# chapter 14

# LONG-TERM ECOLOGICAL SUSTAINABILITY OF WATTLE PLANTATIONS

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## 14.1 INTRODUCTION

Nambiar (1996), in discussing sustained productivity of forests, proposed the following goals for plantation management:

- ensure that productivity is non-declining while maintaining the quality of the soil resource base;
- ensure that plantation management practices do not adversely affect the environment;
- ensure that plantation forestry is economically viable and contributes to the economic prosperity of local people.

This chapter deals only with aspects of ecological/biological sustainability (social and economic factors are not discussed). The factors placing sustainable production at risk are explored and highlighted with results from studies that have been conducted in wattle plantations.

Major threats to ecological sustainability include:

- Loss of soil;
- Soil physical degradation (e.g. organic matter loss, compaction);
- Soil chemical degradation (e.g. nutrient depletion, acidification, salinization);
- Degradation in environmental water quality or quantity;
- Loss of genetic diversity of planting material (with associated increase in risk of large-scale losses due to attack by pests or pathogens);
- Loss of biodiversity in the system, with long-term impacts on the eco-physiological processes in the system as a whole;
- Climate change.

Discussion in this chapter will focus mainly on the first four threats listed above. Most of the listed issues fall under the direct control of the forest estate manager and strategic planners and careful management will ensure that sustainability is not compromised. Loss of biodiversity cannot be controlled directly, but some steps (such as the introduction of inter-cropping, cover cropping or crop rotations) could go a long way towards increasing the biodiversity of the system. Threat of climate change falls outside the direct control of the forester, yet some steps can be taken to manage the forest estate under such circumstances. In the sections that follow, published studies on factors affecting the sustainability of wattle plantations are discussed. Management strategies aimed at minimising negative impacts, or at rehabilitating degraded sites are evaluated. In addition, integrated cropping systems that have the potential to improve soil conditions for plant growth are explored.

## 14.2 LOSS OF SOIL

Nambiar (1996) stated that it is the soil that underpins sustainable productivity in forestry. Soil loss arguably constitutes the most devastating threat to the ecological sustainability of plantation forestry: large volumes of soil can be lost in an extremely short period compared to the extremely long periods of time required for substantial quantities of soil to be produced by rock weathering. The bulk of soil losses in most systems are through water and wind erosion following disturbance of the vegetative cover and/or forest floor. Such disturbances can be caused by fire, soil cultivation, harvesting operations, vegetation management, road construction or over-utilization of land. Severe degradation of the soil resource has proven too costly or impractical to rehabilitate, in many instances, worldwide.

Sherry (1953, 1954, 1961, 1964 and 1971) documented the effects of slope gradient and slash management regime on surface run-off, litter and soil loss from wattle stands under conditions of varying rainfall intensity and crop age spanning two crop cycles. Sites with slopes of between 5 and 15 degrees were used in the study. Slash was stacked in brushwood rows on the contour at 25 m intervals and either left to rot, subjected to burning of alternative rows, or subjected to burning of all the rows. In the second crop cycle the treatment with alternate brush-row burning was changed to a brushwood removal treatment without burning. It is also important to note that weed control was done by hoeing in the first cycle and by slashing in the second cycle. The main conclusions drawn from the results are presented below, with added contributions from the author of this paper:

All figures for soil loss referred to in the study should be viewed with caution since the methodology only refers to soil collected from so-called silt traps (with a mesh size of 0.2 mm), despite the fact that most of the soil particles have smaller dimensions than that. There is no reference to any methodology estimating loss of clay and silt-sized particles from the system. All soil classification systems classify clay as particles < 0.002 mm in size whereas silt sized particles are usually classed as being larger than 0.002 mm but smaller than either 0.05 or 0.02 mm depending on the system used (Russell, 1961). Similarly, fine sand is that portion of the sand fraction smaller than either 0.2 or 0.25 mm. A sieve with a mesh size of 0.2 mm will thus let through all clay, all silt, and either all or most of the fine sand, depending on the classification system used. The textural analysis given in Sherry (1953) shows that the clay + silt + fine sand fractions make up > 95% of the soil, on a mass basis. It thus seems possible that the values reported as "soil loss" actually refer to the coarser sand fractions only, and thus make up a very small fraction of the total soil lost. The author of this paper scrutinized the original experimental files (ICFR Archives) but could not find any evidence of measurement of soil particles in the clay- and silt-sized fractions. Despite this potential error in the total quantity of soil eroded, some data are presented below as this data set displays important principles with regard to the *relative magnitude* of soil loss caused by specific environmental and site management conditions. All values for "soil loss" have been converted to metric units.

**The effect of precipitation and soil-water content on soil erosion**: The volume of run-off is affected mainly by the intensity of precipitation, and to a lesser extent by rainfall volume, the infiltration capacity of the soil, and soil-water content at the onset of the time period in question (the latter reflecting the capacity of the soil to hold additional water). Data are presented to show the quantity of soil lost in three rainstorms of varying intensity, namely 37, 44 and 63 mm $h^{-1}$ during the first cycle. On moderate slopes (5 degrees), soil erosion was negligible in all slash treatments at the lower intensities of rainfall, but increased at the highest intensity rainfall event, amounting to approximately 2.5 t $ha^{-1}$ where alternate brushwood (slash) rows were burnt, and 17.5 t $ha^{-1}$ where all brushpiles were burnt. The soil loss at the highest intensity event on moderate slopes was similar in magnitude to the soil erosion on steep (15 degree) slopes at the medium intensity rainfall event, but thereafter increased exponentially with increase in rainstorm intensity. Soil erosion was estimated to total 20 t $ha^{-1}$ where alternate brushpiles were burnt and 85 t $ha^{-1}$ on treatments where all brushpiles were burnt. One has to keep in mind that weeds were controlled by hoeing which would have caused considerable disturbance of the topsoil. It is interesting to note that the total soil loss in the treatment with all brushwood rows burnt on the steep slope amounted to 113.7 t $ha^{-1}$, which means that 74% of the total soil loss during the first growing season took place in one rainfall event lasting 75 minutes. This finding shows that measures implemented to limit erosion should take cognisance of extreme rainfall events that could potentially occur on a given site.

**The effect of slash management**: There is relatively little run-off, soil erosion and litter loss when brushwood is stacked in rows on the contour. These variables are increased when brushwood is removed from the site or when alternate brushwood rows are burnt. All three variables are greatly and significantly increased when all brushwood rows are burnt. It appears that the fine material in the forest floor offers considerable protection against erosion (probably through protection of the mineral soil from raindrop impact) and that the stacking of brushwood on the contour (at approximately 25 m intervals) further decreases the risk of erosion. Sherry (1964) suggests that the destruction of the bulk of the forest floor layer by burning, rather than the actual burning of the brushpile holds the key to the large increases in soil erosion under burning conditions.

**The effect of the slope of the terrain:** Run-off, soil erosion and litter loss generally increase in magnitude and frequency with increase in slope steepness. However, there is a strong interactive effect with the slash management regime. The soil erosion on either slope type was small when brushwood rows were left intact, but soil and litter loss increased significantly when the rows were burnt with the most marked increases on steep slopes.

**Effect of ground cover and soil disturbance**: A decrease in the density of vegetative ground cover (the tree crop and the understorey or weeds present on the site) will increase the run-off with subsequent effects on soil and litter loss. Vegetation management employed in the first crop cycle (hoeing) resulted in greatly increased levels of run-off and soil erosion when compared to weed control by slashing the above-ground parts which was employed in the second cycle. In the treatment most susceptible to erosion, the plot with all brushwood rows burnt on the steep slope, cumulative erosion totalled 113.7 t $ha^{-1}$ in the first two years of the first cycle (hoeing employed) and only 11.4 t $ha^{-1}$ in the first two years of the second cycle (slashing employed as weed control). The corresponding figures for the treatment without burning on steep slopes amounted to 4.6 t $ha^{-1}$ (first cycle, hoed) and nil t $ha^{-1}$ (second cycle, weeds slashed). Although the experimental design did not allow a direct comparison of these treatments, the rainfall pattern and water run-off over both periods were similar, suggesting that the method of weed control was the main contributor to the variance observed regarding soil loss. This important conclusion cannot be emphasized enough - soil disturbance on steep slopes (as a result of either tillage or mechanical weed control) is probably one of the biggest single threats to sustainable forestry.

It appears that three factors play major roles in determining the relative magnitude of soil erosion during the re-establishment period when vegetation cover is sparse:

- soil disturbance (through hoeing in this case),
- destruction of the bulk of the forest floor layer (through burning of all brushpiles),
- steep slopes in the terrain (approximately 15 degrees in these trials).

There is a very good probability that the site will receive (at least) a couple of rainfall events of fairly high intensity during the first year after establishment when vegetative cover on the land is low. Assuming that probability as a given, it is interesting to compare combinations of the three main factors driving soil loss. Combinations of one, two or three of these factors were compared using the total soil loss data generated over two crop cycles (***Table 14.1***). Although the data are not strictly comparable (since soil disturbance through hoeing was confined to one crop cycle), it is still very informative to look at the trend that emerges:

- Where any single one of these three factors was present, soil erosion was small in each and every case (< 1 t $ha^{-1}$).
- Where any two factors were combined, soil loss rose to values between 4 and 18 t $ha^{-1}$.
- Where all three factors were combined, a total of 114 t $ha^{-1}$ were lost.

**TABLE 14.1**: Data comparing soil loss with increase in the number of major factors governing the magnitude of soil erosion.

| Number of factors | Description | Soil loss (t $ha^{-1}$) Ranges are given where 2 values exist. |
|---|---|---|
| One | Steep slopes only (i.e. no burning or hoeing)<br>Burning only (i.e. No hoeing and moderate slopes)<br>Hoeing only (i.e. no burning and moderate slopes) | nil<br>0 - 0.81<br>0 - 0.37 |
| Two | Burning on steep slopes (without hoeing)<br>Burning and hoeing (on moderate slopes)<br>Hoeing on steep slopes (without burning) | 11.40<br>10.15 - 17.56<br>4.61 |
| Three | Burning and hoeing on steep slopes | 113.7 |

A study into the use of vetiver grass as vegetative cover on firebreaks was initiated by Nicholson (1991d). This is a perennial rhizomatous grass which tillers strongly, and when planted in rows it grows to form a very densely tufted hedge with stems up to 2 m tall. It does not produce viable seed and is therefore not likely to become an invasive weed. Vetiver grass showed great potential as a tool for consideration in erosion management control, and has become widely used in commercial forestry.

## 14.3 SOIL PHYSICAL DEGRADATION

The potential impacts of vehicular traffic and harvesting operations on the compaction and erosion hazard for southern African soils have been documented by Smith (1999). He identified the major site and management factors which would affect erosion and compaction damage. The site factors are soil properties, slope, rainfall distribution and intensity, and the management factors include vehicle type, season of felling/extraction, mode of operation and slash distribution. A risk assessment system based on soil types and sensitivity indices based on soil physical properties has been developed to assist with operations scheduling and strategic planning. Appropriate planning will minimize the risk of erosion or compaction by using harvesting and extraction systems appropriate to the site conditions. Optimal scheduling will ensure that the impacts on sensitive sites are confined to the seasons during which damage is least likely.

## 14.4 SOIL CHEMICAL DEGRADATION

Several processes (many of which fall under the direct control of the forest manager) can result in soil chemical changes. Each of these processes are discussed in turn.

### 14.4.1 Nutrient depletion through removal of crops or crop residues

The quantity of nutrients in the biomass of wattle stands across the range of commonly recorded productivity has received little attention from researchers to date. One publication listing nutrient contents in the biomass of an eight year-old wattle stand could be found in the published literature (Williams 1928). The fact that both wood and bark is harvested from wattle stands, coupled to the relatively short rotation length, result in the removal of large quantities of nutrients within a relatively short period of time. The partial removal of the forest floor has been one of the major factors responsible for forest decline in Europe, and has been the major trigger to launch investigations into nutrient cycling processes during the 1900's (Johnson, 1994). A related but similar phenomenon is common in Southern Africa: the collection of branches in the harvesting residue for firewood. If bark, timber and large branches are removed from a site at the end of each rotation, only a very small fraction of nutrients (that contained in the leaves and twigs) are returned to the soil.

The quantities of P, K and Ca removed in harvests of conventional intensity (calculated from the data of Williams, 1928) are listed in ***Table 14.2***, alongside values that are inclusive of branch removal for firewood. The standing crop upon which the nutrient removals are based had a stocking of 1500 stems $ha^{-1}$ and produced a theoretical timber volume of 200 $m^3$ $ha^{-1}$ and a bark yield of 19.8 t $ha^{-1}$. All the macronutrients listed are exported from the site in large quantities. More than 80 % of the P, Ca and Mg in the aboveground biomass are removed when harvesting is followed by branch-wood collection.

**TABLE 14.2:** Comparison of nutrient removal in stands of *Eucalyptus* and *A. mearnsii* crops using conventional harvesting regimes.

| | Standing crop (kg $ha^{-1}$) | | | | | Removal in wood and bark harvesting | | Removal in wood and bark harvesting plus large branches (firewood) | |
|---|---|---|---|---|---|---|---|---|---|
| | Large branches | Twigs and leaves | Bark | Wood | Total above-ground biomass | kg/ha | % of above-ground biomass | kg/ha | % of above-ground biomass |
| Ash | 289 | 438 | 509 | 1092 | 2328 | 1601 | 69 | 1890 | 81 |
| Ca | 53 | 60 | 135 | 208 | 456 | 343 | 75 | 396 | 87 |
| K | 47 | 97 | 56 | 154 | 354 | 210 | 59 | 257 | 73 |
| P | 4 | 9 | 9 | 9 | 27 | 19 | 70 | 23 | 85 |
| Mg | 16 | 21 | 14 | 69 | 120 | 83 | 69 | 99 | 82 |

### 14.4.2 Nutrient depletion through burning of harvesting residue (slash)

Slash burning has the potential to reduce the potential of the soil to sustain productivity since nutrients are lost through oxidation, volatilization or export of particle matter in smoke. Furthermore, nutrients in the ash can be lost through wind or water erosion. Beard (1951, 1961b) compared the effects of burning on plantation yield. Three pairs of trials that had been subjected to either slash burning or slash conservation practices for two crop cycles did not show any detrimental effects on tree growth, bark yield, disease rate, or soil properties (pH, humus content, water holding capacity). The experiments were repeated for a third cycle and extended to four additional sites. At the same time, additional treatments were introduced: Ash was added (to one member of a pair on a split plot basis) to compensate for nutrients removed during harvesting. The second member of the split plot was swept clean of all ash after burning or left untreated (unburnt sites). In the burnt treatments, the sub-plots where ash was added were significantly superior in bark yield to those where ash was removed. The same trend could not be observed for tree diameter and stocking was not affected. It is highly likely that the burning combined with ash application created a situation where nutrient availability was greatly increased (at least in the short term) and that the trees responded in much the same way as they would do to fertilizer. Beard (1961b) concluded that burning per se is unlikely to affect tree growth unless the ash is lost from the site through wind or water. Analysis of the soil pH and carbon content between treatments in this study revealed no significant differences.

Nitrogen is most often the nutrient that is lost in the greatest quantities when slash burning is practised (Fölster and Khanna, 1997). The fact that wattle can fix atmospheric nitrogen through symbiotic bacterial associations makes it less susceptible to the threat of N depletion in the system (this threat is very real when slash burning is practised in non N-fixing crops). It has to be stressed that substantial losses of nutrients other than N could occur as a result of slash burning. There is a need to quantify potential nutrient losses from slash burning in wattle plantations more accurately.

### 14.4.3 Evidence of soil acidification

Williams (1932), Musto (1992, cited in ICFR 1992) and Du Toit (1993) compared the properties of virgin grassland soils with that of adjacent land that had been under continuous wattle cultivation for varying periods (between one and five rotations). Such studies, although retrospective in nature, can be completed in a short time and can yield important information regarding changes that took place in the soil as a result of afforestation. Williams compared three paired sites of grassland and plantation, where the plantation had existed for approximately 45 years and concluded that:

- The quantity of exchangeable Ca in the wattle subsoil is consistently lower than that of the grassland soil. The same trend was not apparent for the surface soil layers. This finding is congruent with the fact that wattle harvesting will result in large Ca exports from the site.
- The acidity of wattle topsoils and subsoils were consistently greater than that of the grassland soil horizons.

The studies of Musto (1992) and Du Toit (1993) concentrated on changes in topsoils after afforestation with pine, eucalypts or wattle. In particular, each of these studies included comparisons of seven paired samples of wattle and adjacent grassland, with the following results:

- Soil pH was consistently and significantly lower under wattle stands in both studies, the average difference (measured in 1M KCl) being 0.22 and 0.35 units, respectively. The drop in pH is most marked in soil with the highest initial values for base saturation and pH.
- Significant decreases in exchangeable Ca and Mg were observed. This decrease in base cations was met with a significant increase in extractable acidity. Base cation stripping is more pronounced in soils with higher initial base saturation, illustrating that the process of base cation stripping becomes progressively self-limiting as acid saturation increases.
- Effective cation exchange capacity of soils (i.e. the sum of the exchangeable cations and extractable acidity) did not change significantly following afforestation.
- Organic carbon contents of forested and grassland members were similar (i.e. not significantly different) although wattle soils did seem to increase the C status of soils on average[1].

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[1] Research on N-fixing trees in temperate and tropical forests has shown a tendency to increase the soil nitrogen and carbon pools (Binkley and Giardina, 1997)

- The mean change in acid neutralising capacity of the topsoils (expressed as an equivalent quantity of agricultural lime per hectare to reverse the effects of acidification) amounted to 1.7 t $ha^{-1}$ of $CaCO_3$ (range = 0.7 to 5.0).
- Comparison of the changes that took place in base cation stripping and acid neutralising capacity as a result of afforestation with three different genera in the study of Du Toit (1993) revealed that wattle had a slightly larger impact than the other two genera. However, the result was only very weakly significant[2] (p  0.1).

It can be concluded that afforestation of grasslands will increase the demand on the base cation reserves of the soil. This finding agrees with experimental evidence of base cation losses in wattle and other short-rotation hardwood systems through the processes of wood and bark harvesting, firewood collection and burning of harvesting residue.

## 14.5 DEGRADATION IN ENVIRONMENTAL WATER QUALITY OR QUANTITY

One of the first recommendations on afforestation and water use that could be traced was published by Wicht (1949). Wicht drew tentative conclusions about the potential impacts of exotic plantations on water supplies and proceeded to make the following recommendations:

- Forestry should only be attempted where good profits are likely.
- Extensive afforestation should be restricted to areas of high rainfall.
- Long rotation crops should be preferred to short rotation crops.
- Where streams are used for agricultural, industrial or municipal purposes, moist areas around streams should not be planted up.

In the early 1950's, soil moisture monitoring equipment was installed in grasslands and adjacent areas that had been, or were going to be, afforested. Beard (1963) made the following conclusions from the soil moisture studies:

- Plantations dry out soils much more rapidly during dry spells than grassveld. In the KwaZulu-Natal Midlands, forest soils would approach wilting point within one or two months of the cessation of summer rains while grassland soils would only approach this point towards the end of winter (a period of approximately four or five months).
- Plantations probably use similar amounts of water to indigenous forests.

A modelling approach to assist in assessing the potential impacts of afforestation on stream-flow in a given location has been put forward by Scott *et al.* (1998). Estimates of reductions in both dry season-flow and total stream-flow can be made as a function of site and plantation characteristics. Unfortunately appropriate calibration studies to construct stream-flow reduction curves have not yet been conducted. Surrogates currently used for this information could lead to potential over- or under-estimations. A comprehensive study has recently been started to monitor stream-flow in (a) wattle plantations with riparian areas afforested (b) after clearing of the riparian trees and (c) stream-flow after clearfelling the entire stand (Everson, 2001, pers. comm.).

The impact of tree stands in general (and invasive pockets of wattles in particular) on water quality or quantity has received much publicity during the last decade. The focus of stream-flow and water quality research has recently been broadened to include thickets of invasive acacia

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2 Some studies with N-fixing species in other countries have also shown elevated levels of soil acidification (e.g. Van Miegroet and Cole, 1985; Binkley and Sollins, 1990), presumably due to: (a) the presence of larger quantities of nitrate that would act as a mobile accompanying anion, thus facilitating base cation leaching from the solum, (b) accumulation base cations in the vegetation and their subsequent export during harvesting.

species in riparian areas (e.g. Prinsloo and Scott, 1999; Dye and Poulter, 1995), i.e. it is not confined strictly to wattle trees in plantations.

## 14.6 LOSS OF GENETIC DIVERSITY

The history of plant-based cropping systems has shown that the loss of resistance to pests or diseases is probably the most rapid mechanism whereby sustainability can be threatened. One of the most powerful safeguards against such a catastrophe is the maintenance of genetic diversity. Due to a wide range of environmental conditions, the genetic diversity in the Southern African forestry industry is relatively large, thereby diminishing the chances of an extremely large-scale catastrophe. However, the diversity within South African wattle is probably fairly small in comparison.

It is theoretically possible to replace one genotype with another (resistant) genotype within a relatively short period of time (a matter of several years), which means that potential damage from pests or diseases is arguably less "terminal/final" than soil loss or soil degradation. However, the practicalities of changing an existing tree crop to another genus are daunting and very costly in practice.

## 14.7 LOSS OF BIODIVERSITY IN THE SYSTEM (EFFECTS ON SOIL BIOLOGY)

Changes in the soil biology of the system may have long-term impacts on the eco-physiological processes in the system as a whole if biodiversity is compromised. Studies on the effects of wattle trees on the soil biology are not numerous, but the following information could be sourced:

Binkley and Giardina (1997) reviewed the effects of N-fixing trees. One of their conclusions was that the rate of mineralisation of nutrients appears to be greater in N-fixing stands in general than in non-N-fixing stands, apparently due to increases in microbial and soil faunal activity. However, it appears that nitrification may be slightly inhibited (or retarded for short periods) by the presence of tannins in the soil (Hesse, 1957) but the effect appears to be limited at low concentrations (Basaraba, 1964). *Acacia mearnsii* has particularly high levels of tannin in its tissues. The author would like to speculate that the temporary inhibition/retardation of nitrification could potentially have more positive than negative consequences:

- The growth rate of vegetation that require large quantities of N in the form of nitrate may be temporarily checked. However, forest crops are not dependent on nitrate as a source of N since it can satisfy its demand for N from ammonium. It is thus possible that inhibition of nitrification may create a competitive advantage for plants adapted to nitrate poor (generally equated to acidic) soil environments.
- When tree crops are clearfelled for harvesting, both soil temperature and the quantity of water percolating through the soil profile will increase. This situation will create more favourable conditions for nitrification by soil bacteria and consequent leaching of base cations since nitrate is a mobile anion and there is no tree crop to take up excess N. It follows that substances constraining nitrification may effectively limit the amount of base cations that can be lost through this pathway.
- Schumann *et al.* (1995) have shown that forest plantation residues may inhibit the germination of weed seeds. Pine, eucalypt and wattle residues were tested and wattle was found to have the smallest effect.
- Samways *et al.* (1996) found that populations of invertebrate soil fauna are affected by afforestation with exotic tree species, apparently through a complex interaction of factors. Species richness and diversity was generally lower under exotic than under indigenous vegetation. Exotic tree crops caused a change in the assemblage of invertebrate species.

- Otha (1990, cited in Binkley and Giardina, 1997) compared grasslands with stands of *Pinus keysia* and *Acacia auriculiformis* in the Phillipines. It was found that the biomass and abundance of soil animals, particularly earthworms, had increased under the *Acacia* stand.

## 14.8 CLIMATE CHANGE

Indications are that climate change is not just a remote possibility any more, but that it is a reality. It appears that fires on the savanna and grasslands of the southern African sub-continent may contribute to increases in greenhouse gas concentrations, although quantification of the problem is difficult (Scholes, 1995). Foresters may be able to counter possible effects of climate change by changing to types of planting material that are better suited to the changed conditions. However, there is little that forest managers can do pro-actively to stop climate change. The potential effects of climatic changes on vegetation types are discussed by Scholes and West (1996). Possible scenarios of the effect of climate change on the areas where the major commercial timber species can be grown have been explored by Schulze and Kunz (1995).

## 14.9 THE ROLE OF WATTLE IN ENSURING SUSTAINABILITY OF INTEGRATED CROPPING SYSTEMS

Nitrogen-fixing species have the ability to greatly improve the soil conditions for tree growth. Darby (1954, cited in Sherry, 1971) estimated that wattle stands can fix approximately 200 kg N $ha^{-1}$ $a^{-1}$, which is a substantial quantity when compared to a range of between 50 and 150 kg N $ha^{-1}$ $a^{-1}$ fixed by a range of associations with Casuarina and other tree legumes, cited in Binkley and Giardina (1997). In addition to the obvious effect of nitrogen enrichment of the soil, it appears that many N-fixing species may accelerate the rate of litter decomposition. N-fixing trees have been shown to increase soil pools of N and C across a variety of ecosystems (Binkley and Giardina, 1997). Sherry (1971) concludes from various sources that organic matter deposition during a ten-year rotation (litterfall and harvesting residue) could amount to between 75 and 125 t $ha^{-1}$ in wattle stands of the eastern seaboard of South Africa.

Several integrated cropping systems are used in forestry and agroforestry:

- Cover cropping is essentially an attempt to cover the site with a desirable vegetation type (such as a legume) that will minimise the germination and growth of unwanted species.
- Inter-cropping is the term used when annual crops are planted between the lines of perennial crops such as trees.
- Crop rotation refers to a situation where one crop is cultivated at a time but rotated with a different, complementary crop when appropriate.

## 14.10 RESULTS FROM INTEGRATED CROPPING SYSTEMS WITH WATTLE IN SOUTH AFRICA

The Wattle Research Institute experimented with the rotation of wattle and maize crops (essentially, land degraded by agriculture was used to grow one rotation of wattle and was subsequently planted to successive crops of maize). Sherry (1971) drew the following general conclusions from the results: Maize crops planted in old wattle lands appear to have adequate N and K nutrition in the first year and adequate N nutrition until the second year. Thereafter, additional fertilizer applications are necessary to maintain productivity. One has to recognise the fact that most maize producers today use some form of liming when cultivating maize on acid soil. The choice of maize as a cropping partner with wattle has to be questioned since maize does not tolerate acidic conditions while wattle thrives under those conditions. It has also been shown that liming of wattle stands would cause a significant depression in growth (see chapter 6 for further information). Crop rotation or inter-cropping with other tree species shows much more promise since site requirements can be more closely matched and many growers have experience with working with more than one tree crop.

Empirical fertilizer trials with eucalypts on land that was previously under wattle showed much improved growth rates and responses to P fertilization compared to land that was simply replanted to eucalypts (Herbert, in ICFR, 1988). This system holds great promise since each tree crop is planted in turn, thus not competing for resources at the same time.

Inter-cropping systems may enrich the site and enhance productivity, but the simultaneous cultivation of two crops on the same tract of land implies that the two crops will compete for growth resources. Despite this fact, De Bell *et al.* (1997) have shown that the total yield from such a system can be greater than that of a monoculture. The primary crop in this study (eucalypts) had a greater productivity than eucalypts in monoculture, and, in addition, the *Albizia* trees (secondary crop) produced a small amount of biomass. Similar systems could be used in South Africa where *Acacias* (secondary crop) could be harvested and used for firewood.

Management systems based on principles of crop rotation or inter-cropping (with one crop being a nitrogen fixer) shows great promise to improve site quality while enhancing productivity. Research into these systems should be initiated.

## 14.11 FUTURE RESEARCH

The major threats to sustained productivity in wattle forestry, from an ecological perspective, appear to revolve around erosion control and the maintenance of soil fertility.

The processes which increase the risk of erosion are relatively well understood but good management is required if they are to be implemented. It is essential that appropriate management of fire, plantation residue and soil disturbance activities, especially on sloping land, are implemented so that erosion is minimised. Pro-active management plans for the prevention and control of wildfires also need to be in place.

There are, however, gaps in our scientific understanding of the maintenance of soil fertility (nutritional sustainability), and the associated practical implementation issues. The rate at which nutrient removal takes place from pure wattle stands, mixed stands or crop rotation systems, needs to be studied further, especially where additional products such as firewood are removed. The process whereby the soil is enriched with both N and soil carbon also deserves more attention as it creates opportunities for soil improvement or soil rehabilitation, and at the same time increases the risk of soil acidification. There are numerous sites in South Africa that have been afforested with wattle for between five and ten rotations (i.e. 50 to 100 years). These sites afford an excellent opportunity to study the impacts of plantations in the long-term (e.g. Bloemendal experiment station).