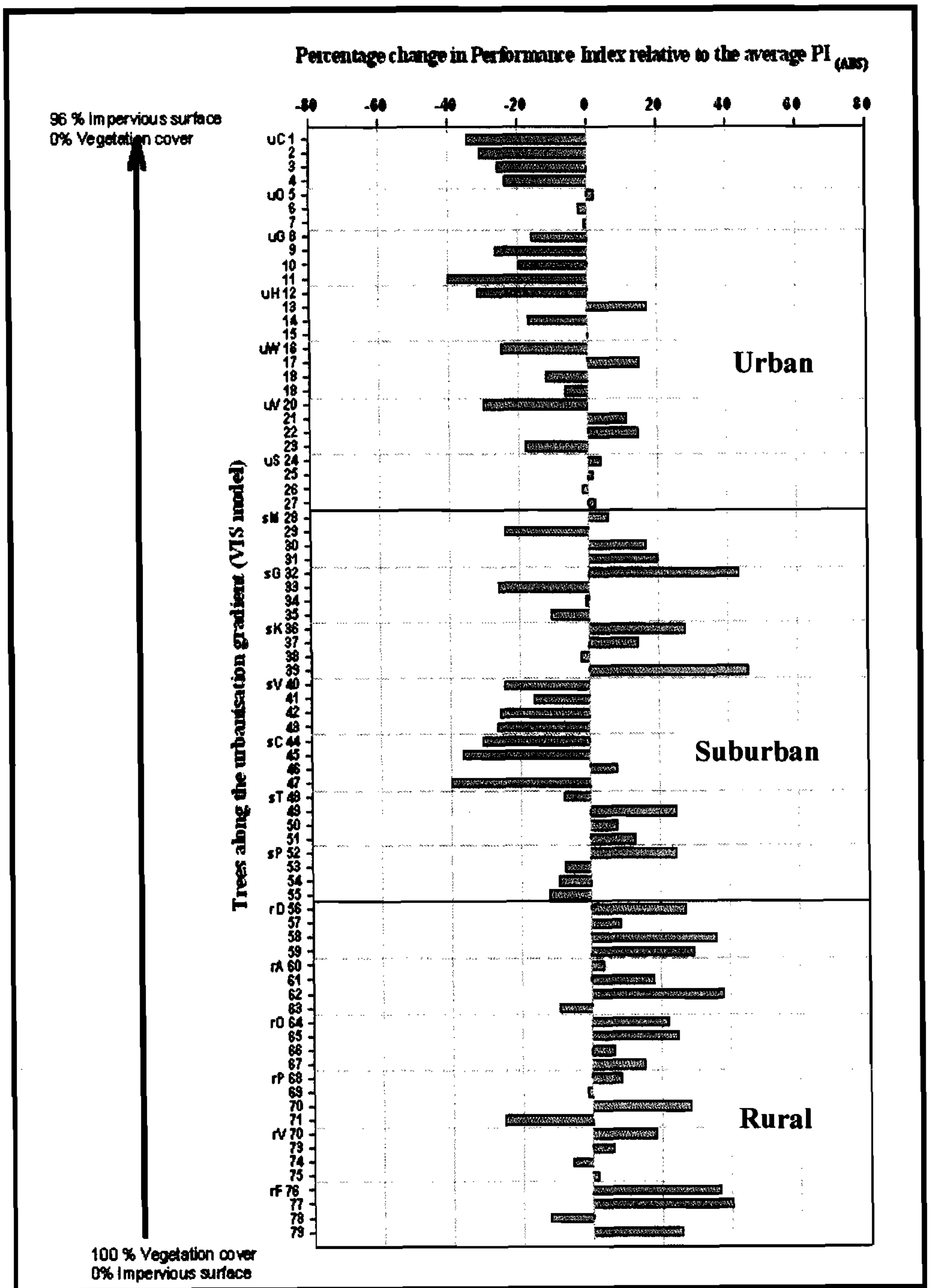

Figure 5.1 Percentage deviation in the Performance Index (PI_{ABS}) relative to the average Performance Index (PI_{ABS}) of all the trees over a three-month period (February-April 2005). The study sites were grouped into three different groups based on the urbanization gradient. Group 1 included the urban study sites, Group 2 included the suburban study sites and Group 3 included the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

This group formed the transition zone between Group 1 (Worse performing group) and Group 3 (Best performing group). The study sites in Group 2 not only formed a transition zone between the "Worse" and "Best" performing trees, but also had approximately the same percentage vegetation cover and impervious surface and thus formed a transition zone between the urban and rural study sites. Group 3 (study sites rD - rF) was the "Best performing" group. Most of the trees in this group (72 % of the trees) performed better than the average PI_{ABS} value and thus had a higher percentage deviation in the PI_{ABS} value relative to the average PI_{ABS} value.

Although the trees with the highest percentage deviation in PI_{ABS} relative to the average PI_{ABS} did occur in Group 2, the overall PI_{ABS} value of the group was lower than that of Group 3 and the percentage of trees that perform better than the average PI_{ABS} value was lower than that of Group 3. The best performing study sites (average of 3-4 trees per study site) were study sites rD (Dassierand, Table 2.3), rF (Farm, Table 2.3) and sK (Kynoch), which is a study site in the industrial area, Kynoch (Table 2.3).

The PI_{ABS} values of the trees did not show any significant change from February to March ($p = 0.47$), but did, however, show a significant change between February and April ($p = 4.9^{-13}$). The pattern of the PI_{ABS} values of the three months was more or less the same as the overall PI_{ABS} as shown in Figure 5.1. Figure 5.2 is an example of the PI_{ABS} values of the trees during one of the three months (March 2005). As can be seen from Figure 5.2, the pattern of the PI_{ABS} values was more less the same as that of the average PI_{ABS} values of the trees over the three-month period. In the "Worst performing" group (urban), approximately 84% trees performed worse than the average PI_{ABS} value of March. In the transition zone (suburban), approximately 50% of the trees performed better than the average PI_{ABS} value and 50% performed worse than the average PI_{ABS} value of March. In the "Best performing" group (rural), approximately 78% trees performed better than the average PI_{ABS} value. It is very clear that the general response during March looked very similar to the average over the three-month period (Figure. 5.1). The Performance Index values can be viewed in Appendix A, Table 7 & 8.

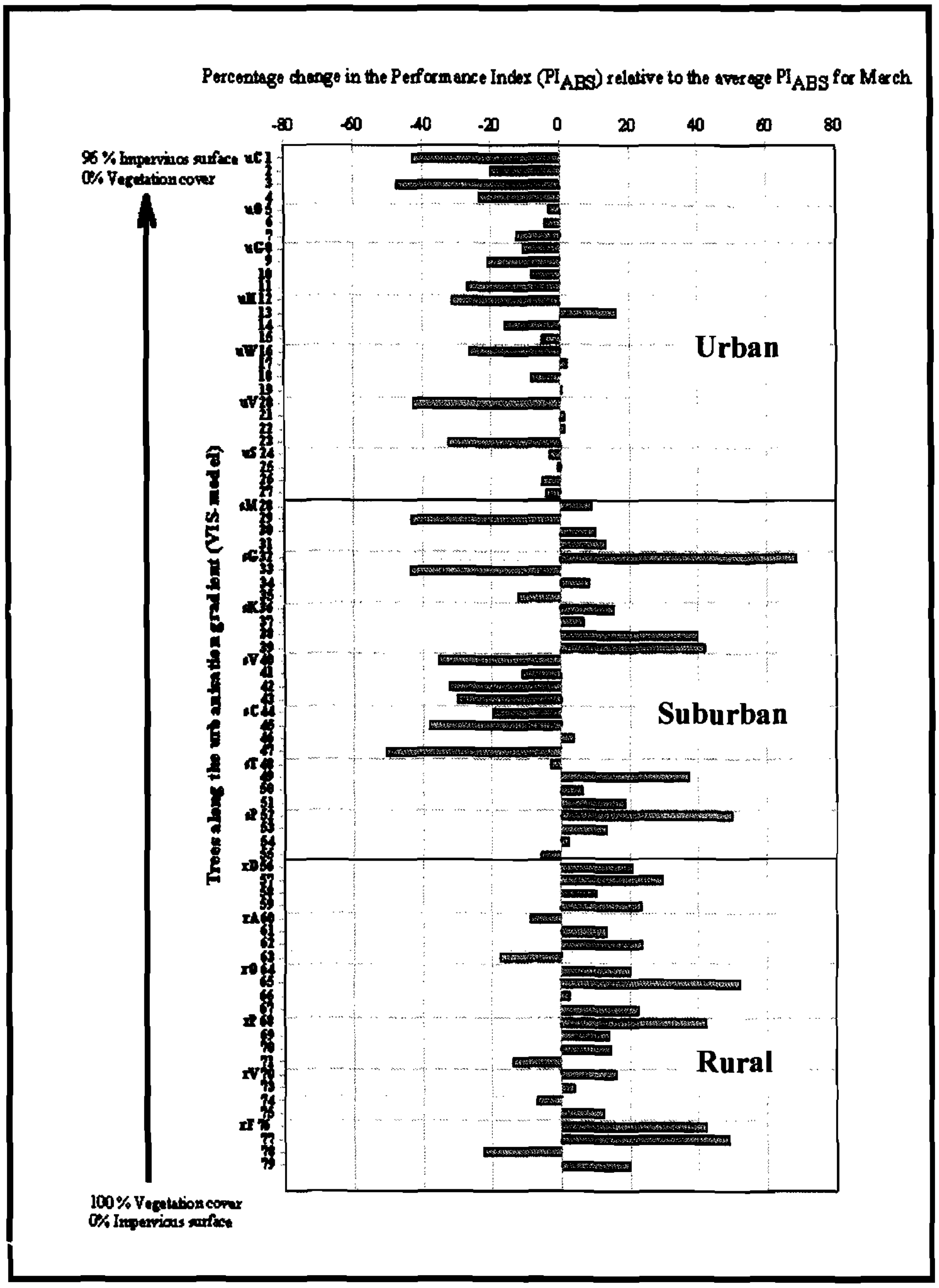

Figure 5.2 Percentage deviation in the Performance Index (PI_{ABS}) during March 2005 relative to the average Performance Index (PI_{ABS}) of all the trees over the three-month period (February-April 2005). The study sites were grouped into three different groups based on the urbanization gradient. Group 1 included the urban study sites, Group 2 included the suburban study sites and Group 3 included the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

Chlorophyll fluorescence data give information on the state of Photosystem II (PS II) activity, thus the efficiency of PS II-photochemistry. According to Maxwell and Johnson (2000:660), the flux of electrons through PS II is indicative of the overall rate of photosynthesis under different conditions and this gives us the potential to estimate photosynthetic performance. The key to the electron transport chain is the presence of two large multimolecular complexes i.e. Photosystem I (PS I) and PS II. These two photosystems operate in series, linked by a third multiprotein aggregate, the cytochrome complex. The effect of the chain is to extract low-energy electrons from water and, using light energy trapped by chlorophyll, raise the energy level of those electrons to produce a strong reductant NADPH and ATP (Hopkins, 2004:68). Photosynthetic electron transport produces NADPH and ATP, which reduce CO_2 in the Photosynthetic Carbon Reduction Cycle (Calvyn Cycle). The PCR cycle is a sequence of reactions all plants use to reduce CO_2 to organic carbon. The Performance Index related to the function of one of the main complexes (PS II), can thus be used as a tool to estimate photosynthetic performance.

It is evident from Figure 5.1 and Figure 5.2 that the photosynthetic performance of *Acacia karroo* declines along the urbanization gradient ($p = 3.31^{-06}$). Although not all the trees along the urbanization gradient showed a decline in photosynthetic performance, the overall result was a decline in performance index along the urbanization gradient. It is thus evident that urbanization has a negative impact on the vitality of trees.

5.2.2 Leaf water potential (Ψ_L)

As an additional tool to determine whether human activities influence the tree vitality, we measured the leaf water potential of each tree. The water potential can be used as an indicator of water stress (drought stress) of the tree. By using a Scholander pressure chamber, the water potential of the trees was measured.

Figure 5.3 is an illustration of the percentage deviation in the pre-dawn leaf water potential relative to the average leaf water potential over a three-month period (February – April 2005). The y-axis is the percentage deviation of the leaf water potential in three months relative to the average leaf water potential of the three months. The zero-line represents the average leaf water potential (-0.77) over the three-month period. The study sites are arranged along the x-axis according to their percentage impervious surface and percentage vegetation cover (VIS-model, Table 2.2).

The study sites were divided into three groups based on the percentage impervious surface and the percentage vegetation cover at each study site. The three groups represent the urban (uC - uS), suburban (sM - sP) and the rural (rD - rF) study sites, as previously discussed in this chapter and in Chapter 2. It is evident from Figure 5.3 that the study sites could not be divided into a worst performing, best performing and transition zone based on the leaf water potential values as could be done with the PI_{ABS} values of the trees. The best performing study sites were study sites uH (High School), uO (Opkoms) and sC (Cemetery), while the worst performing sites included sites from all three the groups i.e. study sites rD (Dassierand), sK (Kynoch) and uG (Gimnasium). It is thus evident that the leaf water potential was not correlated with the urbanization gradient and could therefore not be used as an indicator to quantify the urbanization gradient in this particular study.

The best performing trees were trees from the more urbanized study sites. uH was a High School in a residential area and had an average leaf water potential value of -0.58 Mpa and a 28.3% deviation from the average leaf water potential value of all the trees over the three-month period (February – April 2005), calculations can be viewed in Appendix A, Calculation 2. The study site was a garden at an old age home and had an average leaf water potential value of -0.57 Mpa, presenting a 26% deviation from the average leaf water potential, while the trees at study site sC (Cemetery) had an average leaf water potential value of -0.59 Mpa, presenting a 23.5% deviation from the average leaf water potential of all the trees over the three month period (February – April 2005).

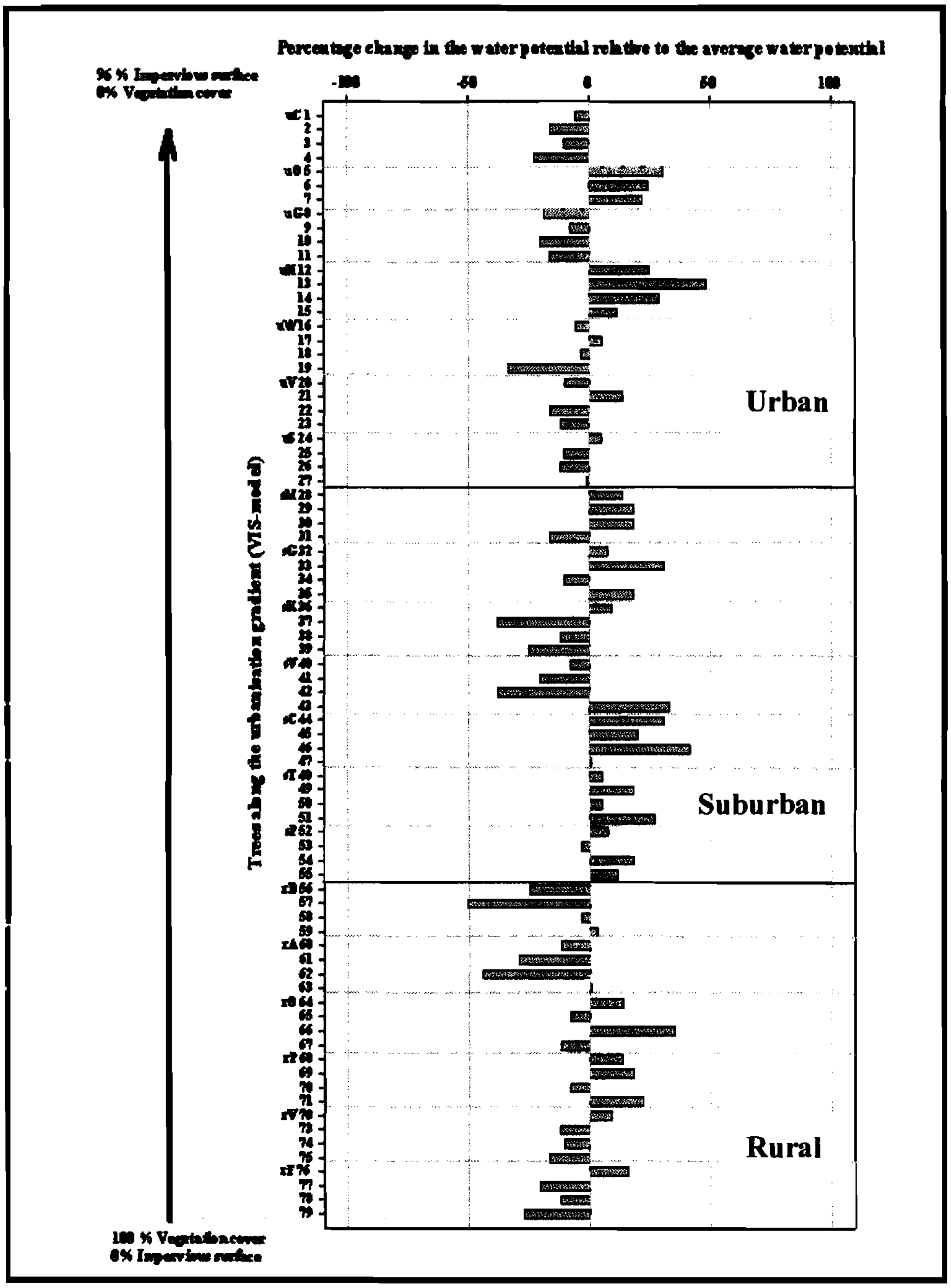

Figure 5.3 Percentage deviation in the pre-dawn leaf water potential relative to the average water potential of all the trees over the three-month period (February-April 2005). The study sites were grouped into three different groups based on the urbanization gradient. Group 1 included the urban study sites, Group 2 included the suburban study sites and Group 3 included the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

The study sites with the worst performing trees were not from a specific group but were scattered along the urbanization gradient. Study site rD was an open veldt in Dassierand and the trees on the site had an average leaf water potential value of -0.92 Mpa, presenting a 16.4% deviation from the average leaf water potential of all the trees over the three-month period (February – April 2005). sK (Kynoch), a study site in the industrial area of Potchefstroom, had an average leaf water potential value of -0.9 Mpa, presenting a 15.8% deviation from the average leaf water potential value, while uG (Gimnasium) had an average leaf water potential value of -0.89 Mpa, presenting a 13.7% deviation from the average leaf water potential value of all the trees over the three-month period (February – April 2005).

The average water potential value of each month did decline over the three months and showed a significant change from February to March to April ($p = 5.22359$ E-16). The pattern of the water potential stayed more or less the same month after month and thus had the same pattern as the average water potential over the three-month period as shown in Figure 5.3. To illustrate this pattern we used the pre-dawn data from the water potential measurements of February 2005 (Figure 5.4). In the Urban group, approximately 56% of the trees performed better than the average PI_{ABS} value of February. In the suburban group, approximately 64% of the trees performed better and 36% performed worse than the average PI_{ABS} value of February. In the rural group, approximately 46% trees performed better than the average PI_{ABS} value. The water potential values can be viewed in Appendix A, Table 9 & 10.

It is evident from Figure 5.3 and Figure 5.4 that the water potential of the trees was not correlated to the urbanization gradient. The trees in urban environments do therefore not necessarily perform worse than those in rural areas. As is evident from the results as discussed above, it was the trees in the urban and suburban areas that had better overall water potential values. One reason for this could be that the trees were irrigated through out the year while trees in rural areas only receive water when it was raining. Other factors such as the soil factor could also have had an impact on the water potential of the trees.

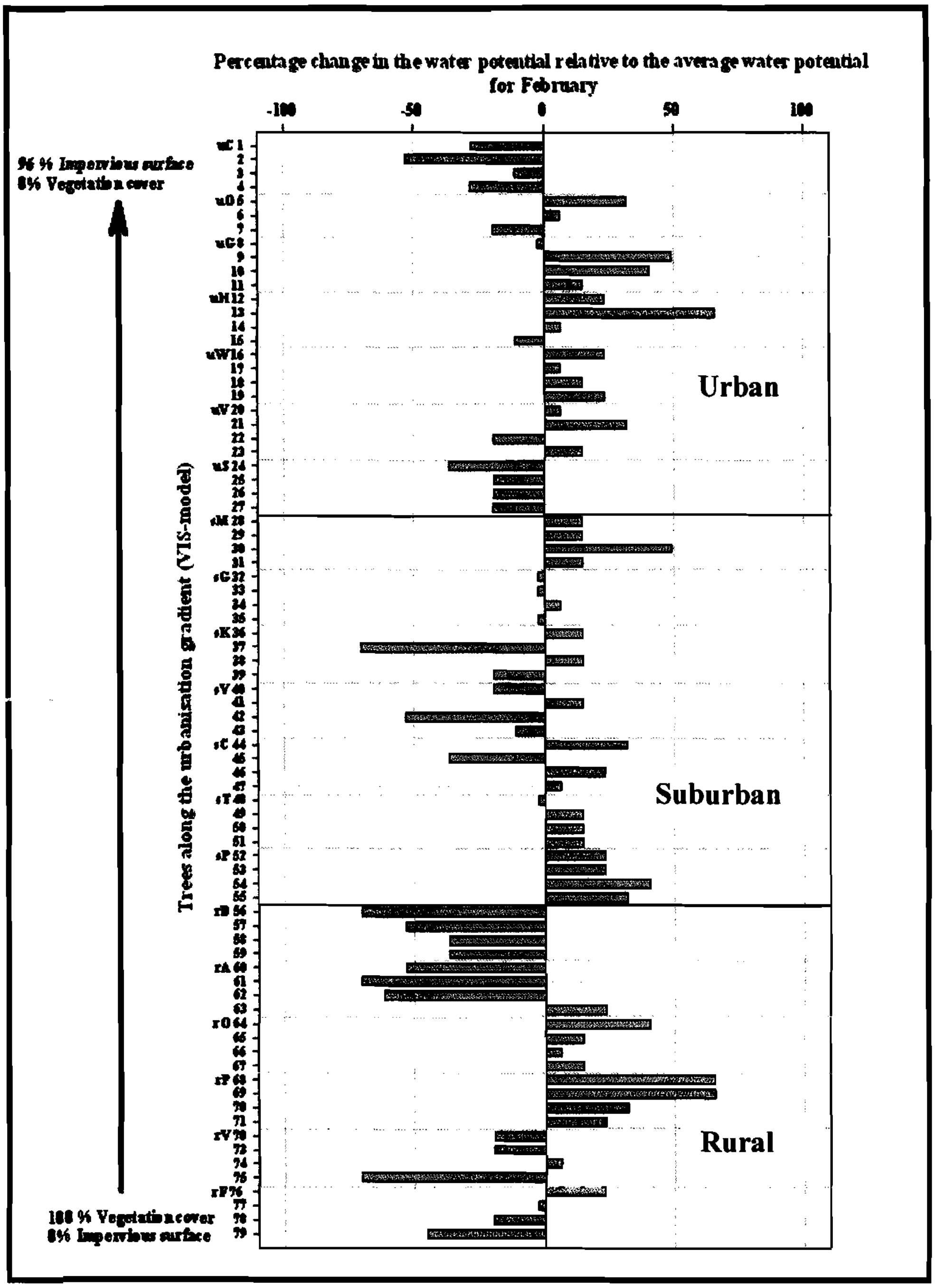

Figure 5.4 Percentage deviation in the pre-dawn leaf water potential for February 2005 relative to the average leaf water potential of all the trees over the three-month period (February-April 2005). The study sites can be grouped into three different groups based on the urbanization gradient. Group 1 included the urban study sites, Group 2 included the suburban study sites and Group 3 included the rural study sites. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

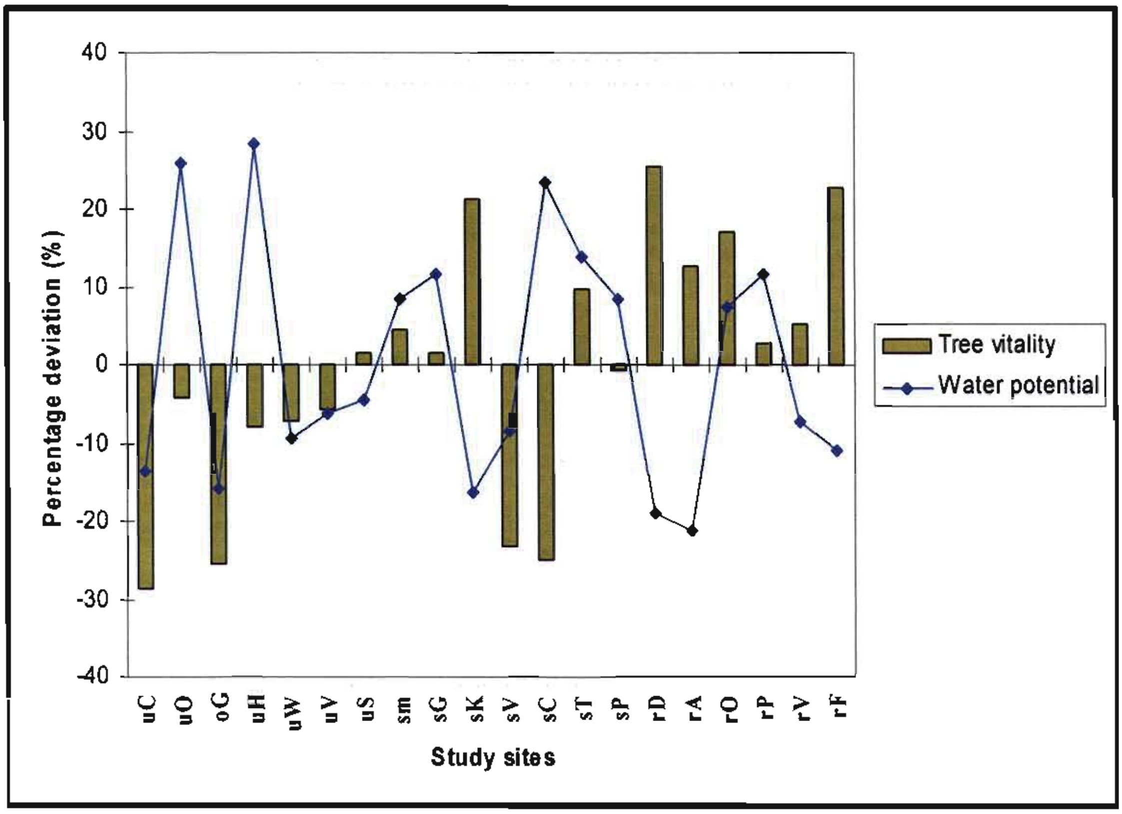

Figure 5.5. Correlation between the percentage change in the leaf water potential relative to the average leaf water potential over the three-month period (February –April 2005) and the percentage change in the PI_{ABS} relative to the average PI_{ABS} over the three-month period (February –April 2005). The green bars represent the tree vitality and the blue dots the leaf water potential. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

Figure 5.5 illustrates the relation between the average leaf water potential and the average tree vitality (PI_{ABS}) of each study site. The Figure illustrates the percentage deviation of each study site from the average leaf water potential and the average tree vitality of all the study sites. The y-axis is the percentage deviation and the x-axis is all the study sites arranged according to the urbanization gradient. It is evident from Figure 5.5 that there was no correlation between the PI_{ABS} values and leaf water potential values of the study sites. One of the study sites with a high PI_{ABS} value (Study site rD-Dassierand) had a low leaf water potential value and one of the study sites with a low PI_{ABS} value (Study site sC-Cemetery) had a high leaf water potential value. There were, however, some of the study sites with trees having both a low vitality (PI_{ABS}) value and a low leaf water potential value. There are thus other factors (soil, tree structure, rainfall) that influenced tree vitality.

5.3 Conclusion

In the current study the urban, suburban and rural study sites were divided into a best performing group, transition zone and a worst performing group. This technique was adapted from Hermans *et al.* (2003:84). According to the studies done by Herman *et al.* (2003:84) they classified each one of the trees into a best performing, worst performing and normal group based on the percentage deviation of the Performance Index value of a tree from the average Performance Index value of all the trees. In the current study the urban, suburban and rural groups were classified into a performance group and not each one of the trees. It was evident from the studies of Herman *et al.* (2003:86) that the performance Index could be used as a tool to distinguish between groups of trees based on their vitality as was confirmed and elaborated by the current study.

It is evident from the results that the tree vitality was negatively influenced by the urbanization gradient. According to Hermans *et al.* (2003:86) forest trees could have a higher Performance Index value than urban trees as urban trees are exposed to anthropomorphic (anthropogenic) activities, which was evident from the current study. Although not all the trees showed a significant decrease the average PI_{ABS} value of each site over the three months showed a decrease.

The leaf water potential of the trees was not influenced by the urbanization gradient as is evident from the variation in the leaf water potential values along the urbanization gradient.

Chapter 6

Association between the Ecophysiological components, Soil contents, Vegetation composition and Tree monetary values.

6.1 Introduction

In this chapter the association between the ecophysiological components (Performance Index and Leaf water potential), the soil components and the vegetation composition at each study site was studied. For the current study, Redundancy Analysis (RDA) was used to illustrate the associations between the study sites and the different components, as mentioned above. By comparing the different environmental components with the Performance Index and the leaf water potential association between different study sites, specific environmental or ecophysiological components could be observed. From this data we could make certain assumptions regarding the impact of urbanization on the trees at the different study sites.

6.2 Results and Discussion

Figure 6.1 is an RDA illustration of the association between the soil chemical components and macro-elements, the vegetation composition (total species and native species of each study site) and the ecophysiological components, Performance Index values (PI) and leaf water potential (WP) of the three months (February – April 2005). The soil macro-elements Mg and Na, the soil pH and the PI - March (PI-Mar) were strongly associated with ordination axis 1 (E = 0.2), while PI – February (PI-Feb), PI – April (PI – Apr), NH_4, total species (Totssp) and native species (native) were associated with ordination axis 1 to a lesser degree. The leaf water potential of April (WP-Apr) and March (WP-Mar) and the soil macro-element NO_3 were strongly associated with ordination axis 2 (E = 0.13), while WP – February (WP-Feb), tree monetary values (TMV) and the soil macro-elements P and SO_4 were associated with ordination axis 2 to a lesser degree. The rural study sites were grouped to the left of ordination axis 1 and were more associated with the high Performance Index values, while some of the suburban and urban study sites were scattered along ordination axis 1 and ordination axis 2 and were associated with the high Performance Index values to a lesser degree.

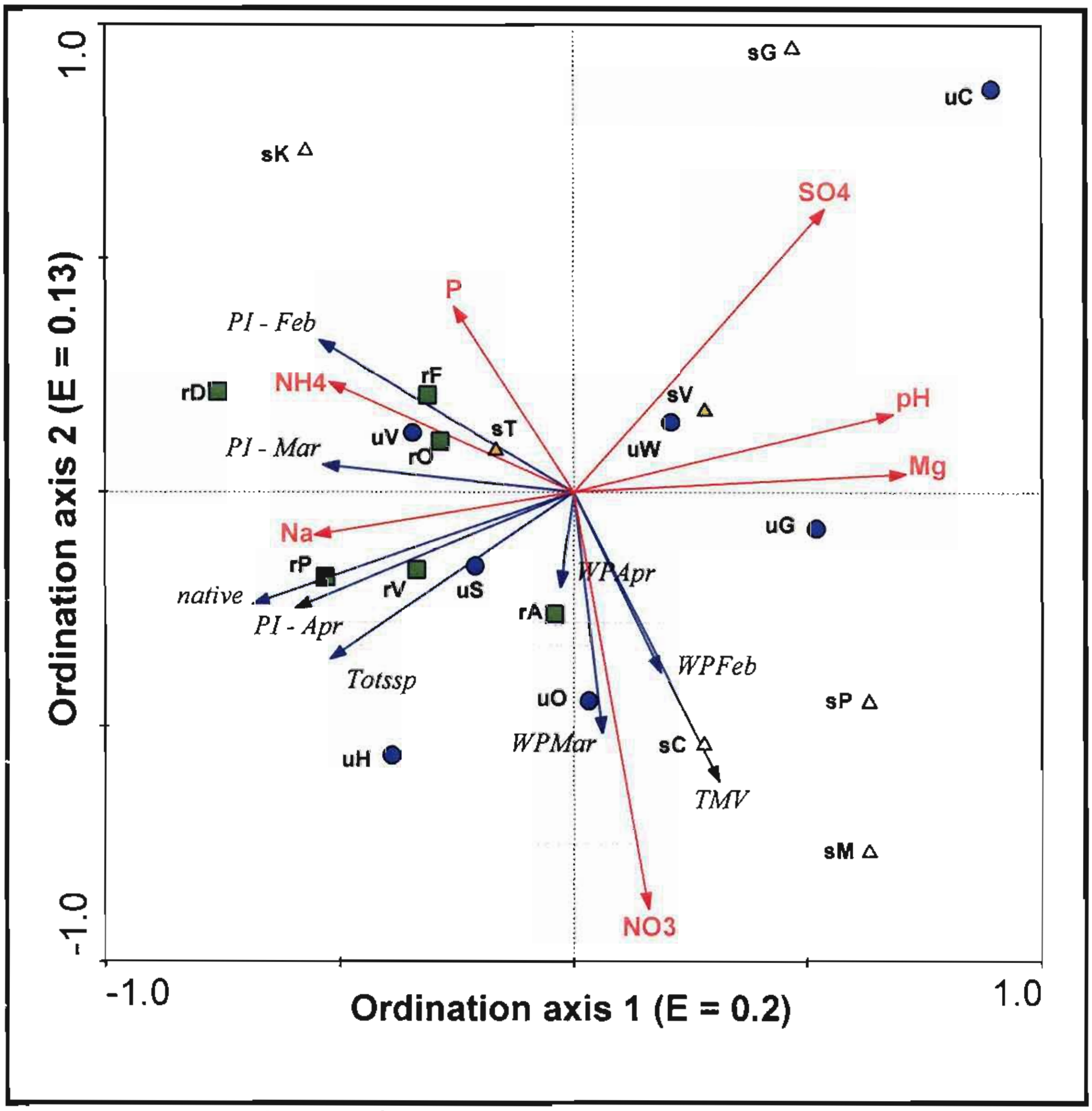

Figure 6.1 RDA of the different environmental components (soil macro-elements, chemical components and vegetation components (total species and native species of each study site) and the ecophysiological components (Performance Index, PI, and leaf water potential, WP) of each study site in the Potchefstroom Municipal Area. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

It is evident from Figure 6.1 that the leaf water potential values over the three months and the Performance Index values over the three months were not associated with each other, as was indicated and discussed in Chapter 5. The leaf water potential values over the three months were, however strongly associated with NO_3 and the tree monetary values (TMV). The study sites that were strongly associated with leaf water potential, tree monetary values (TMV) and NO_3 were the study sites uO (Opkoms), sC (Cemetery), and rA (Agricultural) to a lesser extent. The study sites uH (High School), sP (Mooivallei Park), sM (Meadow Street) and uS (Station Road) were associated with the leaf water potential of the three months, the tree monetary values (TMV) and NO_3 to a lesser degree. As previously discussed in Chapter 3, NO_3 is produced through the mineralization of N stored in organic matter (Hausenbuiller, 1978:278). The suburban and rural study sites were either not maintained or received maintenance to a lesser degree and thus had enough organic matter, such as dead leaves, under the trees which provided the soil with N. According to Craul (1992:97), soil in rural areas contains more organic matter than soil in urban areas because organic matter is removed through maintenance activities. It could be that the urban study sites that were associated with NO_3 received it through additional application of NO_3 to the soil or through the application of organic matter. A high level of organic matter in soil contributes to better water movement and less compaction of the soils (Glinski & Stepniewski, 1983:137; Craul, 1992:95). This could be one of the reasons for better water movement in the soil and thus a better leaf water potential value of the trees.

From Figure 6.1 it is clear that the tree monetary values (TMV) were strongly associated with the leaf water potential of the trees over the three-month period and were not associated with the Performance Index values of the trees. In general it indicated that most of the trees with high monetary values were not under water stress. It is also evident from the Figure that the tree monetary values (TMV) were not associated with the urbanization gradient, as was discussed in Chapter 4.

The Performance Index values of February (PI–Feb) and March (PI–Mar) were strongly associated with NH_4 and P to a lesser degree. The study sites uV (Viljoen Street), sT

(Technical High School), rD (Dassierand), rF (Farm) and rO (Oudedorp) were strongly associated with PI – February and PI – March, while the study site sK (Kynoch) was associated to a lesser degree. The Performance Index values of April (PI-Apr) were strongly associated with Na, native species (native) and total species (Totssp) per study site. The study sites uS (Station Road), rP (Pienaarskamp), rV (Vyfhoek) and uH (High School) were associated with PI-Apr, native, Totssp and Na. As discussed in Chapter 3, the association between the PI – February and PI – March and the soil macro-elements, NH_4 and P with the study sites uV (Viljoen Street) and sK (Kynoch) could be due to the fertilizer plant which is situated close to these study sites. N is one of the most important macro-elements which promotes plant growth (Kontunene-Soppela, 2001) and N-fertilizers have been used to increase wood production and forest growth. This could be one of the reasons for the strong association of PI – February and PI – March with NH_4. PI – April was associated with NH_4 and P to a lesser degree. It could be that the trees were preparing for the winter and the leaves were in the final stage of life which is the senescence stage. The senescence stage is characterized by a decline in photosynthesis and an orderly disassembly of macromolecules (Hopkins & Hüner, 2004:302).

From Figure 6.1 it is clear that the Performance Index of the three months was negatively associated with SO_4 and pH, while the leaf water potential of the three months was not associated with SO_4 and pH. This means that the study sites where the trees had a high Performance Index value mostly had relatively low pH values and low levels of SO_4. The study sites uW (Wasgoedspruit) and sV (Van der Hoff Park) were strongly associated with SO_4 and pH while uC (Church) and sG (Grimbeek Park) were associated with SO_4 and pH to a lesser degree. These study sites were thus negatively associated with the Performance Index, because the trees in these sites had low PI_{ABS} values, which is evident from Chapter 5.

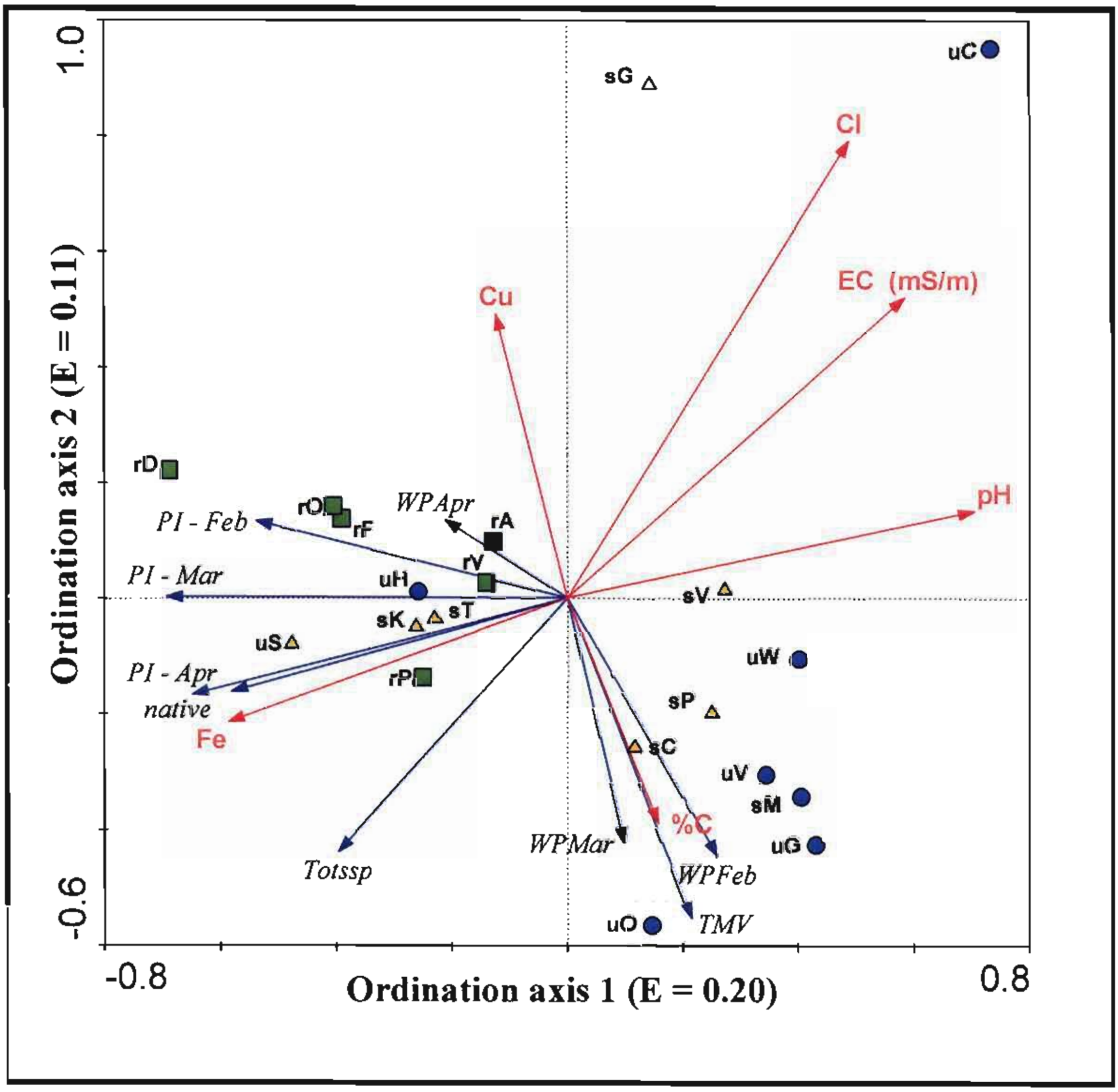

Figure 6.2 RDA of the different environmental components (soil micro-element, chemical components and vegetation components) and the ecophysiological components (Performance Index, PI, and leaf water potential, WP) of each study site in the Potchefstroom Municipal Area. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

Figure 6.2 is an RDA illustrating the association between the ecophysiological components, Performance Index values (PI) and the leaf water potential (WP) of the three months (February – April 2006), the soil components, which include the micro-elements and the soil chemical elements, and the vegetation components (total species and native species) of the different study sites. The Performance Index values of all three the months, native species, the leaf water potential for April, Fe and pH were strongly associated with ordination axis 1 (E = 0.21). The leaf water potential of February and March, the tree monetary values (TMV) as well as the soil elements Cu and C (% C) were associated with ordination axis 2 (E = 0.11). The soil micro-element, Cl, and the total species (Totssp), were associated with ordination axis 2 to a lesser degree. The rural study sites were arranged to the left of ordination axis 1 and approximately all the rural study sites were strongly associated with the high Performance Index values of the three months. The urban and suburban study sites were scattered along ordination axis 1 and ordination axis 2.

It is evident from Figure 6.2 that most of the trees in rural study sites had a high Performance Index value and thus had a better photosynthetic performance, while only some of the urban and suburban study sites were strongly associated with the high Performance Index values as discussed in Chapter 5. The Performance Index values for February and March were not associated with the leaf water potential, but the leaf water potential of April was associated with the Performance Index of that month.

The study sites uO (Opkoms) and sC (Cemetery) were strongly associated with high leaf water potential of February and March and also associated with the soil component C, while the study sites uV (Viljoen Street), uG (Gimnasium), sM (Meadow Street) and sP (Mooivallei Park) were associated with these components to a lesser degree. The tree monetary values (TMV) were not associated with the urbanization gradient, but were strongly associated with the leaf water potential values as is evident from Figure 6.2 and Chapter 4.

The Performance Index values for April were negatively associated with the soil components pH, EC and Cl, while PI – February and PI – March were negatively associated with pH. The study site sV (Van der Hoff Park) was strongly associated with pH while the study sites uC (Church) and sG (Grimbeek Park) were associated with Cl and EC. Study sites uC (Church) and sG (Grimbeek Park) were sites that usually received water through irrigation. Irrigation water usually contains minerals such as Cl, Ca and Mg (Anon, 2003). These salts are also associated with the soil EC as the soil EC is related to dissolved solutes (salinity) (Brady & Weil, 2002:426) as discussed in Chapter 3. This could also be the reason for the association between Cl, EC and pH as a more alkaline soil (high pH) is associated with salts in the soil.

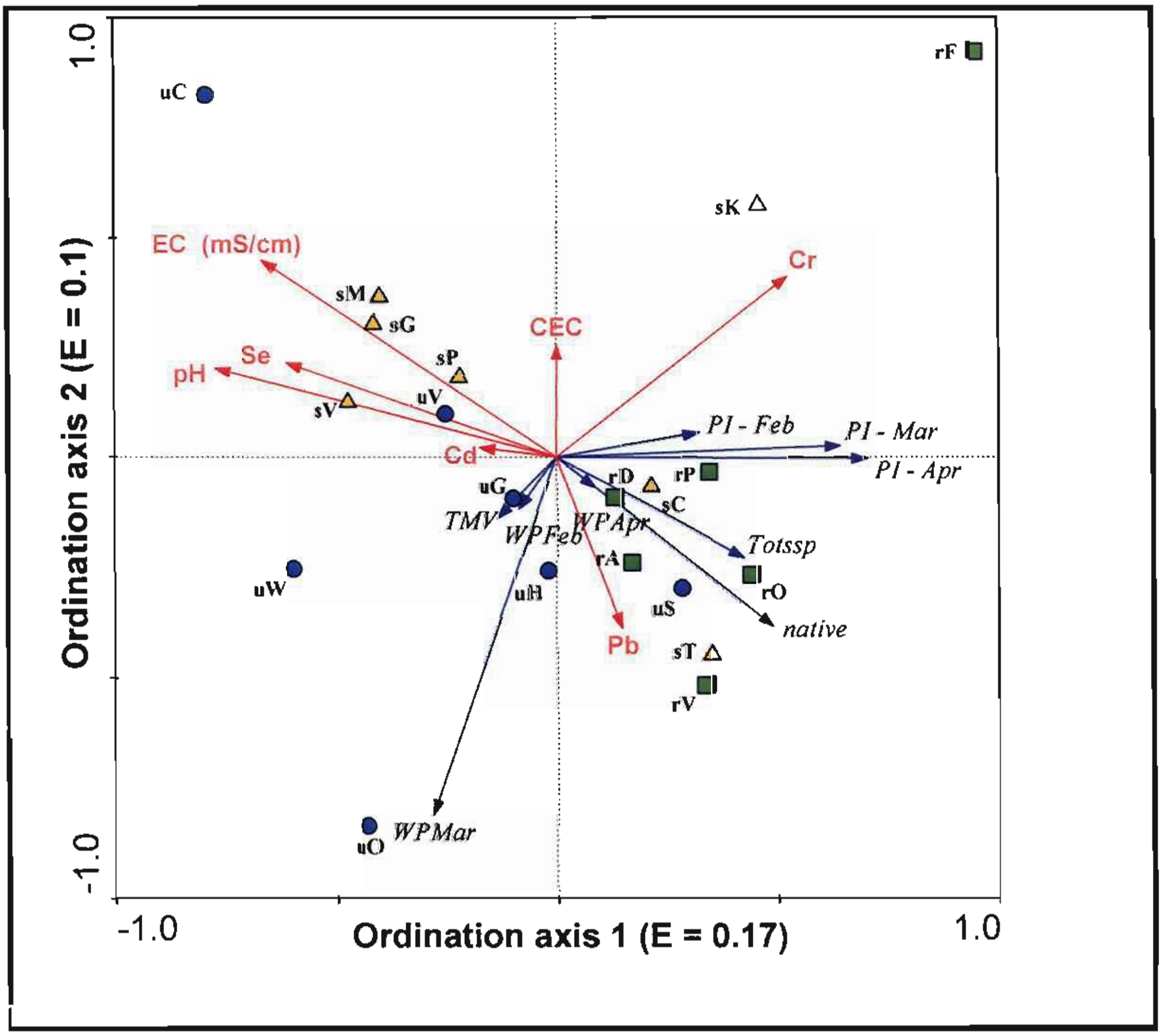

Figure 6.3 RDA of the different environmental components (soil heavy metals, chemical components and vegetation components) and the ecophysiological components (Performance Index, PI, and leaf water potential, WP) of each study site in the Potchefstroom Municipal Area. Symbols for the study sites refer to more detailed descriptions of the study sites in Table 2.3 in Chapter 2.

Figure 6.3 is an RDA illustrating the association between the ecophysiological components; Performance Index values (PI) and the leaf water potential values (WP) for the three months February – April 2005, the soil heavy metals and the soil chemical elements as well as the vegetation components (total species and native species) of the different study sites. The Performance Index values of the three months and the soil heavy metal, Cd, were strongly associated with ordination axis 1 (E = 0.17) while WP – April, native species, total species (Totssp), pH and Se were associated with ordination axis 1 to a lesser degree. WP – February, Pb and CEC were strongly associated with ordination axis 2 (E = 0.1), while WP – March and tree monetary values (TMV) were associated with ordination axis 2 to a lesser degree. Most of the rural study sites were arranged along the right of ordination axis 1, while the suburban and the urban study sites were scattered along ordination axis 1 and ordination axis 2.

The Performance Index values of the three months were not associated with the leaf water potential values of the three months, as was discussed in Chapter 5. It is evident from Figure 6.3 and Chapter 5 that the study sites uH (High School), uO (Opkoms), uG (Gimnasium), sC (Cemetery) and rD (Dassierand) were strongly associated with high leaf water potential values of the three months. The rural study sites were more associated with high Performance Index values of the three months as is evident from Figure 6.3 and discussed in Chapter 5. The Performance Index values of the three months were negatively associated with EC, pH and Se. It is evident from Figure 6.3 and the previous two Figures (Figures 6.1 and 6.2) that the Performance Index values were negatively associated with pH. This means that these components negatively influence the Performance Index values and thus the photosynthetic performance of the trees, as was also indicated by Hopkins & Hüner (2004:475). The study sites which were strongly associated with high pH values were study sites uV (Viljoen Street) and sV (Van der Hoff Park) and it is evident from Chapter 5 that these study sites had low Performance Index values.

6.3 Conclusion

It is thus evident from the three figures that the leaf water potential and the Performance Index values were not associated with each other, as was discussed in Chapter 5. It was, however, evident that the two physiological components were influenced by other environmental factors such as soil contents as well as by urbanization factors such as high levels of maintenance, which was subjectively noticed and not measured. It is also evident that the rural study sites were more associated with high Performance Index values and that the effects of urbanization did not necessarily negatively affect the leaf water potential values. It is evident from the three figures that the TMV (Tree Moneary Value) were not associated with the Performance Index values of the trees. The TMV was rather associated with the urban and suburban study sites and not the rural study sites.

Chapter 7

Conclusion

The main objective of the study was to determine the general anthropogenic and environmental impacts on trees. In the literature it was already indicated that, although trees offer huge benefits to urban dwellers, they are also severely impacted on by these beneficiaries in a direct or indirect manner. A comparative approach using the urbanization gradient as a focal point was used in this study as it was impossible to study each human impact on trees in the urban environment separately. Although urbanization gradient studies are clearly a simplification of the complex patterns produced by urbanization (Hahs & McDonnell, 2006:435), it is a useful way to indicate the changing ecological patterns and processes across a landscape (McDonnell & Pickett, 1990:1234). The V-I-S model (Ridd, 1995:2173) used to quantify the urbanization gradient in this study was successful in distinguishing between rural and urbanized areas, but not in clearly distinguishing between urban and suburban areas, as a rather subjective distinguishing measure (50% imperviousness) was used.

The vegetation composition studies of the *Acacia karroo* – associated plant communities characterized the urbanization gradient further and confirmed earlier studies done in the Potchefstroom municipal area. There was an increase in the total plant species richness and native plant species richness and a decrease in exotic species richness from rural to more urbanized areas. In this study, similar plant communities were described for rural and more urbanized areas than were described in earlier studies by Cilliers and Bredenkamp (1999a; 1999b; 1999c; 2000). Before any future urbanization gradient studies in Potchefstroom are done, it will be well worth the effort to quantify the urbanization gradient after testing the seventeen measures proposed by Hahs and McDonnell(2006:438).

The soil composition of each study site indicated that some (for example, pH) of the soil characteristics could be associated with the urban-rural gradient. The soil characteristics are not necessarily typical of urban or rural areas, but are rather dependent upon specific human activities within that area, for example the application of fertilizer, irrigation and soil compaction. It was evident from the results of the soil characteristics and the PI_{ABS} values that human activities do influence certain soil characteristics and thus the overall vitality of trees.

The effects of human impacts on *Acacia karroo* along the urbanization gradient was quantified in terms of tree vitality measured as Performance Index (PI_{ABS}) and leaf water potential. Additionally, the general appearance of the trees (qualitative aspects) was used to determine the monetary values of *Acacia karroo* along the urbanization gradient. Tree vitality, leaf water potential and monetary values also formed part of the hypothesis of this study that stated that tree vitality and leaf water potential value of trees will decrease along the urbanization gradient from the rural to the more urbanized areas while the monetary value of the trees will increase along the urbanization gradient. Only the first part of this hypothesis was indicated to be true in this study.

Results have indicated that the "best performing trees" did indeed grow in the rural areas and the "worst performing trees" in the urban areas. In the suburban areas there was a combination of high and low PI_{ABS} values. The fact that there were individual trees in urban areas with higher PI_{ABS} values and trees in rural areas with lower PI_{ABS} values indicated the importance of local soil conditions and specific aspects of maintenance for the general vitality of the trees.

In this study, the hypothesis that leaf water potential will decrease along an urbanization gradient was not proved. The trees with the "highest" leaf water potential values occurred in the urban, suburban and rural study sites and the trees with the "lowest" leaf water potential occurred in rural and suburban study sites. The leaf water potential was thus not influenced by the effects of urbanization as such, but was rather influenced by other components such as the soil characteristics and other aspects not necessarily measured during this study.

The monetary values of *Acacia karroo* did not increase along the urbanization gradient as was suggested by the hypothesis. Although the trees in the rural areas had a lower average monetary value than the trees in the urban areas, there was not a consistant increase in the monetary value from rural to more urbanized areas. One would also exspect that the trees in the rural areas would actually have a higher monetary value as these trees are not really influenced by human activities. This was, however, not true in this study. Both the trees with the highest and lowest monetary values were trees that occurred in urban and suburban study sites. The monetary values of *Acacia karroo* were thus not influenced by the position of the trees along the urbanization gradient, but rather by the value they add to a certain environment or landscape.

Although this study showed that human activities do have a negative impact on trees, it also indicated that some human acivities have a positive influence on trees. It was evident from the soil data and Performance Index values that the trees close to the Kynoch fertilizer plant were positively influenced by the high concentration of nitrogen and phosphorus in the soil. It is also evident from the monetary values that trees that were maintained by humans had a higher monetary value. There are however a few suggestions, which would make subsequent studies even more valuable.

- Although there was a change over three months in the Performance Index as well as the water potential of the trees, it would be better if samples were collected and measured over a longer period. If the samples were taken over a whole growth period, the results would probably show a more significant change in the Performance Index and the leaf water potential of the trees. In the current study time was, however, limited as the leaves of *Acacia karroo* trees could not be collected during the winter months.

- Another suggestion is that more than one soil sample should be collected over the time period. This will give a better idea of what the soil composition is as soil contents are quite variable in space.
- The measurement of more environmental and ecophysiological factors such as soil compaction and chlorophyll content would assists in describing the impact of human activities on tree vitality.

References

ACOCKS, J.P.H. 1988. Veld types of South Africa. 3rd ed. Memoirs of the Botanical survey of South Africa. 147 p.

ALLOWAY, B.J. 1995. The origins of heavy metals in soils. (*In* Alloway B.J. *ed.* Heavy Metals in soils (2nd ed.). London: Blackie Academic. p. 38-57.)

ANON. 2003. Alkaline soils. http://ag.mdsharris.com/education_train/ak12.asp Date of access: 9 May 2006.

ASHMAN, M.R. & PURI, G. 2002. Essential Soil Science. Blackwell Publishing. 198p.

BARAL, A. & GUHA, G.S. 2004. Trees for carbon sequestration or fossil fuel substitution: the issue of cost vs. carbon benefit. *Biomass and Bioenergy*, 27:41-55, Nov.

BARNES, R.D., FILER, D.L. & MILTON, S.J. 1996. *Acacia karroo*. Monograph and Annotated Bibliography. *Tropical Forestry Papers,* 32.

BECKETT, K.P., FREER-SMITH, P.H. & TAYLOR, G. 1998. Urban Woodlands: their role in reducing the effects of particulate pollution. *Environmental Pollution,* 99(3):347-360, Dec.

BERNATZKY, A. 1978. Tree ecology and preservation. Amsterdam: Elsevier. 357 p.

BEZUIDENHOUT, H. & BREDENKAMP, G.J. 1991. The vegetation of the Bc land type in the western Transvaal Grassland, South Africa. *Phytocoenologia*, 19(4):497-518, Jul.

BEZUIDENHOUT, H., BREDENKAMP, G.J. & THERON, G.K. 1993. Syntaxonomy of the vegetation of the Fb land type in the western Transvaal Grassland, South Africa. (*In* Bezuidenhout, H. *ed.* Syntaxonomy and synecology of western Transvaal grasslands. University of Pretoria (Thesis – D.Phill) 405 p.

BIASIOLI, M., BARBERIS, R. & AJMONE-MARSAN, F. 2006. The influence of a large city on some soil properties and metal content. *Science of the Total Environment* 356(1-3):154-164, Mar.

BIDDLE, G. 1979. Practical tests and conclusions: (*In* Aldous, T. *ed.* Trees and Buildings: Compliment or conflict? London. RIBA Publications Limited, pp. 31-39)

BIDDLE, G. 1981. Physical problems caused by trees to buildings and services. (*In* Clouston, B. & Stansfield, K. *eds.* Trees in Towns: Maintenanca and management. London: Architectural Press Ltd, pp. 17-47)

BOLHÀR-NORDENKAMPF, H.R. & ÖQUIST, G. 1993 Chlorophyll fluorescence as a tool in photosynthesis research: (*In* Hall, D.O., Scurlock, J.M.O., Bolhàr-Nordenkampf, H.R., Leegood, R.C. & Long, S.P. *eds.* Photosynthesis and Production in a Changing Environment: a field and laboratory manual. London: Chapman & Hall, pp 193-206)

BOLUND, P. & HUNHAMMAR, S. 1999. Ecosystem services in urban areas. *Ecological Economics,* 29 (2):293-301, May.

BOTHA, C. 2001. Common weeds of crops and gardens in Southern Africa. Halfway House: Agricultural Research Council, Syngenta. 384 p.

BOTHA, L. (lbotha@giscoe.com) 7 February 2006. Quantification of urbanization gradient. E-mail to: Pelser, A.Y. (plbayp@puk.ac.za).

BRADY, N.L. & WEIL, R.R. 2002. The Nature and properties of soil. 2nd ed. New Jersey: Prentice Hall. 960 p.

BREDENKAMP, G.J., JOUBERT, A.F. & BEZUIDENHOUT, H. 1989. A reconnaissance survey of the vegetation of the plains in the Potchefstroom – Fochville – Parys area. *South African Journal of Botany*, 55:199-206, Aug.

BREDENKAMP, G.J., & VAN ROOYEN, N. 1996. Dry Sandy Highveld Grassland. (*In* Low, A.B. & Rebelo, A.G. *eds*. Vegetation of South Africa, Lesotho & Swaziland. Department of Environmental Affairs and Tourism. Pretoria.)

BULLOCK, P. & GREGORY, P.J. 1991. Soils: A neglected resource in urban areas. (*In* Bullock, P. & Gregory, P.J. *eds*. Soils in the urban environment. London: Blackwell Scientific Publications. p. 1-4.)

CAIRNS, R.D. & LASSERRE, P. 2004. Reinforcing economic incentives for carbon credits for forests. *Forest Policy and Economics*, 6(3-4):321-328, Jun.

CAMPLING, J.D. 1979. A surveyor's view: (*In* Aldous, T. *ed*. Trees and Buildings: Compliment or conflict? London. RIBA Publications Limited, pp 13-22)

CAPLAN, L. 2004. People pressure problems on trees. http://www.ces.purdue.edu/vanderburgh/horticulture/extnotes/2004/peoplepressure.htm Date of access: 26 Jan 2005.

CHIESURA, A. 2004. The role of urban parks for the sustainable city. *Landscape and Urban Planning*, 68(1):129-138, May.

CILLIERS, S.S. & BREDENKAMP, G.J. 1999a. Analysis of the spontaneous vegetation of intensively managed urban open spaces in the Potchefstroom Municipal Area, South Africa. *South African Journal of Botany*, 65(1):59-68, Feb.

CILLIERS, S.S. & BREDENKAMP, G.J. 1999b. Ruderal and degraded natural vegetation on vacant lots in the Potchefstroom Municipal Area, North West Province, South Africa. *South African Journal of Botany*, 65(2):163-173, Apr.

CILLIERS, S.S., VAN WYK, E. & BREDENKAMP, G.J. 1999c. Urban Nature Conservation: vegetation of natural areas in the Potchefstroom Municipal Area, North West Province, South Africa. *Koedoe*, 42 (1):1-30.

CILLIERS, S.S. & BREDENKAMP, G.J. 2000. Vegetation of road verges on an urbanization gradient in Potchefstroom, South Africa. *Landscape and Urban Planning*, 46(4):217-239, Feb.

CLOUSTON, B. & STANSFIELD, K. 1981. Trees in Towns; Maintenance and management. London, Architectural Press Ltd. 168 p.

COSTANZA, R., d'ARGE, R., DE GROOST, R., FARBER, S., GRASSO, M., HANNON, B., LIMBURG, K., NAEEM, S., O'NIEL, R. V., PARUELO, J., RASKIN, R. G., SUTTON, P. & VAN DEN BELT, M. 1997. The value of the world's ecosystem services and natural capital. *Nature,* 387 (6630):253-260, May.

CRAUL, P.J. 1992. Urban soil in landscape design. New York: John Wiley & Sons. 396 p.

DAVYDOVA, S. 2005. Heavy metals as toxicants in big cities. *Microchemical Journal*, 79(1-2):133-136, Jan.

DE GOUVENAIN, R.C. 1996. Indirect impacts of soil trampling on tree growth and plant succession in the North Cascade Mountains of Washington. *Biological Conservation*, 75(3):279-287.

DWYER, J.F., MCPHERSON, E.G., SCHROEDER, H.W. & ROWNTREE, R.A. 1992. Assessing the benefits and costs of the urban forest. *Journal of Arboriculture*, 18(5):227-234, Sep.

DWYER, J.F., NOWAK, D.J. & NOBLE, M. H. 2003. Sustaining urban forests. *Journal of Arboriculture*, 29(1):49-55, Jan.

EFFLAND, W.R. & POUYAT R, V. 1997. The genesis, classification and mapping of soils in urban areas. Urban Ecosystems, 1(4):217-228. Des.

ESRI. 2006. GIS and Mapping Software. Website: **ESRI**. 2006. GIS and Mapping Software. Website: www.esri.com

FARBER, S.C., COSTANZA, R. & WILSON, M.A. 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*, 41 (3):375-392, Jun.

FEDERER, C.A. 1976. Trees modify the urban microclimate. *Journal of Arboriculture*, 2(7):121-127, Jul.

FORCE, L., CRITCHLEY, C. & VAN RENSEN, J.J.S. 2003. New fluorescence parameters for monitoring photosynthesis in plants. *Photosynthesis Research*, 78(1):17-33, Oct.

FORMAN, R.T.T. & GODRON, M. 1986. Landscape Ecology. New York, John Wiley & Sons.

GASTON, K.J., SMITH, R.M., THOMPSON, K. & WARREN, P.H. 2005. Urban domestic gardens (IV): the extent of resource and its associated features. *Biodiversity and Conservation*, 14(2):395-413, Feb

GLINSKI, J. & STEPNIEWSKI, W. 1983. Soil aeration and its role for plants. United States: CRC Press Inc. 229 p.

GOULD, A.B. 1993. Tree problems caused by people in suburban landscape. Rutgers Cooperative Extension, New Jersey Agricultural Experimental Station, Rutgers, The State of New Jersey.

GRAHN, P. & STIGSDOTTER, U.A. 2003. Landscape planning and stress. *Urban Forestry & Urban Greening*, 2(1):1-18.

HAHS, A.K. & MCDONNELL, M.J. 2006. Selecting independent measures to quantify Melbourne's urban-rural gradient. *Landscape and Urban Planning*, 78(4): 435-448, Nov.

HALL, D.O., SCURLOCK, J.M.O., BOLHAR-NORDENKAMPF, H.R., LEEGOOD, R.C. & LONG, S.P. 1993. Photosynthesis and production in a changing environment: a field and laboratory manual. London, Chapman & Hall. 464 p.

HALVERSON, H.G. & HEISLER, G.M. 1981. Soil temperature under urban trees and asphalt. USDA. Forestry Services Research Papers, NE-481.

HAMMIT, W.E. 2002. Urban Forests and Parks as Privacy Refuges. *Journal of Arboriculture,* 28(1):19-26, Jan.

HAUSENBUILLER, R. L. 1978. Soil Science: Principles and Practices. 2nd ed. New York: John Wiley. 611p

HENDERSON, L. 2001. Alien weeds and invasive plants: A complete guide to declared weeds and invaders in South Africa. South Africa: Agricultural Research Council. 300 p.

HENNEKENS, S.M. 1996a. TURBOVEG: software package for input, processing, and presentation of phytosociological data. IBN-DLO, University of Lancaster.

HENNEKENS, S.M. 1996b. TURBOVEG: a visual editor for phytosociological tables. Giesen & Geurts, Ulft.

HERMANS, C., SMEYERS, M., RODIGUEZ, R.M., EYLETTERS, M., STRASSER, R.J. & DELHAYE, J. 2003. Quality assessment of urban trees: A comparative study of physiological characterization, airborne imaging and on site fluorescence monitoring by the OJIP-test. *Journal of Plant Physiology,* 160(1):81-90.

HODGE, S.J. 1995. Creating and managing woodlands around towns. London: HMSO Publications. 176 p.

HOPKINS, W.G. & HÜNER, N.P.A. 2004. Introduction to plant physiology (3^{rd} ed.). New York: John Wiley & Sons, Inc. 560 p.

IMPENS, R.A. & DELCARTE, E. 1979. Survey of urban trees in Brussels. Belgium. *Journal of Arboriculture,* 5:169-176.

ISA, (INTERNATIONAL SOCIETY OF ARBORICULTURE). 2003. Why topping hurts trees? http://www.treesaregood.com/treecare/topping.asp Date of access: 2 Jan. 2005.

JAMES, K. 2003. Dynamic loading of trees. *Journal of Arboriculture,* 29(3):165-171, May.

JIM, J.C. 2003. Protection of urban trees from trenching damage in compact city environments. *Cities,* 20(2):87-94, Apr.

KAUTSKY, H. & HIRSCH, A. 1931. Neue versuche zur kohlensäure assimilation. *Naturwissenschaften* 19: 964.

KELLING, K.A. 1999. Understanding plant nutrients: Soil and applied Boron. http://s142412519.onlinehome.us/uw/pdfs/A2522.PDF Date of access: 22 Mar. 2006.

KENT, M. & COKER, P. 1992. Vegetation Description and Analysis: A practical Approach. London: John Wiley & Sons. 363 p.

KIEKENS, L. 1995. Zinc. (*In* Alloway B.J. *ed.* Heavy Metals in soils (2nd ed.). London: Blackie Academic. p. 284-305).

KONIJNENDIJK, C.C., RICARD, R.M., KENNEY, A. & RANDRUP, T.B. 2006. Defining urban forestry – A comparative perspective of North America and Europe. *Urban Forestry & Urban Planning,* 4(3-4):93-103, Apr.

KONTUNENE-SOPPELA, S. 2001. Dehydrins in Scots Pine tissues: responses to annual rhythm, low temperature and nitrogen. http://herkules.oulu.fi/isbn9514259114/ Date of access: 9 May 2006.

KRÜGER, G.H.J., TSIMILLI-MICHEAL, M. & STRASSER, R.J. 1997. Light stress provokes plastic and elastic modifications in structure and function of photosystem II in camellia leaves. *Physiologia Plantarum* 101(2):265-277, Oct.

KUO, F.E., SULLIVAN, W.C., COLEY, R.L. & BRUNSON, L. 1998. Fertile Ground for Community: Inner-City Neighborhood Common Spaces. *American journal of Community Psychology*, l 26(6):823-851, Dec

LAND TYPE SURVEY STAFF. 1984. Land types of the maps 2626 Wes-Rand, 2726 Kroonstad. *Memoirs on the Agricultural Natural Resources of South Africa*, 4:1-441

LAVERNE, R.J. & WINSON-GEIDEMAN, K. 2003. The influence of trees and landscaping on rental rates at office buildings. *Journal of Arboriculture*, 29(5):281-290. Sep.

LAZÁR, D, 2006. The polyphasic chlorophyll a fluorescence rise measured under high intensity of exciting light. *Functional Plant Biology*, 33(1):9-30, Jan.

LEE, C.S., LIA, X., SHIB, W., CHEUNGB, S.C. & THORTON, I. 2005. Metal contamination in urban, suburban, and country park soils of Hong Kong: A study based on GIS and multivariate statistics. *Science of the total environment*, 356 (1-3):45-61, Mar.

LEHVÄVIRTA, S., RITA, H. & KOIVULA, M. 2004. Barriers against wear affect the spatial distribution of tree saplings in urban woodlands. *Urban Forestry & Urban Greening*, 3(1):3-17, Jul.

LEUNG, C-M. & JIAO, J.J. 2006. Heavy metal and trace element distributions in groundwater in natural slopes and highly urbanized spaces in Mid-Levels area, Hong Kong. *Water Research*, 40(4):753-767, Feb.

LI, F., WANG, R., PAULUSSEN, J. & LIU, X. 2005. Comprehensive concept planning of urban greening based on ecological principles: a case study in Beijing, China. *Landscape and Urban Planning*, 72(4):325-336, May.

LOW, A.B. & REBELO, A.G. 1996. Vegetation of South Africa, Lesotho, Swaziland. Department of Environmental Affairs and Tourism. Pretoria. 85 p.

LUTTIK, J. 2000. The value of trees, water and open space s reflected by house prices in the Netherlands. *Landscape and Urban Planning*, 48(3-4):161-167, May.

MARX, C.W. 2005. The development of a tree appraisal model for the urban environment of South Africa. *Unpublished.* Pretoria: UNISA. (Thesis – MTech).

MAXWELL, K & JOHNSON, G.N. 2000. Chlorophyll fluorescence – a practical guide. *Journal of Experimental Botany,* 51(345):659-668, Apr.

MCDONNELL, M.J. & PICKETT, S.T.A. 1990. Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology. *Ecology*, 71(4):1232-1237, Aug.

McGRATH, S.P. 1995. Chromium and Nickel. (*In* Alloway B.J. *ed.* Heavy Metals in soils (2nd ed.). London: Blackie Academic. p.152-178.)

MCINTYRE, N.E., KNOWLES-YANEZ, K. & HOPE, D. 2000. Urban ecology as an interdisciplinary field: differences in the use of "urban" between social and natural sciences. *Urban Ecosystem,* 4(1):5-24, Jan.

MCKENZIE, R. 2000. What's wrong with topping trees? http://www.agriculture.purdue.edu/fnr/index.html Date of access: 2 Jan 2005.

MCPHERSON, E.G. 1998. Atmospheric carbon dioxide reduction by Sacramento's urban forest. *Journal of Arboriculture*, 24(4):215-223, Jul.

MCPHERSON, E.G. 2000. Urban Forestry Issues in North America and their Global Linkages. Paper presented at the 20th Session of the North American Forestry Commission.

MCPHERSON, E.G. & PEPER, P.J. 1995. Infrastructure repair costs associated with street trees in 15 cities. (*In* Watson. G.W. & Neely, D. *eds*. Trees and Building Sites. International Society of Arboriculture, Champaign, IL. pp49-63.)

MCPHERSON, E.G., SIMPSON, J.R., PEPER, P.J., XIAO, Q., PETTINGER, D.R. & HODEL, D.R. 2001. Tree guidelines for inland empire communities. USDA forest services. 124 p. Jan.

MILLENNIUM ECOSYSTEM ASSESSMENT (MA). 2003. Ecosystems and human well-being: A framework for assessment. Washington: Island Press. 266 p.

MOLL, G & EBENRECK, S. 1989. Shading our cities: A resource guide for urban and community forests. Washington, Island Press. 329 p.

MOORE, R., CLARK, W.D. & VODOPICH, D.S. 1998. Botany (2nd ed.). USA: WCB McGraw-Hill Companies, Inc. 919 p.

MOOTER, D.P., HARRELL, M.O., ALLISON, R.A. & MURROW, J.C. 2000. Landscape tree appraisal. http://www.ianrpubs.unl.edu/epublic/live/g1533/build/g1533.pdf Date of access: 4 April 2006.

MUCINA, L., RUTHERFORD, M.C. & POWRIE,L.W. (*eds*). 2005. Vegetation Map of South Africa, Lesotho and Swaziland, 1: 1 000 000 scale sheet map. South Africa National Biodiversity Institute, Pretoria. ISBN 1-919976-22-1

MULLINS, C.E. 1991. Physical properties of soils in urban areas. (*In* Bullock, P. & Gregory, P.J. *eds*. Soils in the urban environment. London: Blackwell Scientific Publications. p.87-118.)

NAKAMARU, Y., TAGAMI, K. & UCHIDA, S. 2005. Effect of phosphate addition on the sorption–desorption reaction of selenium in Japanese agricultural soil. *Chemosphere*. 61(1):109-115, Mar.

NEAL, R.H. 1995. Selenium. (*In* Alloway B.J. *ed.* Heavy Metals in soils (2^{nd} ed.). London: Blackie Academic. p. 261-283).

NEL, L.T., TRUTER, F.C. & WILLEMSE, J. 1939. The geology of the country around Potchefstroom and Klerksdorp. Geological Survey, Department of mines, Union of South Africa, Goverment Printer: Pretoria, 156 p.

NIEMELÄ, J. 1999a. Ecology and Urban Planning. *Biodiversity & Conservation,* 8(1): 119-131, Jan.

NIEMELÄ, J. 1999b. Is there a need for a theory of urban ecology? *Urban Ecosystems*, 3(1):57-65, Mar.

NOWAK, D.J. 1993. Compensatory value of an urban forest: an application of the tree-value formula. *Journal of Arboriculture*, 19(3):173-177, May.

NOWAK, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's Urban Forest. (*In* McPherson, E.G., Nowak, D.J. & Rowntree, R.A., *eds*. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA. p 83-94.)

NOWAK, D.J. & CRANE, D.E. 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution,* 116(3):381-389, Mar.

NOWAK, D.J., STEVENS, J.C., SISINNI, S.M. & LULEY, C.J. 2002. Effect of urban tree management and species selection on atmospheric carbon dioxide. *Journal of Arboriculture,* 28(3):113-121, May.

O'NEILL, P. 1995. Arsenic. (*In* Alloway B.J. *ed.* Heavy Metals in soils (2nd ed.). London: Blackie Academic. p. 105-121).

PERCIVAL, G.C. & SHERIFFS, C.N. 2002. Identification of drought-tolerant woody perennials using chlorophyll fluorescence. *Journal of Arboriculture,* 28(5):215-223, Sep.

PERKINS, H.A., HEYNEN, N. & WILSON, J. 2004. Inequitable access to urban reforestation: the impact of urban political economy on housing tenure and urban forests. *Cities,* 21(4):291-299, Aug.

PHINN, S., STANFORD, M., SCARTH,P., MURRAY, A.T. & SHYY, P.T. 2002. Monitoring the composition of urban environments based on the vegetation-impervious surface-soil (V-I-S) model by subpixel analysis techniques. *International Journal of Remote Sensing,* 23 (20):4131-4153, Aug.

PULFORD, I.D. 1991. Nutrient provision and cycling in soils in urban areas. (*In* Bullock, P. & Gregory, P.J. *eds*. Soils in the urban environment. London: Blackwell Scientific Publications. p. 119-138.)

QUIGLEY, M.F. 2004. Street trees and rural conspecifics: Will long-lived trees reach full size in urban conditions? *Urban Ecosystems*, 7(1):29-39, Mar.

RASHED, T., JOHN, J.R., GADALLA, M.S. & HILL, A.G. 2001. Revealing the anatomy of cities through spectral mixture analysis of multispectral satellite imagery: a case study of the Greater Cairo Region, Egypt. *Geocarta International*, 16(4):5-15, Dec.

REYNOLDS, E.R.C. 1979. Problems of proximity: (*In* Aldous, T. Trees and Buildings: Compliment or conflict? London: RIBA Publications Limited, pp 23.30)

RICHARDSON, A.D., AKENS, M. BERLYN, G.P. & MARSHALL, P. 2004. Drought stress and Paper Birch (Betula papyrifera) seedlings: Effects of an organic biostimulant on plant health and stress tolerance, and detection of stress effects with instrument-based, noninvasive methods. *Journal of Arboriculture*, 30(1):52-61, Jan.

RIDD, M.K. 1995. Exploring a V-I-S (Vegetation, Impervious surface, Soil) model for urban ecosystems analysis through remote sensing: comparative anatomy for cities. *International Journal of Remote Sensing*, 16(12):2165-2185, Sep.

ROBERTS, B.R. 1977. The response of urban trees to abiotic stress. *Journal of Arboriculture*, (1977):75-78, Apr.

ROBERTS, D., BOON, R., CROUCAMP, P. & MANDER, M. 2005. Resource economics as a tool for open space planning in Durban, South Africa. (*In* Ted Trzyna, *ed*., *The Urban Imperative*. California Institute of Public Affairs, Sacramento, California.)

RUTHERFORD, M.C. AND WESTFALL, R.H. 1994. Biomes of southern Africa: an objective categorisation. National Botanical Institute. Pretoria. 94 p.

SALISBURY, F.B. & ROSS, C.W. 1992. Plant Physiology (4th ed.). California: Wadsworth Publishing Company. 682 p.

SANESI, G. & CHIARELLO, F. 2006. Residents and urban green spaces: The case of Bari. *Urban Forestry & Urban Greening*, 4(3-4):125-134, Apr.

SCHEYER, J.M., & K.W. HIPPLE. 2005. Urban Soil Primer. http://soils.usda.gov/use Date of access: 22 Mar. 2006.

SCHOENEWEISS, D.F. 1978. The influence of stress on diseases of nursery and landscape plants. *Journal of Arboriculture*, 4(10): 217-225, Oct.

SCHULTE, E.E. 1999. Understanding plant nutrients: Soil and applied Iron. http://s142412519.onlinehome.us/uw/pdfs/A3554.PDF Date of access: 22 Mar. 2006.

SCHULTE, E.E. 2004. Understanding plant nutrients: Soil and applied Zinc. http://s142412519.onlinehome.us/uw/pdfs/A2528.PDF Date of access 22 Mar. 2006.

SCHULTE, E.E. & KELLING, K.A. 1999. Understanding plant nutrients: Soil and applied manganese. http://s142412519.onlinehome.us/uw/pdfs/A2526.PDF Date of access: 22 Mar. 2006.

SCOTT, K.I., MCPHERSON, E.G. & SIMPSON, J.R. 1998. Air pollutant uptake by Sacramento's urban forest. *Journal of Arboriculture*, 24(4):224-234, Jul.

SEZGIN, N., OZCAN, H.K., DEMIR, G., NEMLIOGLU, S. AND BAYAT, C. 2004. Determination of heavy metal concentrations in street dusts in Istanbul E-5 highway. *Environment International* 29(7):979– 985, Jan.

SHASHUA-BAR, L. & HOFFMAN, M.E. 2000. Vegetation as a climatic component in the design of an urban street: An empirical model for predicting the cooling effect of urban green areas with trees. *Energy and Buildings*, 31(3):221-235, Apr.

SHASHUA-BAR, L. & HOFFMAN, M.E. 2003. Geometry and orientation aspects in passive cooling of canyon streets with trees. *Energy and Buildings*, 35(1): 61-68, Jan.

SHASHUA-BAR, L. & HOFFMAN, M.E. 2004. Quantitative evaluation of passive cooling of the UCL microclimate in hot regions in summer, case study: urban streets and courtyards with trees. *Building and Environment*, 39(9):1087-1099, Sep.

SIMPSON, J.R. 2002. Improved estimates of tree-shade effects on residential energy use. *Energy and buildings*, 34(10):1067-1076, Nov.

SMIT, N. 1999. Guide to the *Acacias* of South Africa. Pretoria: Briza Publications. 223p.

SMITH, K. A. & PATERSON, J.E. 1995. Manganese and Cobalt. (*In* Alloway B.J. *ed.* Heavy Metals in soils (2nd ed.). London: Blackie Academic. p. 224-244)

SOIL CLASSIFICATION WORKING GROUP. 1991. Soil classification. A taxonomic system for South Africa (2nd ed.). Pretoria: Dept. Agricultural Development. 262 p.

STATISTICA (data analysis software system), version 7.1 2005. [Computer program manual]. Tulsa: StatSoft, Inc. www.statsoft.com.

STOFFBERG, G.H. 2005. Growth and carbon sequestration of street trees in the City of Tshwane, South Africa. *Unpublished.* Pretoria: University of Pretoria. (Thesis – DPhill.)

STRASSER, R.J. (1978) The grouping model of plant photosynthesis. (In Akoyunoglou G *ed*. Chloroplast Development, pp 513--524. Elsevier/North Holland)

STRASSER, R.J. & GOVINDJEE, 1992. The F_0 and the O-J-I-P fluorescence rise in higher plants and algae. (*In* Argyroudi-Akoyunoglou, J.H. *ed.*, Regulation of chloroplast biogenesis. Plenum Press, New York, USA, pp. 423-426.)

STRASSER, B.J. & STRASSER, R.J. 1995. Measuring fast fluorescence transients to address environmental questions: The JIP-test. (*In* Mathis, P. *ed*, Photosynthesis: from light to biosphere. Kluwer Academic Publishers, The Netherlands, pp. 977-980.)

STRASSER, R.J., SRIVASTAVA, A. & TSIMILLI-MICHAEL, M. 2000 The fluorescent transient as a tool to characterize and screen photosynthesic samples. From "Probing Photosynthesis: mechanisms, regulation and adaptation". (*In* Yunus M, Pathre U, Mohanty P *eds*., Taylor and Francis, London, pp. 445-483.)

STRASSER, R.J. & TSIMILLI-MICHAEL, M. 2001 Stress in plants, from daily rhythm to global changes, detected and quantified by the JIP-test. *Chimie Nouvelle* (SRC). 75:3321-3326.

STRASSER, R.J., TSIMILLI-MICAEL, M. & SRIVASTAVA, A. 2004. Analysis pf the Chlorophyll a Fluorescence Transient. (*In* Papageorgiou, G.C. & Govindjee *eds*. Chlorophyll Fluorescnence: A signature of Photosynthesis. Netherlands, Kluwer Academic Publishers. pp. 321-362)

TAIZ, L. & ZEIGER, E. 2002. Plant Physiology Online (3[rd] ed.). Sinauer Associates, Inc. http://www.plantphys.net/. Date of access: 4 July 2006.

TATTER, T.A. 1980. Non-infectious diseases of trees. *Journal of Arboriculture*, 6(1):1-4, Jan.

TAYLOR, A.F., KUO, F.E. & SULLIVAN, W.C. 2001. Coping with ADD: The surprising connection to green play settings. *Environment and Behavior*, 33(1):54-77, Jan.

TENNESSEN, C.M. & CIMPRICH, B. 1995. Views to Nature: Effects on attention. *Journal of Environmental Psychology*, 15(1):77-85, Mar.

TER BRAAK, C.J.F. 1988a. CANOCO-a FORTRAN Program for Canonical Community Ordination by [Partial] [Detrended] [Canonical] Correspondence Analysis (Version 2.0). TNO Institute of Applied Computer Science, Washington;

TER BRAAK, C.J.F. 1988b. CANOCO-an extension of DECORANA to analyze species-environment relationships. *Vegetation,* 75(3):159-160, Jun.

THORNTON, I. 1991. Metal contamination of soils in urban areas. (*In* Bullock, P. & Gregory, P.J. *eds.* Soils in the urban environment. London: Blackwell Scientific Publications. p. 47-75.)

TSIMILLI-MICHEAL, M. & STRASSER, R.J. 2001. Fingerprints of climate changes on the photosynthetic apparatus behaviour, monitored by the JIP-test. (In: Walther, G-R, Burga, C.A., Edwards, P.J. *eds.* Fingerprints of Climate Changes – Adapted Behaviour and Shifting Species Ranges. Kluwer Academic/Plenum Publishers. New York and London, pp229-247.)

TURNBULL, C. 2005. Five reasons to stop topping trees. http://www.plantamnesty.org/stoptopping/5reasonstostoptopping.htm Date of access: 2 Jan 2005.

VAN OUDTSHOORN, F. 2004. Guide to grasses of Southern Africa. Pretoria: Briza. 288 p.

VAN RENSBURG, L., KRUGER, G.H.J., UBBINK, B., SCHOLES, M.C. & PEACOCK, J. 1997. A phytocentric perspective of *Asterolecanium quercicola* Bouche infestation on *Quercus robur* L. trees along an urbanization gradient. *South African Journal of Botany*, 63(1):25-31, Feb.

VON STÜLPNAGEL, A., HORBERT, M. & SUKOPP, H. 1990. The importance of vegetation for the urban climate. (*In* Sukopp, H., Hejny, & Kowarik, I. *eds*, Urban ecology: Plants and plant communities in urban environments. Netherland: SPB Academic Publishing, pp 175-193.)

VOOGT, J.A. 2004. Urban Heat Island: hotter cities. http://www.actionbioscience.org/environment/voogt.html Date of access: 30 Mar 2006.

WATSON, G. 2002. Comparing Formula Methods of Tree Appraisals. *Journal of arboriculture*, 28(1):11-18, Jan.

WEEKS, J.R., LARSON, D. & RASHED, T. 2003. Cotrast or continuum? The creation and application of an urban gradient index using remotely sensed imagery and GIS. (*In* The Annual Meeting of the Population Association of America, Minneapolis. May.)

WILLIAM, R.C. 2006. Does night lighting harm trees? Natural and Urban Resources, Urban Forestry, Purdue University.

WILSON, C.L. 1977. Emerging tree diseases in urban ecosystems. *Journal of Arboriculture*, 1977:69-71, Apr.

WOLF, K.L. 2004. Public value of Nature: Economics in urban trees, parks and open space. (In Miller, D. & Wise, J. A. *eds.* Design with Spirit: Proceedings of the 35th Annual Conference of the Environmental Design Research Association. Edmond, OK: Environmental Design Research Association)

WONG, N.H. & YU, C. 2005. Study of green areas and urban heat island in a tropical city. *Habitat International*, 29(3):547-558, Sep.

XIAO, Q., MCPHERSON, E.G., SIMPSON, J.R. & USTIN, S.L. 1998. Rainfall interception by Sacramento's urban forest. *Journal of Arboriculture*, 24(4):235-244, Jul.

YANG, J., McBRIDE, J., ZHOU, J. & SUN, Z. 2005. The forest in Beijing and its role in air pollution reduction. *Urban Forestry and Urban Greening*, 3(2):65-78, Jan.

Appendix A

YUNIBESITI YA BOKONE-BOPHIRIMA
NORTH-WEST UNIVERSITY
NOORDWES-UNIVERSITEIT

15 Februarie 2005

TOESTEMMING VIR NAVORSINGSPROJEK

Geagte Mnr/Me

Ek is 'n MSc student aan die Noordwes-Universiteit, Potchefstroom kampus. Ek is besig met 'n projek waar ons ondersoek hoe die ekofisiologie van bome langs 'n stedelike gradiënt verander. Dit doen ons deur die vitaliteit en die waterpotensiaal van die bome te meet. Deur die vitaliteit van die bome langs 'n stedelike gradiënt te vergelyk kan ons bepaal hoe mense die bome en algemene omgewing langs hierdie gradiënt beïnvloed. Ons bepaal nie net die vitalitiet en waterpotesiaal nie maar ook die monetêre waarde van die bome (ek sal die inligting vir u gee) deur 'n verskeidenheid van metings te doen. Die boom wat gebruik word is die baie algemene soetdoringboom (*Acacia karroo).*

Sommige van die opnames word tussen 03:00 en 05:00 in die oggend gedoen, met ander woorde voor sonop. Dit gebeur een keer 'n maand vir die volgende vyf maande. Die opname behels slegs die afknip van ongeveer 10 takkies, waarna die takkies na die straat geneem sal word om die nodige metings te doen – dit sal met die nodige stilte en inagneming van u privaatheid gepaardgaan. Die bome sal ook nie beskadig word nie. Al die ander opnames sal op ander dae tydens gewone werksure geskied. Met hierdie brief vra ek asseblief toestemming om die bome te gebruik wat op u erf staan. Ek sal 'n dag voor die opname bel en 'n reëling tref ten opsigte van toegang tot u eiendom waar die bome staan.

Baie Dankie

Groete

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Skool vir Omgewingswetenskappe en -Ontwikkeling
Plantkunde

SOUTHERN AFRICA TREE APPRAISAL METHOD

SATAM

GENERAL INFORMATION

CLIENT'S NAME: ______________________________

ADDRESS: ______________________________

TEL NO: ______________ **FAX NO:** ______________

APPRAISERS NAME: (PRINT NAME): ______________________

DATE OF EVALUATION: ______________________

CONTACT DETAILS OF EVALUATOR: ______________________

EMAIL: ______________ **CELL NO:** ______________

APPRAISERS REGISTRATION NO: ______________________

GLOBAL POSITION SYSTEM (GPS) READING (OR GRID SQUARE):
____

ACCURATE LOCATION DETAIL: ______________________

COMMENTS: ______________________________

Appendix A

SECTION A – SPECIES APPRAISED										
1. Plant Name (BOTANICAL NAME)										
2. Rural, Urban or Nature reserve?	Rural		Urban		Per-Urban		Nature Reserve		Forest	

3. Province						
	Eastern Cape		Free State		Gauteng	
	Kwa-Zulu Natal		Limpopo		Mpumalanga	
	Northern Province		North West Province		Western Cape	

4. Classification of the tree (If the tree is protected, indigenous, exotic, invader category 1, 2 or 3) (Compulsory to complete) Please complete all questions								
4.1.1 Is the tree an indigenous species?					Yes		No	
4.1.2 Is this tree endemic to the area where it is standing?			Yes		No		Unknown	
4.1.3 Is the tree on the protected tree list?			Yes		No		Unknown	
4.2 Is this tree an invader? If the answer is no – ignore question 4.2.1 – 4.2.4. If invader category 1, the rest of the evaluation can be ignored as the tree has to be removed.	No		Category 1		Category 2		Category 3	
4.2.1 Is the tree standing outside 30 meters of the 1:50 year flood line of any watercourse or wetland? (Contact the local authorities (town planning) on information pertaining to flood lines.)			Category 1 trees should be removed and not evaluated.		Category 2		Category 3	
4.2.2 Does the owner have a permit to grow the tree?					Yes		No	
4.2.2.1 If not (permit) does the owner want to apply for a permit?					Yes		No	
4.2.2.2 Permit number								
4.2.3 Has a notice for the removal of the tree been given to the client?							Yes	No

SECTION B – HISTORICAL, CULTURAL OR GENETIC CONSERVATION VALUE			
5. Historic value (Optional – only to completed if applicable)			
5.1 Does this tree have any historical value/status?	Yes	No	Unknown
5.2 Is the historic value International, National or Local?			

5.3 Who planted the tree?					
5.4 When was it planted?					
6. Cultural / Traditional / Commemorative value (Optional – only to be completed if applicable)					
6.1 Does the tree have any cultural, traditional or commemorative value?	Yes	No	Unknown		
6.2 Who or what is commemorated?					
6.3 Does this tree provide edible fruits to the community?				Yes	No
6.4 Is this tree being used for medicinal purposes?				Yes	No
6.4.1 By whom is it used for medicinal purposes.					
6.4.2 What is being treated?					
7. Genetic Conservation (Optional – only to be completed if applicable)					
7.1 Is this tree used for genetic conservation? (e.g. is this tree one of the only genetically pure *Celtis africana*?) <u>A sample of the tree needs to be taken for evaluation.</u>	Yes	No	Unknown		
7.2 Is this a very rare an /or unusual exotic tree?				Yes	No
8. Condition Appraisal (Compulsory to complete for any trees considered non hazardous) Please answer all the questions.					
8.1 Height of the tree in meters.					
8.2 Circumference of the trunk at 1.4 m above the ground					
8.3 Spread of the crown in meters.					
8.4 Height (trunk) from where the crown spreads in meters.					
8.5 In which age class will you categorise the tree?	Young		Semi-mature		
	Mature		Over mature/ senescent		
8.6 Condition Appraisal: GENERAL					
8.6.1 Does the tree show a loss in vigour?				Yes	No
8.6.2 Has this tree recently became a risk for failure due to a sudden exposure to wind? (Previously part of a large group of trees that was removed.)				Yes	No
8.6.3 Does the tree that is been evaluated, have a significant history of failure?				Yes	No
8.6.4 Have any of the adjacent trees failed?				Yes	No
8.6.5 Is the tree properly maintained?				Yes	No
8.6.6 Is the shedding of branches due to bad maintenance?				Yes	No
8.6.7 Has the tree been topped or otherwise overly pruned?				Yes	No
8.6.8 Are there large amounts of creepers in the upper canopy of the tree?				Yes	No

8.6.9 Does the tree threaten any overhead power, electric, water pipes or telephone lines? (If any other underground servitudes are visible, the same question should be asked.)	Yes	No	N/A
8.6.10 Are previously implemented preventive repair and maintenance procedures (if any) still effective?	Yes	No	N/A
8.7 Condition Appraisal: ROOTS			
8.7.1 Is there any significant mechanical injury to the root-zone within the tree's drip-line?	Yes	No	
8.7.2 Is more than 30 % of the drip-area of the tree permanently compacted or water-logged? (Trees that naturally grow in waterlogged soils should receive "No" for an answer.)	Yes	No	
8.7.3 Are the root flairs visible?	Yes	No	
8.7.4 Is there any visible damage to the root flairs?	Yes	No	
8.7.5 Are any tree fungus, "mushrooms", conks or brackets, visible at the root flairs of the tree or within the drip-line around the tree? (If nothing is seen, ask the owner.) Take samples if unsure if they are an indication of a root problem. Compare to pictures in literature.	Yes	No	
8.7.6 Is the tree free of girdling and/or kinked roots?	Yes	No	
8.7.7 Is the root space available to the tree in proportion to the size of the tree? (i.e. does the tree have enough soil space in the plant box it is standing in?)	Yes	No	
8.7.8 Have any roots been broken off, injured or damaged, within the last six years, by lowering the grade, installing or removal of paving, digging trenches or compacting within the drip line? (May need to ask the client.)	Yes	No	
8.7.9 Has the site recently been changed by construction, raising the grade, installing lawn, gardening? (Recently in tree terms is within the last 6 years.)	Yes	No	
8.8 Condition Appraisal: TRUNK or STEM			
8.8.1 Does the tree have only one trunk? (The absence of co-dominant stems.)	Yes	No	
8.8.2 Has the trunk of the tree developed a lean? If the answer is no, question 8.8.3 to 8.8.5 should be answered N/A.	Yes	No	
8.8.3 Is the lean natural? (Did the lean happen due to recent upheaval, e.g. heavy rains, or strong winds, the answer should be "yes".)	Yes	No	N/A
8.8.4 Did the tree all of a sudden started leaning to one side?	Yes	No	N/A

8.8.5 Is this lean combined with soil heaving or bulging, cavities, excessive end-weight, or large amounts of creepers, or any other complicating factors? (i.e. root damage)	Yes	No	N/A
8.8.6 Does the tree's trunk taper? (Does the trunk decrease in diameter with height?)	Yes	No	
8.8.7 Is the bark and wood sound? (visual assessment)	Yes	No	
8.8.8 Are there any swollen or sunken areas visible on the bark?	Yes	No	
8.8.9 Are there any significant injuries on the trunk / stem?	Yes	No	
8.8.10 Does this tree have any significant cavities, wounds, lightning injuries, vertical cracks or decay on the trunk or branches? (Look out for beehives, nesting holes, borers, termites, etc.)	Yes	No	
8.8.11 Is there any wound/damage on the tree due to severe staking?	Yes	No	
8.8.12 If there is a wound (not including a cavity) on the stem, does it span more than 30 % or 120° of the tree circumference?	Yes	No	
8.8.13 Is there a significant indication of the presence of pathogenic pests, which may cause the decline of the tree?	Yes	No	
8.8.13.1 Name the pathogen if you can.			
8.8.14 Does this tree have any weak crotches, included bark unions/forks and/or multiple attachments in the main trunk?	Yes	No	
8.8.15 Is there any bark on the stem missing off the stem that may have come off in an unnatural way?	Yes	No	
8.9 Condition Appraisal: SCAFFOLD BRANCHES (Only to evaluate dicotyledons ignore when monocots are evaluated)			
8.9.1 Are there any large dead branches visible?	Yes	No	
8.9.2 Is the live crown ratio (LCR) more than 60%? (Live crown in relation to dead branches)	Yes	No	
8.9.3 Is there good callus wood development?	Yes	No	
8.9.4 Do too many/all major branches originates at one point on the stem?	Yes	No	
8.9.5 Are the scaffold branches properly attached to the stem? (Good stem to branch ratio = 3:1 – the diameter of the trunk in relation to the scaffold branch diameter)	Yes	No	
8.9.6 Are there any seams, or cracks on the scaffold branches? (Especially look at the base of the scaffold branches.)	Yes	No	
8.9.7 Do any scaffold branches have included bark in their attachments?	Yes	No	
8.9.8 Is there any unnatural bow or sweep branches present? (Trees that naturally	Yes	No	

grow bow branches will receive a "No" for an answer.)		
8.9.9 Is there any significant die-back (stag-horning) visible?	Yes	No
8.9.10 Is there a significant indication of the presence of pathogenic pests on the scaffold branches, which may cause the decline of the tree?	Yes	No
8.9.10.1 Name the pathogen if you can.		
8.10 Condition Appraisal: SMALLER BRANCHES AND TWIGS (Only to evaluate dicotyledons)		
8.10.1 Is the shoot elongation the same year on year?	Yes	No
8.10.2 Is there an even distribution of healthy twigs?	Yes	No
8.10.3 Is there any poorly attached side-growth from previous topping or other heavy pruning?	Yes	No
8.10.4 Are there any branches with excessive end-weight and little or no taper?	Yes	No
8.10.5 Are there any loose hanging branches in the tree?	Yes	No
8.10.6 Are there narrow branch attachments with included bark?	Yes	No
8.10.7 Is there a significant indication of the presence of pathogenic pests on the smaller branches and twigs, which may cause the decline of the tree?	Yes	No
8.10.7.1 Name the pathogen or insect if you can.		
8.11 Condition Appraisal: FOLIAGE / FRONDS		
8.11.1 Does the tree have any leaves on at present. (If the answer is no the rest of this section should be ignored.)	Yes	No
8.11.2 Is the canopy excessively dense for the species in comparison to other species in the area? (To be determined by the tree species.)	Yes	No
8.11.3 Is there a significant indication of scorching, chlorosis, necrosis, deformity (e.g. mistletoe) or other abnormalities of leaves present on the tree?	Yes	No
8.11.4 Do the leaves have a normal size and shape?	Yes	No
8.11.5 Is the density of the foliage normal and evenly distributed?	Yes	No
8.11.6 Is there any un-seasonal leaf drop or wilted leaves present, especially after heavy rains or wind?	Yes	No
8.11.7 Is there a significant indication of the presence of pathogenic pests on the small branches and twigs, which my case the decline of the tree?	Yes	No
9. Environmental contribution (Please answer all the questions.)		
9.1 Does this tree provide shade?	Yes	No

9.2 Does this tree have a big influence on the utilisation of the area? (e.g. parking area, home, patio, picnic site, pedestrians, and so on.)	Yes	No	
9.3 Does this tree significantly influence the micro-climate of the surrounded environment?	Yes	No	N/A
9.4 If the tree is removed will it have a negative impact on the micro-climate of the surrounded environment?	Yes	No	
9.5 Does this tree act as a wind barrier/break?	Yes	No	
9.6 If the tree is removed will it create a opening in the windbreak that will tunnel the wind and increase the wind velocity?	Yes	No	N/A
9.7 Does this tree act as sound and visual buffer to noisy streets, factories, school or any other unsightly views?	Yes	No	
9.8 If the tree is removed will it significantly influence soil erosion?	Yes	No	
9.9 Is this tree stabilizing a slope, river bank, embankment, and so on?	Yes	No	
9.10 Are there any visible bird nests in the tree?	Yes	No	
9.11 Are there any signs of frequent visiting (roosting or feeding – feathers and droppings will be visible)	Yes	No	
9.12 Does this tree provide food (fruit or nectar) to small animals, birds, butterflies, bees or bats?	Yes	No	

10. Amenity Appraisal (Please answer all the questions) Only for urban areas			
10.1 Is this tree the focal point (accent) of this area?		Yes	No
10.2 Has the tree a specific seasonal value that makes it a focal plant?	Foliage	Yes	No
	Flowers	Yes	No
	Berries	Yes	No
	Bark	Yes	No
	Growth habit	Yes	No
	Fragrance	Yes	No
	Other	Yes	No
10.3 Does the tree has a specific contribution to the setting in the landscape? e.g. colour of the bark, flowers, etc. that is part of the overall design theme.		Yes	No
10.4 If the tree is removed will it negatively influence the design of the garden, park, and so on?		Yes	No
10.5 If this tree is removed will it negatively influence the background of the rest of the garden or park?		Yes	No

10.6 Was this tree planted / or is it currently used to:	Screen unsightly views	Yes	No
	Define a space	Yes	No
	Create a vista or frame a view	Yes	No
	Direct traffic	Yes	No
10.7 If the tree is removed will it negatively influence the:	Design theme	Yes	No
	Vista or view that was created	Yes	No
10.8 Is this tree too big or too small in proportion (scale) to the area it is standing? (e.g. *Celtis africana* in a townhouse garden or *Alberta magna* next to a double story home.)		Yes	No
10.9 Is this tree been planted to attract fauna to the garden or area?		Yes	No
10.10 Was this tree been planted to establish a eco-friendly garden?		Yes	No
10.11 If this tree is removed will it influence the rhythm of the garden, street scape? (e.g. A row of *Jacaranda mimosifolia* as street trees.)		Yes	No
10.12 Was this tree planted to supplement the owner's income? (e.g. fruit trees, vines, timber, fire wood – not on a commercial scale)		Yes	No
10.13 Was the tree planted to provide the family with fresh fruit?		Yes	No

SECTION D

11. Visual Tree Defect Assessment (Trees need to be bigger than 5 meters to evaluate)

Look at: The likelihood of failure

The size of the part likely to fail

The target in the event of failure

Can you identify one or more of the following defects (Matteck, *et al.* 2003):	One side decay	Yes	No
	One side bulge (smooth)	Yes	No
	One side buckling	Yes	No
	Symmetric decay	Yes	No
	Symmetric fibre buckling	Yes	No
	Ring bulge	Yes	No
See Figures 4.49 to 4.62	Decayed butt	Yes	No
	Bottle neck	Yes	No
	Grafting crack	Yes	No

	Open radial crack	Yes	No
	Long open rib	Yes	No
	Included bark	Yes	No
	Double rib	Yes	No
	Internal crack	Yes	No
	Round nose rib	Yes	No
	Spiralled crack	Yes	No
	Spiralled rib	Yes	No
	Radial crack	Yes	No
	Ribs	Yes	No
	Co-dominant branch attachment (separation)	Yes	No
	Cracking and bucking bark	Yes	No
	Vertical cracks in old pruning wounds	Yes	No
	Harshly staking wounds	Yes	No

SECTION E

12. Impairment Factor (Will not influence the evaluation)			
12.1 Does any damage caused by tree influence value of the tree?		Yes	No
12.2 What problem is this tree causing?	Block pool filters with leaves, berries, etc.	Yes	No
	Drop excess leaves on paved areas	Yes	No
	Drop excess leaves on cars	Yes	No
	Blocked gutters with leaves, berries, etc.	Yes	No
	Block the entrance to the site.	Yes	No
	Block sunlight from entering a house/building	Yes	No
	Block beautiful views or vistas	Yes	No
	Excessive germination of seeds in garden.	Yes	No
	Roots damage underground services	Yes	No
	Cause structural damage	Yes	No
	Other	Yes	No

Appendix A

RELEVÉ FORM

A. GENERAL INFORMATION

1. Relevé number ☐   2. Date ....

3. General locality ....

4. Precise locality ....

5. Land use type ....   6. Size of sample plot ....

B. HABITAT INFORMATION

1. Topography ....   2. Geology ....

3. Aspect ....   4. Slope ....

5. Soil type ....   6. Soil profile ....

7. Soil compaction ....   8. Rockiness of soil surface (%) ....

9. Any disturbance

Mowing	☐	Weeding	☐
Trampling	☐	Grazing	☐
Chemicals	☐	Erosion	☐

Other ....

10. Light intensity ....

11. Any other information ....

....

C. PHYSIOGNOMY / STRUCTURE

Tree layer	Shrub layer	Forb layer	Grass layer

Height				
% Cover				

Most important growth form

....

D. FLORISTIC COMPOSITION

Grass	Sca le	Grass	Scal e	Forbs	Scal e	Forbs	Sca le	Shrubs	Scal e	Shrubs	Scal e

		Height classes (m)				
Trees	**Scale**	**0 - 0,5**	**0,5 - 1**	**1 - 2**	**2 - 3**	**> 3**

Table 1. Macro elements found in the soil samples of the twenty study sites in the Potchefstroom Municipal Area.

1:2 Extract										
Macro-elements										
Sample no.	Ca	Mg	K	Na	P	SO_4	NO_3	NH_4	Cl	HCO_3
	Millimol per litre									
sP	1.38	0.92	0.41	0.40	0.01	0.35	3.84	0.07	0.66	0.30
uG	0.92	0.44	0.63	0.03	0.01	0.15	2.62	0.04	0.25	0.30
uW	0.73	0.81	0.40	0.33	0.06	0.20	2.49	0.05	0.58	0.25
uO	0.94	0.85	1.45	0.32	0.04	0.34	3.85	0.06	0.71	0.25
sC	0.95	0.71	1.02	0.05	0.01	0.20	3.62	0.04	0.35	0.09
uS	0.72	0.49	0.95	0.11	0.01	0.22	2.67	0.07	0.44	0.10
sV	1.06	1.27	0.24	0.25	<0.01	0.44	2.77	0.04	1.10	0.45
sT	0.60	0.57	0.49	0.09	<0.01	0.29	1.94	0.05	0.53	0.05
rV	0.45	0.65	1.23	0.06	<0.01	0.23	2.59	0.03	0.53	0.02
sM	1.38	1.36	0.95	0.20	<0.01	0.25	4.92	0.03	0.92	0.35
rD	0.75	0.43	1.25	0.03	0.01	0.22	2.27	0.11	0.75	0.40
sK	1.32	0.57	1.91	0.06	0.95	0.29	2.15	0.13	0.40	0.00
uH	0.95	0.76	0.70	0.13	0.02	0.19	3.39	0.08	0.51	0.03
uV	0.87	0.47	1.71	0.09	0.01	0.20	2.59	0.06	0.72	0.85
uC	0.81	1.14	0.84	7.45	0.07	2.19	1.21	0.06	5.06	1.40
sG	0.56	1.16	0.15	3.39	0.02	1.07	1.05	0.03	2.93	0.85
rO	0.66	0.45	0.75	0.08	0.01	0.27	1.94	0.06	0.59	0.10
rP	0.48	0.51	1.81	0.18	<0.01	0.24	2.83	0.05	0.79	0.10
rA	0.87	0.45	1.05	0.02	0.02	0.19	2.77	0.05	0.52	0.08
rF	0.35	0.42	0.58	0.09	0.01	0.20	1.60	0.05	0.34	0.05

Table 2. Micro elements and other data from the soil samples of the twenty study sites in the Potchefstroom Municipal Area.

1:2 Extract										
Micro-elements and other data										
Sample	Fe	Mn	Cu	Zn	B	pH	EC	P-BRAY 1	C	CEC
no.	*Micromol per litre*						*(mS/cm)*	*PPM*	%	cmol(+)/kg
sP	10.32	1.13	0.65	0.97	14	7.06	0.55	10.37	4.68	19.29
uG	31.58	0.58	0.26	0.27	<1	6.99	0.35	10.92	4.01	19.66
uW	14.40	0.25	0.47	0.47	2	6.70	0.39	31.24	7.19	38.46
uO	81.31	1.42	0.71	0.96	<1	6.52	0.56	32.34	3.38	17.64
sC	23.66	0.34	0.37	0.51	3	5.96	0.45	12.65	2.61	12.99
uS	79.95	1.18	0.70	0.53	3	5.71	0.37	10.72	1.53	13.48
sV	11.61	0.27	0.43	0.41	13	7.02	0.52	4.66	2.07	25.39
sT	67.94	0.60	0.34	0.45	6	5.10	0.31	4.31	1.40	15.18
rV	35.99	0.92	0.22	0.26	7	4.97	0.36	4.31	0.74	12.52
sM	6.81	0.79	0.50	0.42	8	7.14	0.67	5.48	1.73	17.97
rD	73.98	3.49	0.95	0.56	<1	6.61	0.39	4.25	0.96	12.04
sK	10.25	25.79	0.67	8.33	11	4.22	0.60	627.15	4.10	26.40
uH	40.34	2.91	0.50	1.23	3	5.01	0.44	14.85	5.55	31.94
uV	33.96	0.81	0.38	0.70	<1	7.35	0.46	10.37	1.98	17.92
uC	16.79	0.41	1.01	0.72	4	7.60	1.23	50.52	0.96	12.87
sG	5.49	0.16	0.71	0.46	4	7.58	0.70	58.28	0.32	11.51
rO	55.61	0.75	0.44	0.39	4.14	5.38	0.32	3.69	0.53	11.44
rP	87.69	0.71	0.63	0.48	<1	5.69	0.42	5.14	1.81	15.17
rA	18.92	0.90	0.33	0.57	<1	5.53	0.38	9.96	1.55	16.14
rF	69.07	1.61	0.67	0.78	<1	5.10	0.24	4.1	5.97	34.63

Table 3. Heavy metals found in the soil samples of the twenty study sites in the Potchefstroom Municipal Area.

1:2 Extract								
Heavy Metals								
Sample no.	Al	Pb	Cr	Ni	Co	Cd	Se	As
	Microgram per litre							
sP		1.20	3.30			0.30	11.00	1.5
uG		1.40	11.00			0.17	6.80	3
uW		1.00	7.40			0.12	5.40	2.4
uO		4.70	18.00			0.24	5.00	2.9
sC		1.70	8.10			0.19	4.80	<0.10
uS		1.80	15.00			0.11	4.70	1.3
sV		0.38	3.00			0.09	4.20	<0.10
sT		1.20	14.00			0.06	3.30	0.05
rV		1.40	8.60			0.11	3.50	<0.1
sM		0.45	4.10			0.08	3.90	<0.10
rD		1.40	19.00			<0.058	4.10	1.4
sK		1.50	4.60			0.42	2.90	2
uH		0.50	6.60			<0.058	3.60	0.17
uV		1.00	13.00			0.06	4.20	0.55
uC		0.44	12.00			0.12	14.00	5.1
sG		0.23	7.10			<0.058	6.30	0.88
rO		0.59	10.00			<0.058	5.30	<0.10
rP		1.10	27.00			<0.058	7.20	0.14
rA		0.72	5.60			<0.058	2.10	<0.10
rF		2.10	85.00			<0.058	2.40	1.7

Table 4. Soil particle size of the soil samples from the twenty study sites in the Potchefstroom Municipal Area

Particle Size Distribution				
Sample	**> 2mm**	**Sand**	**Silt (% < 2mm)**	**Clay**
sP	11.8	65.7	24.8	9.5
uG	4.8	56.2	25.2	18.5
uW	0.7	57.8	21.4	20.8
uO	14.9	71.0	17.9	11.1
sC	9.3	58.4	24.2	17.3
uS	12.1	66.5	19.4	14.1
sV	1.9	47.9	30.2	21.9
sT	11.0	66.7	22.3	11.0
rV	2.2	73.1	14.4	12.5
sM	9.4	66.6	16.2	17.1
rD	9.1	84.4	15.4	0.2
sK	17.2	62.0	27.2	10.8
uH	7.0	63.6	23.9	12.5
uV	21.4	62.0	23.7	14.3
uC	4.9	77.1	15.9	7.1
sG	1.5	80.1	12.1	7.8
rO	6.2	62.0	25.9	12.0
rP	1.6	64.1	21.7	14.2
rA	2.4	54.3	23.2	22.5
rF	1.3	37.8	32.2	29.9

Table 5. Tree Appraisal characteristics and abbreviation for each characteristic used for the appraisal of Acacia karroo at each study site in the Potchefstroom Municipal Area.

Tree appraisal characteristics		**Study sites**																			
		rO	**rP**	**sP**	**uG**	**uW**	**rV**	**sT**	**sV**	**sM**	**sG**	**rF**	**uV**	**uC**	**uH**	**sC**	**rD**	**sK**	**rA**	**uS**	**uO**
Loss in vigour	**LIV**	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Threat to any overhead power	**OP**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Mechanical injury to the root-zone	**Rzone**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visible root flairs	**VRF**	0	1	0	1	1	0	1	1	0	1	0	0	1	1	0	0	1	0	0	1
Damage to root flairs	**DRF**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Free of kinked roots	**FKR**	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
Root space availability	**RSA**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Root injury	**RI**	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
One trunk	**OT**	0	1	1	1	1	0	1	0	1	1	1	0	1	0	0	1	1	0	1	1
Trunk lean	**TL**	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0
Swollen/sunken bark	**SST**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Injuries on trunk	**IOT**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Significant cavities	**SC**	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Pathogenic pests	**PPT**	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Included bark	**INB**	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0
Missing bark	**MB**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0

Tree appraisal characteristics		Study sites																			
		rO	rP	sP	uG	uW	rV	sT	sV	sM	sG	rF	uV	uC	uH	sC	rD	sK	rA	uS	uO
Dead branches visible	DBV	1	1	0	1	0	1	0	1	1	0	1	0	0	0	0	1	1	1	1	1
Callus development	CD	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1
Branches originate at one place	BO	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Branches properly attached	BPA	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0
Seams/cracks on branches	SOB	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Included bark in branches	IBB	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Unnatural bow/sweep	UB	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1
Pathogenic pests on branches	PPB	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0
Even distribution of healthy twigs	EDT	1	1	0	0	0	1	1	1	1	1	0	1	1	0	0	0	1	1	1	1
Even foliage distribution	EFD	1	1	0	0	1	1	1	1	1	1	0	1	1	0	0	1	1	1	0	1
Influence on utilization of park	IU	0	0	1	1	1	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0
Wind barrier	WB	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Removal-opening in windbreak	RIW	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visible bird nests	VBN	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	1
Frequent bird visiting	FBV	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1
Focal point	FP	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Foliage value	FOILV	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Flowers value	FLOV	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Tree appraisal characteristics		Study sites																			
		rO	rP	sP	uG	uW	rV	sT	sV	sM	sG	rF	uV	uC	uH	sC	rD	sK	rA	uS	uO
Contribution to landscape	CTL	1	0	1	1	1	0	1	0	1	1	0	0	1	1	1	0	1	0	1	1
Influence design	ID	0	0	1	1	1	0	0	0	1	1	0	0	1	1	1	0	0	0	1	1
Influence background	IB	0	0	1	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	1
Screen unsightly views	SUV	0	0	1	1	0	1	1	1	1	0	0	0	0	0	1	0	1	0	0	0
Define a space	DS	1	0	1	1	1	0	1	1	0	0	0	0	1	1	1	0	0	0	0	0
Create frame	CF	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
Direct traffic	DT	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Removed-influence design	RID	1	0	1	1	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Removed-influence view	RIV	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
Tree in proportion	TIP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Attract fauna	AF	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1
Eco-friendly	ECOF	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1

Table 6. Monetary values of Acacia karroo trees at each study site in the Potchefstroom Municipal Area.

Monetary values of *Acacia karroo*	
Study sites	**Monetary value**
uC	R 18 600.00
uO	R 47 000.00
uG	R 54 200.00
uH	R 35 900.00
uW	R 30 500.00
uV	R 13 700.00
uS	R 14 300.00
sM	R67 300.00
sG	R 14 000.00
sK	R 25 100.00
sV	R 17 600.00
sC	R 43 000.00
sT	R 27 700.00
sP	R 46 200.00
rD	R 35 000.00
rA	R 16 500.00
rO	R 34 700.00
rP	R 26 100.00
rV	R 23 400.00
rF	R 24 300.00

Calculation 1. Example of how the percentage deviation of the Performance Index values was calculated

$$\textbf{Percentage deviation} = \frac{\text{Value x} - \text{Average value of all the trees or study sites}}{\text{Average value of all the trees or study sites}} \times 100\%$$

Example: Value x = Value of Tree 1 at study site uC

= **17.524**

Average value of all the trees = **30.6**

$$\textbf{Percentage deviation} = \frac{17.524 - 30.6}{30.6} \times 100\%$$

= -42.8%

Table 7. Performance Index values of all the Acacia karroo trees at each study site in the Potchefstroom Municipal Area.

Performance Index values of all the trees								
Individual trees	**February values**	**Percentage deviation**	**March values**	**Percentage deviation**	**April values**	**Percentage deviation**	**Average value**	**Percentage deviation**
uC 1	17.524	-42.844	25.048	-20.7758	12.489	-42.6228	18.35367	-34.4848
2	24.48	-20.1564	22.744	-28.0632	10.949	-49.6979	19.391	-30.7819
3	16.118	-47.4298	23.71	-25.0078	22.563	3.659341	20.797	-25.763
4	23.495	-23.3691	24.988	-20.9656	15.792	-27.4481	21.425	-23.5213
uO 5	29.64	-3.32665	39.31	24.33334	16.872	-22.4864	28.60733	2.116713
6	29.293	-4.45842	28.564	-9.65511	24.187	11.12035	27.348	-2.3786
7	26.734	-12.8048	34.366	8.695996	22.294	2.423496	27.798	-0.77228
uG 8	27.353	-10.7859	23.58	-25.419	19.696	-9.51228	23.543	-15.9609
9	24.223	-20.9947	19.832	-37.2735	17.856	-17.9656	20.637	-26.3342
10	28.118	-8.29078	24.557	-22.3288	14.789	-32.0561	22.488	-19.7269
11	22.518	-26.5557	22.994	-27.2724	5.033	-76.8773	16.84833	-39.8582
uH 12	21.06	-31.311	20.453	-35.3093	16.002	-26.4833	19.17167	-31.5648
13	35.664	16.32113	34.366	8.695996	28.546	31.14655	32.85867	17.29227
14	25.693	-16.2001	19.043	-39.769	24.834	14.09281	23.19	-17.221
15	28.945	-5.59345	24.441	-22.6957	30.547	40.33958	27.97767	-0.13094
uW 16	22.646	-26.1382	20.574	-34.9266	20.019	-8.02835	21.07967	-24.754
17	31.229	1.856004	38.367	21.35073	26.76	22.94127	32.11867	14.65077
18	28.115	-8.30057	28.387	-10.2149	17.415	-19.9917	24.639	-12.0486
19	30.804	0.469831	30.172	-4.56918	17.536	-19.4358	26.17067	-6.58121
uV 20	17.517	-42.8668	26.696	-15.5634	14.523	-33.2782	19.57867	-30.112
21	30.988	1.069963	38.967	23.24847	23.431	7.647122	31.12867	11.11686
22	30.984	1.056916	37.495	18.59269	27.811	27.7698	32.09667	14.57223
23	20.732	-32.3808	28	-11.439	20.234	-7.04059	22.98867	-17.9397
uS 24	29.618	-3.39841	37.614	18.96907	19.989	-8.16618	29.07367	3.781336
25	30.356	-0.99136	27.565	-12.8148	27.183	24.88463	28.368	1.262389
26	29.044	-5.27056	33.833	7.010174	19.985	-8.18455	27.62067	-1.40529
27	29.444	-3.96592	32.423	2.550494	23.931	9.944231	28.59933	2.088156
sM 28	33.389	8.901026	33.347	5.473008	22.042	1.265753	29.59267	5.633958
29	17.393	-43.2713	28.245	-10.6641	18.087	-16.9044	21.24167	-24.1758
30	33.789	10.20566	37.558	18.79195	26.599	22.2016	32.64867	16.54265
31	34.64	12.98127	37.768	19.45616	28.334	30.17257	33.58067	19.86952
sG 32	51.683	68.56844	41.739	32.01601	27.039	24.22306	40.15367	43.33249

Performance Index values of all the trees								
Individual trees	**February values**	**Percentage deviation**	**March values**	**Percentage deviation**	**April values**	**Percentage deviation**	**Average value**	**Percentage deviation**
33	17.352	-43.405	35.105	11.03337	9.634	-55.7393	20.697	-26.12
34	33.207	8.307417	32.725	3.505688	17.609	-19.1004	27.847	-0.59737
35	26.877	-12.3384	30.673	-2.98457	17.467	-19.7528	25.00567	-10.7398
sK 36	35.481	15.72426	46.882	48.28277	24.954	14.64412	35.77233	27.69289
37	32.609	6.35699	39.507	24.95643	23.648	8.644067	31.92133	13.94636
38	42.813	39.63819	10.226	-67.6563	29.17	34.01334	27.403	-2.18227
39	43.497	41.86912	56.202	77.76094	22.803	4.761953	40.834	45.76101
sV 40	19.842	-35.2837	28.937	-8.47535	14.909	-31.5048	21.22933	-24.2198
41	27.188	-11.3241	31.946	1.041794	11.385	-47.6948	23.50633	-16.0918
42	20.655	-32.632	33.361	5.517288	8.411	-61.358	20.809	-25.7202
43	21.399	-30.2054	29.09	-7.99143	11.205	-48.5218	20.56467	-26.5924
sC 44	24.592	-19.7911	20.453	-35.3093	12.979	-40.3716	19.34133	-30.9592
45	18.916	-38.3039	16.592	-47.5213	18.005	-17.2811	17.83767	-36.3267
46	31.807	3.7412	20.947	-33.7469	37.829	73.79467	30.19433	7.781667
47	15.132	-50.6457	22.626	-28.4364	12.581	-42.2001	16.77967	-40.1033
sT 48	29.704	-3.11791	20.519	-35.1006	27.512	26.39613	25.91167	-7.50574
49	42.166	37.52795	28.406	-10.1548	34.452	58.28	35.008	24.96453
50	32.586	6.281974	36.795	16.37866	21.176	-2.71284	30.18567	7.75073
51	36.26	18.26503	35.353	11.81777	23.316	7.118787	31.643	12.95283
sP 52	45.834	49.49144	28.695	-9.24077	30.484	40.05014	35.00433	24.95144
53	34.691	13.14761	25.886	-18.1253	17.49	-19.6471	26.02233	-7.1107
54	31.299	2.084315	23.607	-25.3336	21.488	-1.27944	25.46467	-9.10135
55	28.847	-5.91309	25.012	-20.8897	20.255	-6.94411	24.70467	-11.8142
rD 56	37.08	20.93953	44.811	41.73242	25.255	16.02698	35.71533	27.48942
57	39.73	29.58273	37.875	19.79459	13.513	-37.9183	30.37267	8.418245
58	33.787	10.19914	49.188	55.5764	31.373	44.1344	38.116	36.05884
59	37.844	23.43138	48.883	54.61172	22.09	1.486275	36.27233	29.47769
rA 60	27.84	-9.1975	37.924	19.94957	21.357	-1.88129	29.04033	3.662349
61	34.687	13.13456	40.929	29.45407	23.751	9.117272	33.12233	18.23345
62	37.79	23.25526	42.245	33.61643	36.031	65.53427	38.68867	38.10303
63	25.267	-17.5896	34.425	8.882607	16.549	-23.9703	25.41367	-9.2834
rO 64	36.764	19.90887	41.387	30.90267	24.272	11.51086	34.141	21.86968
65	46.692	52.28988	38.194	20.80355	19.918	-8.49237	34.93467	24.70276
66	31.441	2.54746	35.918	13.60481	22.165	1.830842	29.84133	6.521598
67	37.514	22.35506	34.327	8.572643	25.011	14.90599	32.284	15.24094

Performance Index values of all the trees								
Individual trees	**February values**	**Percentage deviation**	**March values**	**Percentage deviation**	**April values**	**Percentage deviation**	**Average value**	**Percentage deviation**
rP 68	43.618	42.26377	16.934	-46.4396	30.591	40.54172	30.381	8.447992
69	34.883	13.77383	23.656	-25.1786	24.489	12.5078	27.676	-1.20777
70	35.109	14.51095	44.084	39.43299	28.885	32.70399	36.026	28.59838
71	26.375	-13.9757	22.592	-28.5439	14.038	-35.5064	21.00167	-25.0325
rV 72	35.532	15.8906	33.624	6.349129	30.431	39.80665	33.19567	18.49522
73	31.734	3.503104	29.547	-6.54599	27.792	27.68251	29.691	5.984968
74	28.544	-6.90135	41.107	30.01706	9.687	-55.4958	26.446	-5.59838
75	34.369	12.09738	31.207	-1.29558	20	-8.11564	28.52533	1.824006
rF 76	43.575	42.12352	33.361	5.517288	38.052	74.81918	38.32933	36.82036
77	45.645	48.875	40.745	28.87209	31.535	44.87866	39.30833	40.31499
78	23.68	-22.7657	29.711	-6.02727	20.397	-6.29174	24.596	-12.2021
79	36.653	19.54684	38.748	22.5558	30.242	38.93834	35.21433	25.70105
Average	**30.6**		**31.6**		**21.8**		**28.1**	

Table 8. Average Performance Index values of the Acacia karroo trees at each study site in the Potchefstroom Municipal Area.

Average Performance Index Values of the study sites								
Study Sites	**February values**	**Percentage deviation**	**March values**	**Percentage deviation**	**April values**	**Percentage deviation**	**Average value**	**Percentage deviation**
uC	20.40425	-33.4498	24.1225	-23.7031	15.44825	-29.0274	19.99167	-28.6378
uO	28.55567	-6.8633	34.08	7.791408	21.11767	-2.98084	27.91778	-0.34472
uG	25.553	-16.6567	22.74075	-28.0734	14.3435	-34.1028	20.87908	-25.47
uH	27.8405	-9.19587	24.57575	-22.2695	24.98225	14.7739	25.7995	-7.90613
uW	28.1985	-8.02823	29.375	-7.09001	20.4325	-6.12864	26.002	-7.18328
uV	25.05525	-18.2802	32.7895	3.709694	21.49975	-1.22546	26.44817	-5.59065
uS	29.6155	-3.40656	32.85875	3.928725	22.772	4.619532	28.41542	1.431647
sM	29.80275	-2.79583	34.2295	8.264261	23.7655	9.183888	29.26592	4.467591
sG	32.27975	5.283114	35.0605	10.89263	17.93725	-17.5924	28.42583	1.468831
sK	38.6	25.89714	38.20425	20.83597	25.14375	15.51587	33.98267	21.3045
sV	22.271	-27.3613	30.8335	-2.47693	11.4775	-47.2699	21.52733	-23.156
sC	22.61175	-26.2499	20.1545	-36.2535	20.3485	-6.51456	21.03825	-24.9019
sT	35.179	14.73926	30.26825	-4.26475	26.614	22.27052	30.68708	9.540587
sP	35.16775	14.70257	25.8	-18.3973	22.42925	3.044864	27.799	-0.76871
rD	37.11025	21.03819	45.18925	42.92878	23.05775	5.93233	35.11908	25.36105
rA	31.396	2.400689	38.88075	22.97567	24.422	12.19999	31.56625	12.67886
rO	38.10275	24.27532	37.4565	18.47092	22.8415	4.93883	32.80025	17.08374
rP	34.99625	14.14321	26.8165	-15.1823	24.50075	12.56179	28.77117	2.701532
rV	32.54475	6.147433	33.87125	7.131154	21.9775	0.969426	29.4645	5.176454
rF	37.38825	21.94492	35.64125	12.72948	30.0565	38.08611	34.362	22.65857
Average	**30.6**		**31.6**		**21.8**		**28.1**	

Calculation 2. Example of how the percentage deviation of the water potential values was calculated

$$\textbf{Percentage deviation} = \frac{\text{Value x} - \text{Average value of all the trees or study sites}}{\text{Average value of all the trees or study sites}} \times 100\%$$

Example: Value x = Value of Tree 1 at study site uC

= **-0.75**

Average value of all the trees = **-0.59**

$$\textbf{Percentage deviation} = \frac{17.524 - 30.6}{30.6} \times 100\%$$

= 27.8%

Table 9. Water potential values of all the Acacia karroo trees at each study site in the Potchefstroom Municipal Area.

Water potential values per tree								
Individual trees	**February value**	**Percentage deviation**	**March value**	**Percentage deviation**	**April value**	**Percentage deviation**	**Average value**	**Percentage Deviation**
uC 1	-0.75	27.83147	-0.8	7.665805	-0.9	-9.13772	-0.81667	5.591615
2	-0.9	53.39776	-0.8	7.665805	-1	0.958092	-0.9	16.36627
3	-0.65	10.78727	-0.9	21.12403	-1	0.958092	-0.85	9.901477
4	-0.75	27.83147	-1.2	61.49871	-0.9	-9.13772	-0.95	22.83106
uO 5	-0.4	-31.8232	-0.7	-5.79242	-0.5	-49.521	-0.53333	-31.0422
6	-0.55	-6.25692	-0.4	-46.1671	-0.8	-19.2335	-0.58333	-24.5774
7	-0.7	19.30937	-0.4	-46.1671	-0.7	-29.3293	-0.6	-22.4225
uG 8	-0.6	2.265174	-0.85	14.39492	-1.3	31.24552	-0.91667	18.5212
9	-0.3	-48.8674	-0.7	-5.79242	-1.5	51.43714	-0.83333	7.746546
10	-0.35	-40.3453	-0.45	-39.438	-2	101.9162	-0.93333	20.67613
11	-0.5	-14.779	-0.7	-5.79242	-1.5	51.43714	-0.9	16.36627
uH 12	-0.45	-23.3011	-0.7	-5.79242	-0.6	-39.4251	-0.58333	-24.5774
13	-0.2	-65.9116	-0.5	-32.7089	-0.5	-49.521	-0.4	-48.2817
14	-0.55	-6.25692	-0.5	-32.7089	-0.6	-39.4251	-0.55	-28.8873
15	-0.65	10.78727	-0.5	-32.7089	-0.9	-9.13772	-0.68333	-11.6478
uW 16	-0.45	-23.3011	-0.6	-19.2506	-1.4	41.34133	-0.81667	5.591615
17	-0.55	-6.25692	-0.45	-39.438	-1.2	21.14971	-0.73333	-5.18304
18	-0.5	-14.779	-0.5	-32.7089	-1.4	41.34133	-0.8	3.436684
19	-0.45	-23.3011	-1.15	54.7696	-1.5	51.43714	-1.03333	33.60572
uV 20	-0.55	-6.25692	-0.7	-5.79242	-1.3	31.24552	-0.85	9.901477
21	-0.4	-31.8232	-0.9	21.12403	-0.7	-29.3293	-0.66667	-13.8028
22	-0.7	19.30937	-0.4	-46.1671	-1.6	61.53295	-0.9	16.36627
23	-0.5	-14.779	-0.9	21.12403	-1.2	21.14971	-0.86667	12.05641
uS 24	-0.8	36.35356	-0.7	-5.79242	-0.7	-29.3293	-0.73333	-5.18304
25	-0.7	19.30937	-0.85	14.39492	-1	0.958092	-0.85	9.901477
26	-0.7	19.30937	-0.7	-5.79242	-1.2	21.14971	-0.86667	12.05641
27	-0.7	19.30937	-0.65	-12.5215	-1	0.958092	-0.78333	1.281753
sM 28	-0.5	-14.779	-0.5	-32.7089	-1	0.958092	-0.66667	-13.8028
29	-0.5	-14.779	-0.8	7.665805	-0.6	-39.4251	-0.63333	-18.1126
30	-0.3	-48.8674	-0.8	7.665805	-0.8	-19.2335	-0.63333	-18.1126
31	-0.5	-14.779	-0.8	7.665805	-1.4	41.34133	-0.9	16.36627

Water potential values per tree								
Individual trees	**February value**	**Percentage deviation**	**March value**	**Percentage deviation**	**April value**	**Percentage deviation**	**Average value**	**Percentage Deviation**
sG 32	-0.6	2.265174	-0.55	-25.9798	-1	0.958092	-0.71667	-7.33797
33	-0.6	2.265174	-0.8	7.665805	-0.2	-79.8084	-0.53333	-31.0422
34	-0.55	-6.25692	-0.8	7.665805	-1.2	21.14971	-0.85	9.901477
35	-0.6	2.265174	-0.6	-19.2506	-0.7	-29.3293	-0.63333	-18.1126
sK 36	-0.5	-14.779	-1	34.58226	-0.6	-39.4251	-0.7	-9.4929
37	-1	70.44196	-1.1	48.04048	-1.1	11.0539	-1.06667	37.91558
38	-0.5	-14.779	-0.5	-32.7089	-1.6	61.53295	-0.86667	12.05641
39	-0.7	19.30937	-1	34.58226	-1.2	21.14971	-0.96667	24.98599
sV 40	-0.7	19.30937	-1.1	48.04048	-0.7	-29.3293	-0.83333	7.746546
41	-0.5	-14.779	-0.7	-5.79242	-1.6	61.53295	-0.93333	20.67613
42	-0.9	53.39776	-1	34.58226	-1.3	31.24552	-1.06667	37.91558
43	-0.65	10.78727	-0.5	-32.7089	-0.4	-59.6168	-0.51667	-33.1971
sC 44	-0.4	-31.8232	-0.7	-5.79242	-0.5	-49.521	-0.53333	-31.0422
45	-0.8	36.35356	-0.45	-39.438	-0.6	-39.4251	-0.61667	-20.2676
46	-0.45	-23.3011	-0.5	-32.7089	-0.4	-59.6168	-0.45	-41.8169
47	-0.55	-6.25692	-0.95	27.85314	-0.8	-19.2335	-0.76667	-0.87318
sT 48	-0.6	2.265174	-0.6	-19.2506	-1	0.958092	-0.73333	-5.18304
49	-0.5	-14.779	-0.5	-32.7089	-0.9	-9.13772	-0.63333	-18.1126
50	-0.5	-14.779	-0.9	21.12403	-0.8	-19.2335	-0.73333	-5.18304
51	-0.5	-14.779	-0.6	-19.2506	-0.6	-39.4251	-0.56667	-26.7323
sP 52	-0.45	-23.3011	-0.7	-5.79242	-1	0.958092	-0.71667	-7.33797
53	-0.45	-23.3011	-0.95	27.85314	-1	0.958092	-0.8	3.436684
54	-0.35	-40.3453	-0.65	-12.5215	-0.9	-9.13772	-0.63333	-18.1126
55	-0.4	-31.8232	-0.75	0.936693	-0.9	-9.13772	-0.68333	-11.6478
rD 56	-1	70.44196	-0.8	7.665805	-1.1	11.0539	-0.96667	24.98599
57	-0.9	53.39776	-1	34.58226	-1.6	61.53295	-1.16667	50.84516
58	-0.8	36.35356	-0.8	7.665805	-0.8	-19.2335	-0.8	3.436684
59	-0.8	36.35356	-0.6	-19.2506	-0.85	-14.1856	-0.75	-3.02811
rA 60	-0.9	53.39776	-0.7	-5.79242	-1	0.958092	-0.86667	12.05641
61	-1	70.44196	-0.8	7.665805	-1.2	21.14971	-1	29.29585
62	-0.95	61.91986	-0.8	7.665805	-1.6	61.53295	-1.11667	44.38037
63	-0.45	-23.3011	-0.75	0.936693	-1.1	11.0539	-0.76667	-0.87318
rO 64	-0.35	-40.3453	-0.85	14.39492	-0.8	-19.2335	-0.66667	-13.8028
65	-0.5	-14.779	-0.6	-19.2506	-1.4	41.34133	-0.83333	7.746546

Water potential values per tree								
Individual trees	**February value**	**Percentage deviation**	**March value**	**Percentage deviation**	**April value**	**Percentage deviation**	**Average value**	**Percentage Deviation**
66	-0.55	-6.25692	-0.45	-39.438	-0.5	-49.521	-0.5	-35.3521
67	-0.5	-14.779	-1.1	48.04048	-1	0.958092	-0.86667	12.05641
rP 68	-0.2	-65.9116	-0.8	7.665805	-1	0.958092	-0.66667	-13.8028
69	-0.2	-65.9116	-0.8	7.665805	-0.9	-9.13772	-0.63333	-18.1126
70	-0.4	-31.8232	-1	34.58226	-1.1	11.0539	-0.83333	7.746546
71	-0.45	-23.3011	-0.75	0.936693	-0.6	-39.4251	-0.6	-22.4225
rV 72	-0.7	19.30937	-0.4	-46.1671	-1	0.958092	-0.7	-9.4929
73	-0.7	19.30937	-0.7	-5.79242	-1.2	21.14971	-0.86667	12.05641
74	-0.55	-6.25692	-0.8	7.665805	-1.2	21.14971	-0.85	9.901477
75	-1	70.44196	-0.8	7.665805	-0.9	-9.13772	-0.9	16.36627
rF 76	-0.45	-23.3011	-0.9	21.12403	-0.6	-39.4251	-0.65	-15.9577
77	-0.6	2.265174	-0.9	21.12403	-1.3	31.24552	-0.93333	20.67613
78	-0.7	19.30937	-1	34.58226	-0.9	-9.13772	-0.86667	12.05641
79	-0.85	44.87566	-1.2	61.49871	-0.9	-9.13772	-0.98333	27.14092
Average	**-0.59**		**-0.74**		**-0.99**		**-0.77**	

Table 10. Average Water potential values of the Acacia karroo trees at each study site in the Potchefstroom Municipal Area.

Average water potential values of the study sites								
Study Sites	**February value**	**Percentage deviation**	**March value**	**Percentage deviation**	**April value**	**Percentage deviation**	**Average value**	**Percentage Deviation**
uC	-0.7625	29.96199	-0.925	24.48859	-0.95	-4.08981	-0.87917	13.67261
uO	-0.55	-6.25692	-0.5	-32.7089	-0.66667	-32.6946	-0.57222	-26.014
uG	-0.4375	-25.4316	-0.675	-9.15698	-1.575	59.009	-0.89583	15.82754
uH	-0.4625	-21.1706	-0.55	-25.9798	-0.65	-34.3772	-0.55417	-28.3485
uW	-0.4875	-16.9095	-0.675	-9.15698	-1.375	38.81738	-0.84583	9.362744
uV	-0.5375	-8.38745	-0.725	-2.42786	-1.2	21.14971	-0.82083	6.130347
uS	-0.725	23.57042	-0.725	-2.42786	-0.975	-1.56586	-0.80833	4.514149
sM	-0.45	-23.3011	-0.725	-2.42786	-0.95	-4.08981	-0.70833	-8.41544
sG	-0.5875	0.134649	-0.6875	-7.4747	-0.775	-21.7575	-0.68333	-11.6478
sK	-0.675	15.04832	-0.9	21.12403	-1.125	13.57785	-0.9	16.36627
sV	-0.6875	17.17884	-0.825	11.03036	-1	0.958092	-0.8375	8.285278
sC	-0.55	-6.25692	-0.65	-12.5215	-0.575	-41.9491	-0.59167	-23.5
sT	-0.525	-10.518	-0.65	-12.5215	-0.825	-16.7096	-0.66667	-13.8028
sP	-0.4125	-29.6927	-0.7625	2.618971	-0.95	-4.08981	-0.70833	-8.41544
rD	-0.875	49.13671	-0.8	7.665805	-1.0875	9.791925	-0.92083	19.05993
rA	-0.825	40.61461	-0.7625	2.618971	-1.225	23.67366	-0.9375	21.21486
rO	-0.475	-19.0401	-0.75	0.936693	-0.925	-6.61376	-0.71667	-7.33797
rP	-0.3125	-46.7369	-0.8375	12.71264	-0.9	-9.13772	-0.68333	-11.6478
rV	-0.7375	25.70094	-0.675	-9.15698	-1.075	8.529949	-0.82917	7.207813
rF	-0.65	10.78727	-1	34.58226	-0.925	-6.61376	-0.85833	10.97894
Average	**-0.59**		**-0.74**		**-0.99**		**-0.77**	