ENVIRONMENTAL, MANPOWER AND FINANCIAL ANALYSIS OF LOCUST CONTROL IN SOUTH AFRICA

by

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Abstract

The brown locust, *Locustana pardalina* (Walker), has regularly recurring outbreaks in the region Karoo region of South Africa. The endemic region comprises an area of approximately 40 million hectares. The locusts in the *gregaria* phase cause considerable damage to natural pastures and is in direct competition with stock farming.

The National Department of Agriculture administers locust control campaigns. Trained volunteers (supervisors and assistants) in the locust districts conduct locust control campaigns and are remunerate for their efforts.

Any sustainable agricultural setup and pest control should adhere to the following three criteria: environment, manpower and financial resources. This study was aimed at analyzing the 1996/97 locust control campaign, with the emphasis on the De Aar, Hanover, Hay and Postmasburg locust districts, based on these three criteria. The project was divided into two main parts: a component analysis for managerial purposes and a spatial analysis (in ArcView-GIS) for operational purposes. The component analysis was done on supervisor level within the districts and the spatial analysis was done on both farm and district levels.

Great variation existed between the supervisors and districts analysed in all three criteria. The highest number of bands and swarms was controlled in the Hanover district (5 392), followed by Hay (1 961) De Aar (1 519) and Postmasburg (859).

The supervisors in the De Aar district controlled a higher percentage of hopper versus adult locusts (87 vs. 13 %). The opposite was encountered in Hanover (28 vs. 72 %), Hay (32 vs. 68 %) and Postmasburg (45 vs. 55 %). The highest total area (Ha) bands and swarms was sprayed in the De Aar district (11 410), followed by Hanover (9 493), Hay (5 054) and Postmasburg (2 816). Locusts had the highest impact on grazing in the Hanover district.

Effective control operations resulted in small areas of each district being sprayed: De Aar (2,13 %), Hanover (2,63 %), Hay (0,40 %) and Postmasburg (0,16 %). An early warning system to facilitate locust control is possible with the incorporation of reliable biotic and abiotic data.

Dissimilarities in manpower utilisation were evident through the area (Ha) and amount of pesticide sprayed per assistant per day in the various districts.

The highest numbers of supervisor (800) and assistant (2 039) days were recorded in the Hanover district and the lowest numbers (172 vs. 129) were recorded in the Postmasburg district. A geographic information system enables visual monitoring of job creation and socio-economic implications of locust control.

The pesticide and travelling expenditure accounted for most of the expenses. The expenses per hectare (R/Ha) were the highest in the Hay district (70,07) and the lowest in Postmasburg (23,17). The actual financial damage caused by the locusts was much lower than the potential financial loss. Investment return factors (IRF's) of more than one hundred were achieved in all the districts.

The integrated operational and management information system enables visual access to extensive locust control data. This information system eases management by facilitating proper planning within and among campaigns.

Key words: *Locustana pardalina*, locust control, operational and management information system, geographic information system, cost benefit analysis.

Samevatting

Die bruinsprinkaan (*Locustana pardalina*, Walker) het gereelde uitbrake in die Karoostreek van Suid-Afrika. Die endemiese gebied beslaan 'n area van ongeveer 40 miljoen hektaar. Die sprinkaan in die *gregaria* fase veroorsaak ernstige skade aan natuurlike wieding en is in direkte kompetisie met veeboerdery.

Die Nasionale Departement van Landbou behartig die sprinkaanbeheerveldtogte. Opgeleide vrywilligers (opsigters en arbeiders) in die sprinkaandistrikte voer die veldtogte uit en word daarvoor betaal.

Enige volhoubare landboustelsel en plaagbeheer moet aan die volgende kriteria voldoen: omgewing, mannekrag en finansies. Hierdie studie het die 1996/97 sprinkaanveldtog geanaliseer met die fokus op die De Aar, Hanover, Hay en Postmasburg sprinkaandistrikte en gebaseer op die drie kriteria van volhoubaarheid. Die projek was in twee hoof dele verdeel: 'n komponentanalise vir bestuursdoeleindes en 'n ruimtelike analise (in ArcView-GIS) vir operasionele doeleindes. Die komponentanalise was op opsigtervlak in distrikte en die ruimtelike analise was op beide plaas- en distriksvlak gebaseer.

Daar was groot variasie tussen die opsigters en die distrikte geanaliseer ten opsigte van al drie kriterië. Die grootste aantal voetganger- en vlieërswerms is in die Hanover distrik (5 392) beheer, gevolg deur Hay (1 961), De Aar (1 519) en Postmasburg (859).

Die opsigters het in De Aar die hoogste persentasie voetgangers versus volwasse sprinkane beheer (87 vs. 16 %). Die teenoorgestelde is in Hanover (28 vs. 72 %), Hay (32 vs. 68 %) en Postmasburg (45 vs. 55 %) aangetref. Die grootste totale area (ha) waarop voetgangers en volwasse sprinkane beheer is, was in De Aar (11 410), gevolg deur Hanover (9 493), Hay (5 054) en Postmasburg (2 816). Sprinkane het die grootste impak op weiding in die Hanover distrik gehad.

Klein areas in elke distrik is bespuit as gevolg van die effektiewe beheermaatreëls: De Aar (2,13 %), Hanover (2,63 %), Hay (0,40 %) en Postmasburg (0,16 %). As betroubare biotiese en abiotiese data geinkorporeer word, kan 'n vroeëwaarskuwingstelsel saamgestel word wat behulpsaam is met sprinkaanbeheer.

Verskille in die gebruik van mannekrag in die distrikte was duidelik deur die area (Ha) en hoeveelheid plaagbeheermiddels wat deur die assistente per dag bespuit is.

Die hoogste aantal opsigter- (800) en assistentdae (2 039) was opgeteken in Hanover en die laagste (172 vs. 129) was in die Postmasburg distrik. 'n Geografiese inligtingstelsel maak die visuele monitering van werkskepping en die sosio-ekonomiese implikasies van sprinkaanbeheer moontlik.

Die koste van plaagbeheermiddels en vervoerkoste het die grootste komponente van die uitgawes uitgemaak. Die uitgawes per hektaar (R/Ha) was die hoogste in die Hay distrik (70,07) en die laagste in Postmasburg (23,17). Die werklike skade wat deur die sprinkane aangerig is, was baie laer as die potensiële finansiële skade. Teenprestasiefaktore van meer as een honderd is in al die distrikte bereik.

Die geïntegreerde operasionele en bestuursinligtingstelsel verskaf visuele toegang tot uitgebreide sprinkaanbeheerdata. Hierdie inligtingstelsel vergemaklik bestuur deurdat dit behoorlike beplanning in en tussen veldtoë meebring.

Chapter 1

General introduction

1.1 History.

The problems posed by locusts are not new, in fact they are about as old as mankind itself. The Desert locust, *Schistocerca gregaria* (Forsk.), is the species that was mentioned in the Bible as the eighth plague in Egypt (Smith, 1964; May, 1972). Chiselled out representations of locusts have also been found at Saqqara in the United Arab Republic where they have been part of ornamentation of grave stones dating back to the Sixth Dynasty between 2420 and 2270 BC. Present plaque outbreaks of the desert locust involve some 11 000 000 square miles at one time or another, which represents 20 percent of the area of the world and is occupied by 10 percent of the world's population. It extents from the North West Coast of Africa to India and from Southern Russia to Tanzania in the south. It is therefore not surprising that this locust left such an incredible mark on the old civilisations (Botha, 1969b).

In South Africa, sailors recorded locusts in Table Bay long before Europeans settlement. Van Riebeeck and his people suffered great losses to crops and pasture one-year after arriving in the Cape (1653) by locusts. In 1746 locusts caused dramatic damage to the pastures in the Cape and surrounding districts, resulting in starvation and mortalities of cattle and sheep. The meat prices doubled and sales of food to visiting ships' companies were stopped. According to the current knowledge, these locusts originated further inland and probably within the Karoo (Botha, 1969b).

Four locust species, namely the brown locust, *Locustana pardalina* (Walker, 1870), African migratory locust, *Locusta migratoria migratorioides* (Reiche & Fairmaire), red locust, *Nomadacris septemfasciata* (Serville) and the southern African desert locust, *Schistocerca gregaria flaviventris* (Burmeister), are periodically recorded in outbreaks in South Africa (Anon, 1998d). Of these four species mentioned, the brown locust has the most significant impact on agriculture and is of greater economic importance than any one of the other three species (Uvarov, 1928; Potgieter, 1929; Botha, 1969b; Lea, 1973; Ryke, 1982; Johnsen, 1985; Muzuna, 1988; Anon, 1998d). According to Smith (1964) locust have played a bigger part in the history of South Africa than any other insect pest. The brown locust *L. pardalina* is classified under the order Orthoptera and in the family Acrididae (Dirsh, 1965).

The oldest record of the indigenous brown locust was in 1797, ten years after the founding of the Karoo town, Graaf-Reinet (Botha, 1969a). In present times, all continents of the world, except Antarctica, are liable to widespread and prolonged infestation by locusts (May, 1972). Devastating combinations of locust plaques and poor rainfall had nearly wiped out maize crops in southern Madagascar (Anon, 1997e; Duranton, 1997).

1.2 Grasshoppers vs. locusts.

Both grasshoppers and locusts belong to the order Orthoptera and are classified under the family Acrididae (Uvarov, 1928). Locusts are usually larger than grasshoppers, however this is not a general characteristic. Although grasshoppers can become very abundant, their aggregations are less dense than those of the swarming locusts. They also have a limited migratory ability, due to the fact that many of them have poorly developed wings. According to Matthee (1951) Andrewartha introduced a new division of the Acrididae in 1945. Instead of concentrating on the behaviour of these insects, he evaluated certain physiological and ecological characteristics and concluded that all species of grasshoppers produce diapause eggs, while eggs of the true locusts develop without a diapause. According to Andrewartha's classification the South African brown locust, *L. pardalina,* intermediates the true grasshoppers and true locusts. The brown locust produces both diapause and non-diapause eggs (Matthee, 1951; Matthee, 1953; Price & Brown, 1992; Price, 1988). The fundamental difference between locusts and grasshoppers is that only locusts can change their behaviour and appearance according to density. This phenomenal discovery gave rise to the phase transformation theory of locusts (Botha, 1969a).

1.3 Phase polymorphism and the life-history of the brown locust.

In the early nineteen twenties a Russian scientist, Dr. B.P. Uvarov and a South African, Prof. J.C. Faure, almost simultaneously came to the conclusion about two different locust species they studied (Anon, 1957). They found that locusts do not permanently live in swarm or gregarious form, but can also life in a solitary state, like an ordinary grasshopper. The swarm or gregarious phase locusts actually cause detrimental damage to pastures and crops (Lea, 1969a).

The difference in behaviour is combined with differences in appearance. Locusts in the solitary form or phase behave and look much like grasshoppers. Locusts are normally in the solitary phase during periods of no swarming activity. Swarms develop afterwards from these solitaries in response to successful breeding and a resulting increase in population density. Under favourable conditions the solitary-living individuals multiply rapidly, resulting in loose aggregations. Additional multiplication and denser aggregations result eventually in dense swarms over extended areas (Potgieter, 1929; Faure, 1923; Kennedy, 1956; Lea, 1964, 1969a, 1969b; Uvarov, 1966; Botha, 1969a, 1969b; May, 1972; Johnsen, 1985; Davies, 1988; Anon, 1966, 1997d; Müller & Price, 1997b).

A gregarious *L. pardalina* female can deposit six to 10 egg-pods with each having an average of 48 eggs, thus totalling more than 380 eggs per female. The material of the egg-pods plays an important role in retarding the rate of desiccation of the eggs by reducing the rate of water loss (Petty, 1973a). The heavier, more viable and earlier hatching eggs in the upper layer of the egg-pod, produce larger hoppers and are more sensitive to population density. These qualitative differences between eggs within individual egg-pods and hatching hoppers may be the beginning of phase transformation (Venter & Potgieter, 1967). A single egg-bed may cover anything from about one to 100 morgen (± 0,857 to 85.7 ha) with dozens of egg-pods per square metre. The viability of eggs is best sustained when laid in sand composed of particles with diameters between 0,3 and 1,5 millimetres (Petty, 1973b). Brown locusts lay their eggs in wet or dry soil. Eggs laid in dry soil will not hatch until sufficiently moistened after rain (Lea, 1969b). A relative humidity of more than 30% is desirable for laboratory rearing of brown locust eggs (Petty, 1974). The eggs can survive for more than three years without any rainfall (Lounsbury, 1910; Faure, 1932; Matthee, 1951). Steenkamp[1] (pers. comm.) stated that brown locust eggs survived on the farm Elandvlei, Calvinia district, for a period of 20 years (1976 till 1995). Brown locust eggs compensate for water loss during drought conditions by absorbing moisture from light rains, insufficient to cause hatching. Eggs normally hatch ten days after summer rain, with an incubation period of seven days in warm weather. Lea (1953) found that 16 to 20 days were required for females to mature another egg package in winter conditions. Faure (1923) recorded a period of seven days, probably in the warmer summer months. The five immature stages lasts 56 days and the adult lives an average of 78 days. From hatching to natural death a brown locust can live an average of 134 days (Potgieter, 1929; Botha, 1969b; Nailand & Hanrahan, 1993; Heyns, Greyvenstein & Van der Westhuizen, 1995).

After hatching of the egg, the brown locust develops through five hopper stages of approximately 10 days and reach maturity as an alate. The name "rooibaadjies" (deriving from the reddish colour) refers to the fourth and fifth instar brown locusts. The brown locust is multivoltine with two to four generations occurring annually, depending upon environmental conditions of temperature, rainfall and food quality (Price, 1988). The hoppers can migrate a distance of 25 miles (± 40 km) in their entire lifespan and adults can migrate up to 100 miles (± 160 km) per day (Botha, 1969b).

The eggs of the solitary phase locusts are smaller than those of gregaria phase locusts. After exposure to moisture and warm weather, the eggs deposited in the second half of the summer can develop to a certain stage and then go into a true resting or quiescence phase. They remain in quiescence for varying periods. Under favourable conditions in the laboratory, they can take anything from 20 to 95 days, or even twice as long to hatch. Quiescence terminates after overwintering of the eggs. Under favourable conditions, eggs of solitary and gregaria locusts hatch approximately 10

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[1] Mnr. D. Steenkamp, Agricultural Land and Resource Management, Upington

days after sufficient rain (Botha, 1969b, 1970a). Solitary locusts lay more diapause eggs than gregarious locusts (Smith, 1964; Botha, 1969a, 1970a).

Hoppers that hatch from solitary phase egg-pods do not remain together, but immediately scatter and retain this anti-social behaviour throughout the hopper life. Many were spotted with no fixed colour pattern and develop green or grey colours to match the background. This is in strict contrast to the uniform colour pattern (reddish) of the gregarian hoppers. Solitary hoppers complete their development in 21 to 38 days in contrast to the 42 days of gregarian hoppers (Lea, 1959; Botha, 1969a, 1970a).

There is also sexual dimorphism between the two phases. In the solitary phase, the adult male is much smaller than the female, while in the gregarious phase the two sexes are almost the same size. Solitary hoppers remain near to where they hatched and are rather inactive and sedentary. In contrast, the hoppers of the gregarious phase are extremely active.

The adults or alates of the two phases do not necessarily differ much in appearance, but in their behaviour they do. Solitary adults scarcely fly during the day and when they do, it is only for a few meters at a time. Solitary adults do fly considerable distances on warm nights (Botha & Jansen, 1969; Petty & Jansen, 1970). In contrast the gregarious phase adults migrate actively during the day and roost densely together on vegetation at night. Using these extreme differences in behaviour and appearance, individuals of the brown locust belong either to the *solitaria* (solitary form) or *gregaria* (swarming form). In nature, an intermediate phase exists between the *gregaria* and *solitaria* phases, known as the *transiens* phase. The transient phase locusts are found during incipient swarm outbreaks. Eggs produced by females in incipient swarms may enter diapause to the same degree as those of *solitaria* and *transiens* individuals (Matthee, 1953)

Locust outbreaks are preceded by an increase in the numbers of the solitary phase locusts. The outbreaks are succeeded a generation later by the true swarm or gregaria phase locusts. Solitary-living locusts tend to avoid each other, but with favourable weather conditions more eggs are laid and more hoppers survive. Successive unavoidable contacts have an effect on certain brain cells of all true locusts. Stimuli in the brain lead to changes in behaviour and growth processes, so that the whole nature and appearance of the locusts change during the hopper stages in the direction of the gregaria phase (Botha, 1970a).

Certain activities of hoppers developing gregarian characteristics, increase (Pick & Lea, 1970). These hoppers develop slower, resulting in larger individuals than the solitary hoppers and an obvious change to the typical gregarian colouration. An incipient band may have hoppers of five instars of many different colours. After egg deposition the next first instar hoppers are of mixed appearance, but as they grow older, they become more like real gregarian locusts in density, behaviour and appearance (Botha, 1970a).

This phase phenomenon is only observed in true locusts. Grasshoppers simply do not have the capacity for changing their behaviour and appearance according to their abundance (Botha, 1969a). In spite of the apparently great survival value of the phase mechanism and behaviour, there are only a few species of locusts in the world (Lea, 1959).

Brown locusts tend to migrate in a downwind direction, but there are seasonal differences to be seen between the locusts. Hoppers of all ages tend to march eastwards. Locusts that start to fly in the early summer in the Karoo tend to fly north, north west or north east (Bax, 1991), while those that begin to fly in the late summer mostly migrate towards the east, north east or south east (Du Plessis, 1939; Smith, 1964; Botha 1969b).

1.4 Outbreak and invasion areas.

Solitary locusts can be found over a very large area of a country or even several neighbouring countries, but this does not mean that the whole natural distribution area is suitable for the transformation from the solitary to the gregarious phase. The brown locust is a grass feeder. In African savannas, grasshoppers are the predominant insect herbivores (Gandar, 1979 as quoted by Prendini, Theron, Van der Merwe & Owen-Smith, 1996). Crops of the grass family such as maize, wheat and oats are vulnerable to locust attacks (Botha 1969b) while crops and pastures like lucerne (alfalfa), potatoes, vegetables, weeds and Karoo bushes are not preferred (Faure, 1923; Musuna, 1988).

The endemic area and outbreak region of the brown locust is in the Karoo and Northern Cape Province of South Africa. Solitary locusts periodically increase in numbers and enhance the swarming habit and incipient outbreaks of the *transient* locusts. Normally these outbreaks are followed by true swarm outbreaks of the phase *gregaria*. An outbreak is defined as a marked increase in the number of locusts as a result of concentration, multiplication and gregarisation leading, unless checked, to the formation of hopper bands and adult swarms (Anon, 1998c). If the locusts are not controlled within the outbreak region, the locusts emigrate and cause great damage in the invasion area (Botha, 1969a; Johnsen, 1985; Musuna, 1988; Bateman, Neetling & Oosthuizen, 1998).

The outbreak region of the brown locust comprises an area of roughly 40 million hectares (Botha, 1970c; Van der Westhuizen & Botha, 1997) in the semi-arid Karoo regions of South Africa and southern Namibia (Botha, 1969b; Du Plessis, 1939). The solitary phase locusts inhabit an area of about 25 million hectares (Smith, 1964; Lea, 1969a; Lea, 1973). The Karoo is an arid country suitable for sheep or goat farming (Compton, 1929). The vegetation of the Karoo is divided into various Karoo and Karroid types (Acocks, 1998). The brown locusts are actually in competition with the stock farmer within the outbreak area.

Many parts of the country are subject to invasion once swarming has occurred. At the end of 1950 swarms originating in the outbreak region invaded 31 magisterial districts. Some swarms even got well into the former Transvaal Province and the northern Orange Free State, but were controlled before serious damage was done to crops. The neighbouring territories of Mozambique, Zimbabwe (Pedgley, 1987), Botswana (Anon, 1986) and Lesotho were also invaded. In the past the Kalahari was regularly invaded by escaping swarms. These locusts or those from new generations, re-invade the original outbreak area. The Kalahari was by mistake designated as the true home of the brown locust for a long time (Botha, 1969b). The control and outbreak region of the 1996/97 campaign is shown in appendix 6. Appendix 6 illustrates the magisterial districts affected by the locusts. Only four locust districts (De Aar, Hanover, Hay and Postmasburg) were analysed in this project and are indicated in appendix 5.

1.5 Periodicity of brown locust plagues.

The first intensive attempt of chemical control of brown locusts in South Africa was in 1906 by Mr C.P. Lounsbury and government officials. The locusts were suppressed those years with sodium arsenite pesticides (Anon, 1907) and through natural events (Botha & Lea, 1970b).

In the early 1950s organochlorine insecticides, BHC isomers, were used in locust control (Anon, 1950, 1951, 1952, 1993, 1998d; Lea, 1964, 1969a; Smith, 1964; Botha, 1970c; Hanrahan, 1988). In the 1970s BHC was replaced with organophosphate insecticides (diazinon, dichlorvos and fenitrothion). Due to their extremely high toxicity and effect on birds and humans, these products were replaced with synthetic pyrethroids. Deltamethrin and esfenvalerate are currently used in ultra-low volume (ULV) spray and dusting formulations (Heyns *et al.*, 1995; Anon, 1998d).

A biopesticide, Green Muscle®, developed by an international research project called LUBILOSA, is currently undergoing field trials for locust control (Anon, 1997a; Anon, 1997b; Anon, 1997c; Anon, 1998a; Douro-Kpindou, Langewald, Lomer, Van der Paau, Shah & Sidibé, 1997; Kooyman & Godonou, 1997; Lomer, 1997; Meinzinger, 1997; Müller, 1997; Müller & Price, 1997a; Paraïso, Beye, Djiba, Check, Abdoulaye, Diop, Gan Bobo, Otoïdo, Nadié, Kooyman Lomer Douro-Kpindou, 1997; Prior, 1997; Stephan, Welling & Zimmerman, 1997). The biopesticide is based on a naturally occurring fungal disease, *Metarhiziumm anisopliae* var. *acridum* (previously known as *M. flavoviridae*), which is deadly to locusts and grasshoppers, but harmless to most other organisms. It has a drawback in the fact that it is slower acting than most chemical pesticides (>90% kill in 7 – 21 days) (Bateman, Neethling &

Oosthuizen, 1998). Insecticide research is now in a renaissance of integrating chemicals and biologicals for sustainable pest control with human safety (Casida & Quistad, 1998).

Lounsbury – the first trained Entomologist to be appointed in South Africa (Lea, 1973) - studied historical records and concluded that locust plague outbreaks follows a cyclic nature: plague periods of approximately 13 years are intermediate by quiet or non-plague periods of approximately 11 years. Locust abundance is measured in two manners, firstly by the amount of money spend each year on control measures and secondly by the number of areas outside the outbreak region which have been infested each year by escaping swarms and their progeny. The duration of plague periods and quiet periods with man's intervention now seems to have shortened to about six of seven year cycles (Lea, 1964). The pattern now appears to be two-year cycles alternating between outbreaks and quiet years. The progressively shorter intervals may be due to the reduction of the numbers of natural enemies resulting in the critical level for swarming being reached sooner. By implication natural predators could reduce the frequency and intensity of outbreaks through their effects on solitary phase locusts during inter-plaque periods (Hockey, 1988).

Hockey (1998) stated that the link between life-history characteristics and population (outbreak) dynamics needs to be carefully defined before the mechanism of irruption and subsidence can be fully understood. The question is not why swarming continues year after year, once it has begun, but rather why solitary locusts occur in relatively small numbers year after year preliminary of the following outbreak. Three factors causing periodicity, namely weather conditions, enemies and diseases and the locusts' own behaviour will be discussed (Botha & Lea, 1970b).

Weather conditions

Locusts are well adapted to cold, heat and wind. The most likely influencing component is rainfall. Summer rain initiates the hatching of locust eggs and encourages the growth of grass on which the hoppers and adults feed. Opinions differ with respect to the precise role of vegetation as an environmental factor affecting the distribution and abundance of grasshoppers (Anderson, 1964). Most plague periods have begun with seasons of good and widespread rains and have ended with a drought, especially a relative failure of rain in the early summer. There is evidence that locust numbers do not necessarily increase during wet seasons nor necessarily decrease during seasons that begin with a severe drought. No simple relationship between swarming of locusts and rainfall exists. A study showed that plaque years are not wetter and drier either in the early summers or in the whole seasonal rainfall period than the quiet years. The ups and downs in locust abundance can be broadly related to the ups and downs in the amounts of rain during plaque or quiet years. Rainfall is unlikely to be responsible for the rather regular periodicity of plaques (Botha & Lea, 1970b).

Enemies and diseases

Brown locusts have many natural enemies, especially in their swarming phase. The most conspicuous are birds, in particularly the White Stork, *Ciconia ciconia,* and the White-bellied stork, *Sphenorhynchus abdimii*. There were between 60 000 and 100 000 White Storks alone in the Karoo in 1953 and since each bird can eat at least 1000 locusts per day, they can have a significant effect on locust numbers. Bat-eared jackals and meerkats prey on locusts too. Meerkats destroy large numbers of egg pots (Potgieter, 1929; Lea, 1969a; Botha & Lea, 1970b).

Maggots of the locust egg fly (*Stomorhina lunata*, F.), the locust blow fly (*Wohlfahrtia euvittatta*, Villn.), the locust fly (*Wohlfahrtia pachytyli*, Townsend) and the woolly bee fly (*Systoechus* sp.) feed on the eggs and hoppers and are quite abundant in egg nests (Potgieter, 1929; Dirkse-van Schalkwyk, 1937; Smith, 1964; Amstrong, 1993; Anon, 1993; Saffer, Hanrahan & Brown, 1997).

Heavy infestations of protozoa like *Malameba locustae* (Taylor & King,) do not necessarily kill the locust, but prevents the females from laying viable eggs (Prinsloo, 1961; Venter, 1966). Pathogens that can kill locusts within a few days of infection are the bacteria *Serratia marcescens* (Bizio) and the fungi *Aspergillus parasiticus* (Speare) (Prinsloo, 1960). Nematodes of the family Mermithidae were recorded to attack grasshoppers in the United States (Weiser, Bucher & Poinor, 1976). In the United States poor results were obtained to control Acridoidea with the use of biological control methods on grasslands. Hagen, Viktotov, Yasumatsu & Schuster (1976) further stated that grasslands provide a relatively stable environment, which should be conductive to biological control. Biological control is a strategy that involves the attempt to control a native pest species with an exotic biological control agent. Evidence suggests that the cost of such a strategy greatly exceed the benefits (Lockwood, 1993). Parasites and predators may play an important part in bringing a series of plaque years to an end (Smith, 1964; Botha & Lea, 1970b). White (1976) contributed the locusts' success to the survival rate of the hoppers as the major influencing factor in abundance and not the role of predators and parasites. The massive synchronous hatching of locusts immediately preceding outbreaks clearly is beyond the ability of natural predators to control (Hockey, 1998).

Locusts' own behaviour

Locusts are concentrated in nature by decreasing feeding areas or aggregated on areas suitable for egg laying (Annecke & Moran, 1982). Solitary phase locusts avoid each other and swarming locusts are determined not to lose contact with each other. Solitary locusts do not have the same potential for phase transformation and some may need more stimulation from their neighbours to swarm than others (Nel, 1968; Botha & Lea, 1970b). This offers a long-term survival value to the locusts (Nel, 1967). Venter and Mansfield (1966) found that high population densities both retarded and synchronised sexual maturation of the locusts. These characteristics for quick or slow response to a moderate degree of crowding (the stimulus for swarming) are inherited. It seems that the locusts killed during plaque years are mostly those that require little stimulation for swarming and can be referred to as the "quick swarmers". The solitary phase locusts, which occur at the end of a plaque period, are the progeny of those locusts that require more stimulation for swarming and are referred to as the "slow swarmers" (Botha & Lea, 1970b). They are of a poor quality with regards to viability and swarming potential and die more easily. Thereafter numbers of higher quality begin to increase until a new widespread plague develops (Lea, 1973). This could explain why swarming is sporadic and at a small scale during inter-plaque periods, even though solitary phase locusts may be abundant and often at very high densities. The quick swarmers tend to avoid each other if there is still room available, while the slow swarmers tend to aggregate. This difference in behaviour gives the quick swarmers a better chance on survival since they will not fall prey to natural enemies as easily. The time taken by the natural enemies to replace the slow swarmers (sitters) by the fast swarmers (flitters) probably correspond with the quiet period preliminary to an outbreak. Until this has happened a new plaque will not begin, even under favourable rainfall conditions (Botha & Lea, 1970b).

1.6 Legislation.

An important legislation concerning locust control is the Agricultural Pests Act, 1983 (Act No. 36 of 1983). The National Department of Agriculture administers this act. The National Department of Agriculture is therefore responsible to provide the required infrastructure and expertise to efficiently manage control operations, implement monitoring systems, collect, collate and store data, facilitate and fund research (Anon, 1998d). Other legislation concerned with the management of the locust problem in South Africa includes:

The Act on Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies, 1947 (Act No. 36 of 1947)
The National Parks act, 1976 (Act No. 57 of 1976)
The Environment Conservation Act, 1989 (Act No. 73 of 1989)
The Water Act, 1956 (Act No. 54 of 1956)
The National Health Act, 1977 (Act No. 63 of 1977)
Provincial Ordinances or Acts
Conservation of Agricultural Resource Act, 1983 (Act No. 43 of 1983)

1.7 Organisational structure of the locust control campaign.

The National Department of Agriculture is responsible for the administration of the Agricultural Pests Act (Act no. 36 of 1983). The objective of this act is to prevent locusts from reaching pest status that can lead to a national disaster with regards to food security. The locust control programme is incorporated in this act.

During the 1996/97 campaign, there were three locust regions that functioned as operational units under the National Department of Agriculture.

At present the role of the organised agriculture is limited to the nomination of three individuals in a locust district from which one is appointed by the executive officer as a district locust officer (DLO) for a period of three years (figure 1.1). Although the National Department of Agriculture has a responsibility towards locust control, it still remains the responsibility of the land user to report locust concentrations and to be of assistance in the control actions. It is furthermore stipulated according to article 8 of the Agricultural Pests Act of 1983 (Act no. 36 of 1983) that the Minister of Agriculture can with funding provided by parliament, adopt certain measures to control migratory locusts, hoppers and eggs. The minister delegated these functions to officials in his department in 1985.

The endemic area of these locusts is about 40 million hectares, and due to this large area, the land users are allowed to undertake locust control operations on their own farms in collaboration with, and under the supervision of the National Department of Agriculture. A commando system was adopted from the earlier years of locust control and relates to the times when scouts were sent out ahead to search for locusts. Temporary personnel are deployed in all districts and when outbreaks are reported, control operators are activated. From the depots they are equipped with all the necessities of the spraying campaign, like pesticides, pumps, spray apparatus, protective clothing, etc.

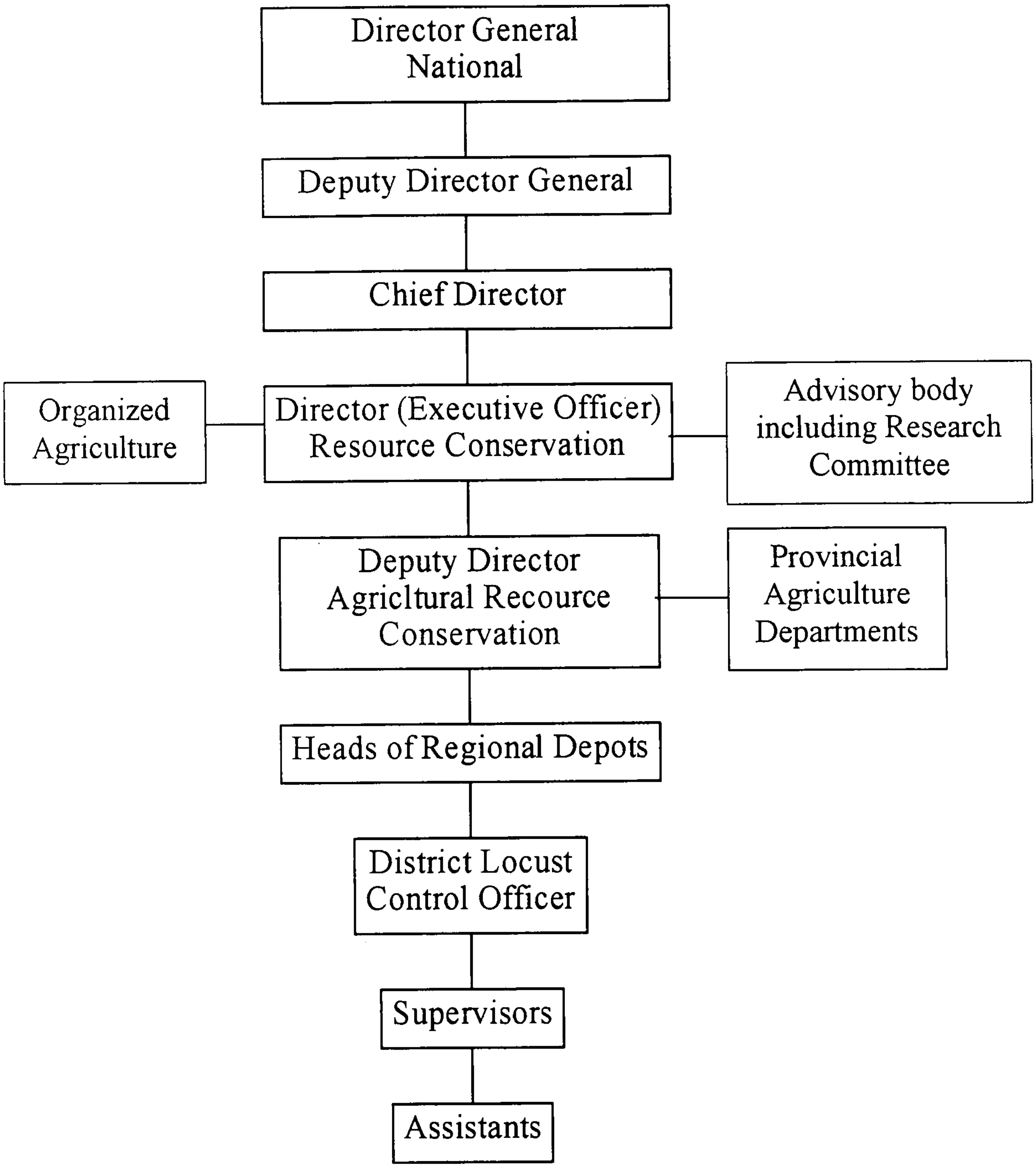


Figure 1.1 Schematic representation of the organisational structure of the South African locust control (redrawn from Anon, 1998d).

During the 1996/97 campaign, South Africa was divided into three locust regions with the centres at Kimberley, De Aar and Middelburg (Eastern Cape). From 1998 onwards the De Aar and Upington-Kimberley depots are responsible for locust control. These regions are divided into locust districts each with a district locust officer in control. Reporting to him are supervisors who administrates the control action with the help of assistants. Local labour resources are preferred for the control measures. The supervisors have to undergo an official training programme of the National Department of Agriculture before they are employed for the locust control programme. In addition to this, only pesticides registered under Act no. 36 of 1947 and approved application equipment are used for locust control operations (Anon, 1998d).

1.8 Conducting the locust control campaign.

The spraying equipment consists of a Power Solo ("bakkie" Solo) pump and a knapsack Solo pump. In South Africa, locusts are mostly controlled by means of ultra low volume (ULV) equipment. Deltamethrin (Decis ® UL 6) is the main insecticide in use and it has a withholding period of 21 days on crops as well as on pastures (Krause, Nel & Van Zyl, 1996).

Deltamethrin belongs to the pyrethroid group of insecticides. This insecticide is a nerve toxin for insects and cold-blooded organisms. Deltamethrin is not a mixture of isomers, but strictly a pure isomer – the d-cis isomer (Anon, b). It is a potent insecticide, which is effective against a wide range of pests, including Coleoptera, Hemiptera, Diptera (Killick-Hendrick, Killick-Kendrick, Focheux, Dereure, Puech & Cadiergues, 1997), Lepidoptera (Çilgi & Jepson, 1995), Thysanoptera, and Orthoptera (Worthing & Hance, 1991; Tomlin, 1997). Deltamethrin control effectively (more than 90%) nymphal and adult brown locusts within 72 hours under field conditions in South Africa (Brown & Kriel, 1994; Brown & Kieser, 1997). It is less toxic to warm-blooded animals than organophosphates. The pyrethroids have a longer residual action than the organophosphates. Deltamethrin kills locusts through contact and ingestion and it is thus important to ensure contact between insecticide and locust (Anon, b).

Deltamethrin has a high intrinsic toxicity to arthropod natural enemies (Theiling & Croft, 1989; Murphy, Jepson, Croft, 1994). It furthermore has no long-term impact on either the diversity or abundance of the fauna and is non-phytotoxic (Steward, Du Preez & Price, 1995; Roux, 1998; Anon, 1999a; Anon, a). It shows a satisfactory selectivity towards a great variety of beneficial fauna and when used on crops it is not dangerous to bees (Soubrier, 1991). Studies conducted on resistance to pyrethroids in Pakistan showed that *Helicoverpa armigera* (Lepidoptera: Noctuidae) showed a low to moderate resistance to deltamethrin (Ahmad, Arif & Attique, 1997).

The efficacy of chemical locust control depends mainly on two factors, i.e. the efficiency of the pesticide and effective pesticide contact. The size of the pesticide droplets, the droplet behaviour, the width of the lane sprayed, execution of the spraying action and climatic conditions during application determine the efficacy of pesticide application or contact. In order to achieve an even and adequate distribution of the ultra low volume insecticide, the formulated product must be broken up into many thousands of droplets by means of a rotating disk, spinning cage or the sheering action of the wind. In the "bakkie" Solo as well as the knapsack Solo pumps, the breaking up of the formulated product into these small droplets is achieved by the shearing action of the wind (Heyns *et al.*, 1995). The application equipment provides a droplet density of between 75 and 85 droplets per cm^2 at an application volume of 2,5 l/ha. Mist to fine spray droplet sizes (60 and 120 μm) is used as ultra low volume applications for locust control (Heyns *et al.*, 1995).

The registered application rate of deltamethrin (Decis ® UL 6) is 2 to 3 l/ha. Deltamethrin is registered at 15 g active ingredient per hectare, and it is formulated or manufactured at 6 g active ingredient per litre (Decis 6UL). Larger locust swarms were controlled using the Solo "bakkie" pump and the smaller swarms and hopper bands were controlled with the use of knapsack Solo pumps (Heyns *et al.*, 1995).

1.9 Procedure used to spray the locusts with the knapsack Solo pumps.

Before starting the spray pump, the locust swarm had to be clearly demarcated with the use of flags, paper, etc. During spraying, the assistants moved at right angles to the wind and progressed upwind in order to ensure minimal contact with the insecticide. The determination of the direction of the wind is very important. The spraying action is started on the down wind side and the two markers (A and B) are placed on either side of the outer boundaries of the swarm and formed a line at right angle to the direction of the wind (figure 1.2).

The hopper bands can only be sprayed in the evening when it is cooler and early in the mornings before it become too hot and the locust starts moving. The assistants are also issued with safety equipment which included respirators, dust goggles, overalls, ponchos and gloves. A control team, using knapsack Solo pumps usually consists of approximately five assistants. Two assistants act as markers and three physically sprayed the locusts. The assistants walk to the opposite marker B at a speed of ± 5 km/h or 25 m in 18 seconds, to ensure the registered pesticide deposit of 2,5 l/ha. They maintained a distance of 4 metres apart.

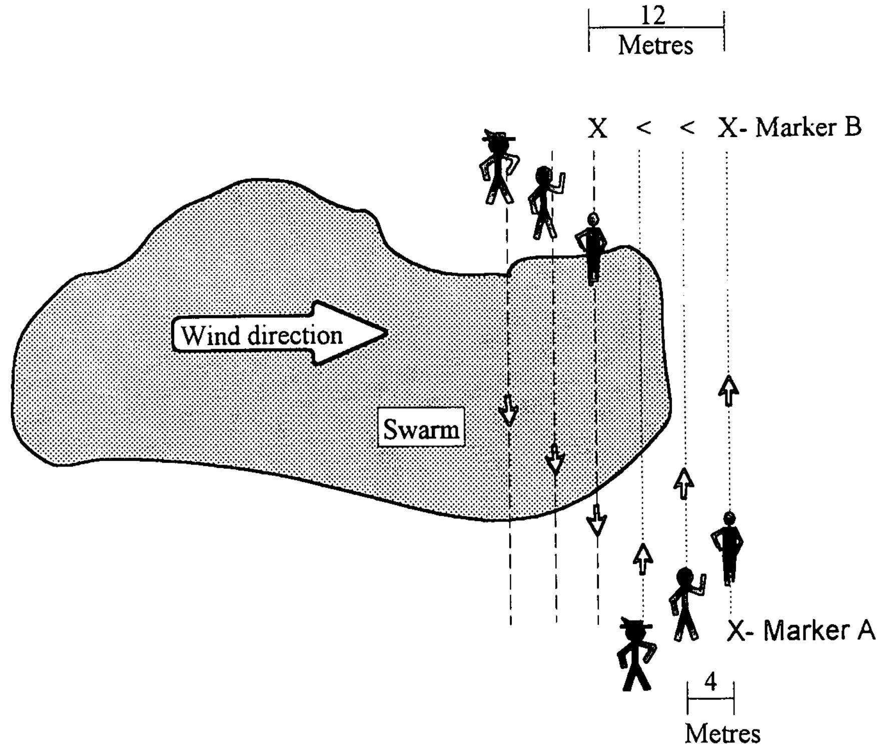


Fig. 1.2 Illustration of spraying locusts with a knapsack Solo pump (redrawn from Heyns *et al., 1995*).

At the end of the swarm at least two more strips of 4 metres apart are sprayed to ensure that the insecticide drifts onto all locusts on the up wind boundary of the swarm (Heyns *et al.*, 1995).

1.10 Procedure used to spray the locusts with the "bakkie" Solo pumps.

Adult swarms are sprayed after sundown, through the night until just after sunrise when they start to move. Locusts must only be sprayed when they are stationary. Before starting the spraying machine, the locust swarm has to be clearly demarcated and paced off in length and width. The direction of the wind also has to be established.

A marker is placed on either side of the swarm on the down wind side. The bakkie move in a straight line across the swarm at right angles to the wind (figure 1.3). The bakkie is driven at walking pace (± 8 km/h or 50 m in 23 seconds) towards the opposite marker.

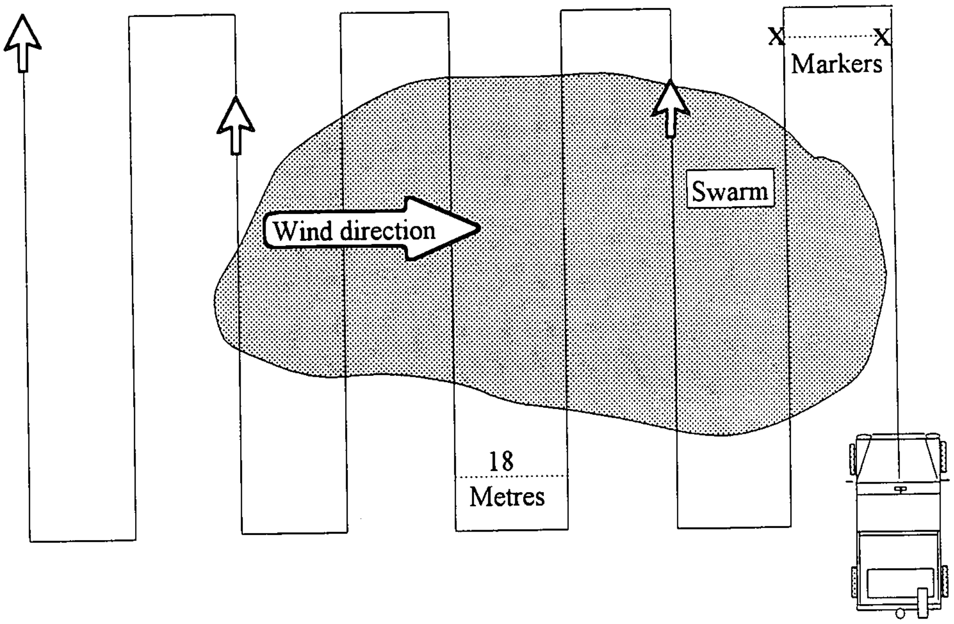


Fig. 1.3 Illustration of spraying locusts with a "Bakkie" Solo pump (redrawn from Heyns *et al., 1995*).

At the boundary of the swarm at least another two strips have to be sprayed upwind. Three assistants are used per bakkie – one at the spraying pump and two as markers.

After spraying the data sheets have to be completed. The following information is provided: the population density, length and width of the swarm, developmental stage, amount of chemicals used and other appropriate information.

1.11 Calculation of the locust densities.

During the 1996/97 campaign, counts were made to estimate the number of locusts per band or swarm. This information is essential to determine the damage and also averted damage of these locusts to especially stock farmers. The number of locusts was determined within 300 mm by 300 mm quadrants and the frequencies of the counts were dependent on the size of the swarm. Bands were classified as small, medium and large. The different sizes were: 120 square metres – small, 120 to 2500 square metres – medium and exceeding 2500 square metres – large. Three, seven and ten counts had to be made in the different size classes. In general the rectangles were position 3 metres from the corner of the swarm and the locusts were counted and recorded. Additional squares were counted at three metre intervals along the diagonal axis of the swarm. For medium swarms, seven counts were made along the diagonal axis (figure1.4).

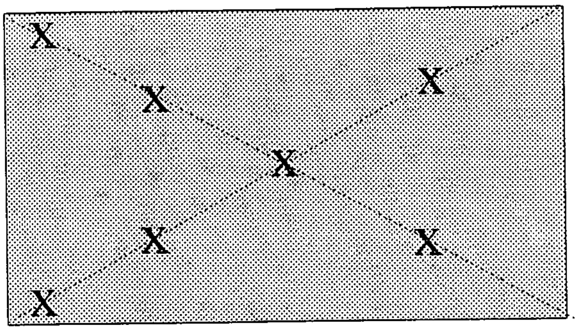


Figure. 1.4 Position of quadrants in medium sized swarms (redrawn from Heyns *et al.*, 1995).

Adult swarms were also divided into small, medium and large. Swarms that measured less than 10 000 square metres were regarded as small; medium those between 10 000 and 90 000 square metres and large swarms those that exceeding 90 000 square metres. Ten squares were counted per kilometre. The locusts were counted after spraying when they were immobilised. Squares were counted at intervals of 100 metres adjacent to the front wheal of the truck. The relevant information is provided on the yellow cards.

1.12 Geographic information systems and spatial analysis.

Pest management is a great priority for many countries today, because many pests and especially agricultural pests, like locusts, compete with humans for plant resources. There are many ways of pest management, ranging from traditional and cultural ways to chemical and highly industrialised means.

Spatial analysis and geographic information systems (GIS) provide a more modern and computerised way of pest management. It can simultaneously look at different criteria of pest management, e.g. the environment, manpower and the economy.

The analysis of maps is a traditional activity of geographers, but in recent years, statistical and mathematical procedures have been newly applied in map analysis and contemporary map analysis has been renamed "spatial analysis" (Taylor, 1977).

A spatial database may contain information about natural phenomena, man-made features, boundaries, ownership, etc. ArcView is an example of a software tool that creates an environment to display and query the contents of a spatial database (Anon, 1992).

A spatial data set consists of a collection of measurements or observations on attributes taken at specific locations. Data sites are referenced so that the relative positions of sites are recorded. The spatial organisation of the data is important whether the purpose of data analysis is to build a model for the data or to assess the relative merits of different hypotheses concerning some arrangement property of the data or some other (non spatial) characteristic of the data (Haining, 1990).

The use of Geographic Information Systems (GIS) has grown dramatically to become very common in businesses, universities and governments where they are used for many diverse applications. One definition of GIS is: "an organised collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information" (Anon, 1992). Another simpler definition may be: "A computer system capable of holding and using data describing places on the earth's surface" (Anon, 1992). In essence, GIS is a data base management system specifically designed for simultaneous processing of spatial and related attribute data (Anon, 1998b).

A GIS is not simply a computer system for making maps, although it can create maps at different scales, in different projections and with different colours. A GIS is an analysis tool. The main advantage of a GIS is that it allows you to identify the spatial relationships between map features. A system is only a GIS if it permits spatial operations on the data.

A GIS does not hold maps or pictures - it holds a database. The database concept is central to a GIS and it is the main difference between a GIS and a simple drafting or computer mapping system, which can only produce good graphic output. A GIS therefore incorporates a database management system. A GIS can link spatial data with descriptive information about a particular feature on a map. The information is stored as attributes or characteristics of the graphically represented feature. A GIS can also use the stored attributes to compute new information about certain map features, for example, to calculate the length of a particular road or the total area of a specific soil type. Essentially, a GIS gives one the ability to associate information with a feature on a map and to create new relationships that can determine the suitability of different sites for development, calculate harvest volumes, evaluate environmental impacts, identify the best location for a new facility, etc (Anon, 1992).

Because of the fact that data can be integrated with GIS, there are powerful and varied ways of looking at and analysing data. Information in a tabular database can be accessed through the map, or maps can be created based on the information in a tabular database.

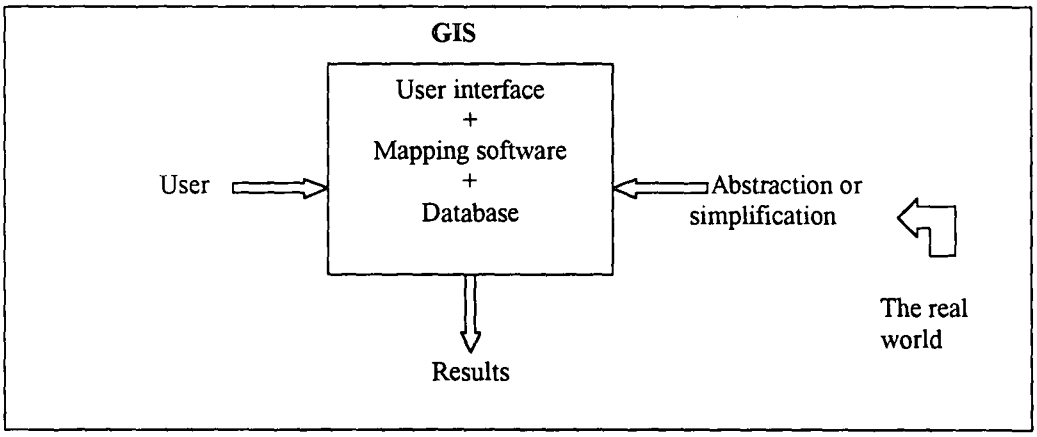


Figure 1.5 The major components that comprise a GIS (redrawn from Anon, 1992 and Cressman, 1997).

A GIS is comprised of software tools that operate on a database. The database is a simplification of the real world. The answers to some questions may require derived data resulting from a model. A model is a set of rules and procedures to derive new information that can be analysed. These models can include a combination of logical expressions, mathematical procedures and criteria for simulating a process, or predicting an outcome. A GIS can be used to create a model that performs analytical procedures to derive new information and to investigate the results of the model. This process is also called spatial analysis and is useful for suitability and capability evaluation, estimation and predictions, and interpretation and understanding. The power of a GIS can best be realised in its ability to perform the many forms of spatial analysis that is needed to solve the broad range of questions people have. The common key between the data sets is geography, or space, and that is why a GIS can do all these operations (Anon, 1992).

1.13 Applications of spatial analysis and GIS in science.

After reviewing the basic principles of Spatial Analysis and GIS, their practical applications in science are discussed. It can be used in a broad field with very diverse applications. Some of it is still in an experimental phase, but the importance of both spatial analysis and GIS in science today is evident.

The advent of new technology for geographical representation and spatial analysis of databases from different sectors offers a new approach to planning and managing the control of tropical diseases. The geographical and intersectoral aspects of the epidemiology and control of African trypanosomiases, leishmaniasis, Chagas disease, etc. are being reviewed. GIS can be used to determine the relative positions of the outbreaks and can also take the environmental factors into account. GIS open a completely new perspective for intersectoral collaboration in adapting new technology to promote control of these diseases (Mott, Nuttall, Des-jeux & Cattand, 1995).

Studies on malaria, tsetse flies, Lyme disease, LaCrosse encephalitis and equine encephalitis are examples for application of GIS, global positioning systems and remote sensing to research and disease surveillance (Kitron, 1998).

GIS-based maps were used to show where, when and how pesticide application in a mosquito control operation could be in conflict with endangered species preservation aimed at the Houston toad. The maps were used to help find optimum control alternatives where a conflict existed. A GIS therefore allows for knowledge from different types of experts, such as wildlife biologists, geographers and entomologists to be written into code and then used to highlight problems requiring judgement (Spradling, Olson, Coulson & Lovelady, 1998).

Farmer decision making and spatial variables in Northern Thailand were investigated. This research had two interrelated objectives. The first was to determine the extent to which a relationship existed between farmer characteristics and farmer practices in three villages in northern Thailand. The second was to use standard statistical incorporating spatial variables into the analysis and to assess the effects of these variables on farmer decision making. Results suggested several hypotheses about the relationships between land and owner characteristics. More significantly, the study concluded that spatial analysis appeared to be most useful when the dependent variable was either continuous or ordinal (Fox, Kanter, Yarnasarn, Ekasingh & Jones, 1994).

The potential of using GIS in analysing pest surveillance data was explored. The Spatial Analysis System (SPANS) was used to construct a spatial data base to study pest distributions using pest surveillance data collected from 152 stations in South Korea. The annual spatial distributions of the striped rice borer (SRB), *Chilo suppressalis,* showed that high densities started to expand in the early 1980's, reaching a peak in 1988. The pattern change appeared to be related to cultivation of japonica and indica-japonica hybrid varieties in South Korea. Japonica varieties have longer duration resulting in the SRB having more time to mature and hibernate in winter (Song & Heong, 1993).

The spatial distribution of *Dreissena polymorpha* (zebra mussel) among inland lakes of Wisconsin was predicted using modelling with a GIS. Previously developed models and limnological data were used to predict absence or presence, categorical population density, and numerical abundance of *Dreissena polymorpha* for 194 inland Wisconsin lakes. A GIS was used to test for associations between predicted lake population density classes and three landscape-scale characteristics (surficial deposits, bedrock type, U.S. Environmental Protection Agency developed eco-regions) that may effect limnological parameters. The study suggested that available lake monitoring data can be used to predict *Dreissena* density for groups of inland lakes, and spatial analysis using GIS methods can provide valuable insight into the overall patterns of the potential spatial distribution of *Dreissena* (Koutnik & Padilla, 1994).

An analytical approach to modelling the likely impact of climate change on the distribution and abundance of wildlife species was described using examples from Scotland data for present day distribution of wildlife and habitat were analysed using map data describing geographic variation in climatic factors. Climate data for the present day were modelled within a GIS. The analytical procedure generated hypotheses defining ecological relationships between species distribution and climatic factors. These relationships are then used to model the distribution of the species directly from climate and predict impacts of climate change on distribution. The analysis takes account of both direct impacts of climate on wildlife and indirect effects manifested through habitat response to climate change. The analytical procedure was implemented as a common tool for inductive spatial analysis in GIS (Aspinall & Matthews, 1994).

Erosion cells in a watershed can be delineated with the use of GIS. The effect of erosion processes can be studied either in terms of sediments produced or in terms of surface-form modifications. The erosion cell approach which uses the land-form modifications caused by erosion processes as one of its major inputs and defines a basic unit, namely the erosion soil cell, has been found very useful for spatial evaluation of erosion in arid and semi-arid climates. In this study an attempt has been made to use this approach for the spatial evaluations of erosions in a watershed having a humid temperate climate. As the emphasis of the study was on the spatial analysis, a geographic information system became useful for analysis (Murty & Venkatachalam, 1992).

Geographical information systems (GIS) provide a means of visualising and modelling the distribution of plants and pests as well as other important attributes of crop protection. GIS uses multiple data bases, with each value referenced to a common co-ordinate system, data can be combined in the form of thematic maps. With the addition of weather and evaluation data pest development can be monitored and predicted over large areas but with local detail. GIS has been used for predicting phenological development of, for instance the gypsy moth and other important insect pests. Similar approaches have been used for plant diseases such as potato bate flight and apple scab. An important feature of GIS for pest prediction is the ability to assess risks of pest development. Most GIS programs also have a set of tools for spatial analysis of the data (Seem, 1993).

Coulson (1992) researched the utilisation of GIS in integrated pest management. The addition of methodologies from artificial intelligence expert systems, permits integration of qualitative knowledge of human experts with quantitative information that is the product of research.

Determining the establishment potential of exotic pests is one of the most complex procedures in pest risk analysis. To facilitate sampling and control of pests in the event of an outbreak, risk maps (created with the use of GIS) should be able to predict pest development at a farm or even field scale (Baker, 1994).

Grasshoppers are of special interest to humans, because many grasshopper species compete with humans for plant resources throughout the world. They are the major aboveground native herbivores on western USA rangelands. By spatially analysing past grasshopper outbreaks, it might be possible to understand the large-scale population dynamics of grasshoppers so more efficient survey strategies and management methods can minimise insecticide applications. This would of cause be more cost effective and less harsh on the environment.

A map that was generated from the annual grasshopper surveys suggested an aggregated pattern to grasshopper outbreaks. The data were expressed as grasshopper outbreak frequency classes (GOFC) and the class value is the number of years a particular grid cell has been infested with at least 10 grasshoppers per square meter, which is the western USA rangeland's approximate carrying capacity. This map that was generated using GIS, can be used to guide grasshopper surveyors onto lands with the greatest potential for supporting severe infestations, which are being targeted for early control in an attempt to prevent large-scale outbreaks. When there are several areas to be treated, the GOFC map is also used as a factor to establish the urgency of treatment. Areas with a history of chronic infestations are given the highest priority. The GOFC map can be used in a knowledge-based grasshopper management program for ranchers. The programme used outbreak history to estimate the likelihood of a persistent infestation and the probability of multiple-year benefits. This is a critical economic condition to justify treatment in many situations. Thus, historical/spatial data are an important parameter in determining the most economical course of action during a grasshopper outbreak.

Remote sensing (through the use of satellites) and GIS can be integrated. The use of satellite imagery to monitor ecological conditions that favour pest outbreaks had been highly successful. Areas that were defoliated by various insects in North America were rapidly and economically identified. Remote sensing was also used to delineate the vegetation that might support locust breeding in normally desiccated habitats in Australia and Africa. The Food an Agriculture Organisation's Remote Sensing Centre in Rome, Italy, used satellite imagery to monitor vegetation and rainfall to provide virtually real-time information regarding potential hatching sites of the desert locust to ground-based scouts in Africa, and that dramatically improved survey and control efficiency (Schell & Lockwood, 1995).

The temporal dynamics of an insect population take place within a spatial context. Population ecology has usually concentrated on dynamics at single locations. Much of the recent attention given to large-scale spatial dynamics had been related to insect migration as a factor in synoptic pest studies. But even insects with limited dispersal, and whose distribution and abundance are affected primarily by local conditions, should be studied in a spatial context. Grasshopper outbreaks are typical examples of large-scale spatial dynamics that are affected by local conditions. Factors that affect the insects' numerical fluctuations are usually variables that have both spatial and temporal characteristics (e.g. weather) and they can be mapped.

Grasshoppers periodically cause severe damage to crops and rangeland in the Canadian Prairies. There need to be an advance warning of changes in the geographical pattern and severity of outbreaks to plan control measures. Previous studies on survey data had indicated that grasshopper abundance correlated with the previous years' populations, with heat accumulation, and negatively with rainfall. Recent technology for the analysis of geographic variables can be adapted to examine the spatial aspects of population dynamics, without having to reduce extensive data sets to district averages. Several forms of spatial analysis and modelling can be applied to the problem of determining the relationship of grasshopper abundance to monthly rainfall and hours of sunshine. These variables have a hypothetical influence on the biogeography of grasshopper outbreaks and are helpful in illustrating a method that can be used in future studies to model pest infestations as functions of more extensive lists of spatial variables.

It is true that the true cause of numerical fluctuations cannot be discovered simply by studying numbers, therefore spatial analysis of insect population dynamics can also be used to discover qualitative differences in the ways that insects respond to environments across their geographic range. This could prove to be a very useful application of the modern techniques of spatial analysis in entomology (Johnson & Worobec, 1988).

Spatial analysis and GIS have vital applications in science. With its help pest management can be optimised. It is possible to study the distribution of pests over a large area and many diverse spatial variables can be combined to obtain an accurate holistic picture. It can also be used to build models to see the effects of changing certain variables on a pest management program, e.g. using different kinds of insecticides or equipment.

1.14 Aim of the study.

A sustainable agricultural set-up or food security in South Africa, referring to plant production or stock farming systems, depends on a sustainable environment, manpower and financial resources. Pest control, however, should address the same criteria of sustainability to ensure agricultural survival and food security. During the 1996\97-locust control campaign more than 76816 hopper bands and 7049 adult swarms of the brown locust were chemically controlled. The locusts were effectively controlled on less than 0,25 % (92 000 ha) of the outbreak area of 40 million hectares. These control actions cost the government nearly R14 million (Van der Westhuizen & Botha, 1997).

The main objective of the project was to develop an integrated operational and management information system which incorporate all the facets of locust control in South Africa (figure 1.6). The research project consists of two parts, namely the analysis of the campaigns and the presentation thereof in a geographical information system (GIS) environment. Equations used in the project were represented to aid system programmers in writing a user-friendly interface for analysis of future locust control data.

1. A database containing locust control data from the De Aar, Hanover, Hay and Postmasburg districts were used (figure 1.6). Data from other districts and future campaigns can be added.
2. Abiotic and other biotic data (rainfall and grazing capacity of farms) was added to the database.
3. Spatial analysis (using ArcView GIS) was done for operational purposes. This was done on farm and district levels. Within each level the environmental, manpower and financial criteria were analysed.
4. An early warning system resulting from data in the criterion: environment at farm level was attempted.
5. A component analysis of the environmental, manpower and financial aspects were done on district level for managerial purposes. The system can easily be extended to depot and national level.

Environmental, Manpower and Financial Information System

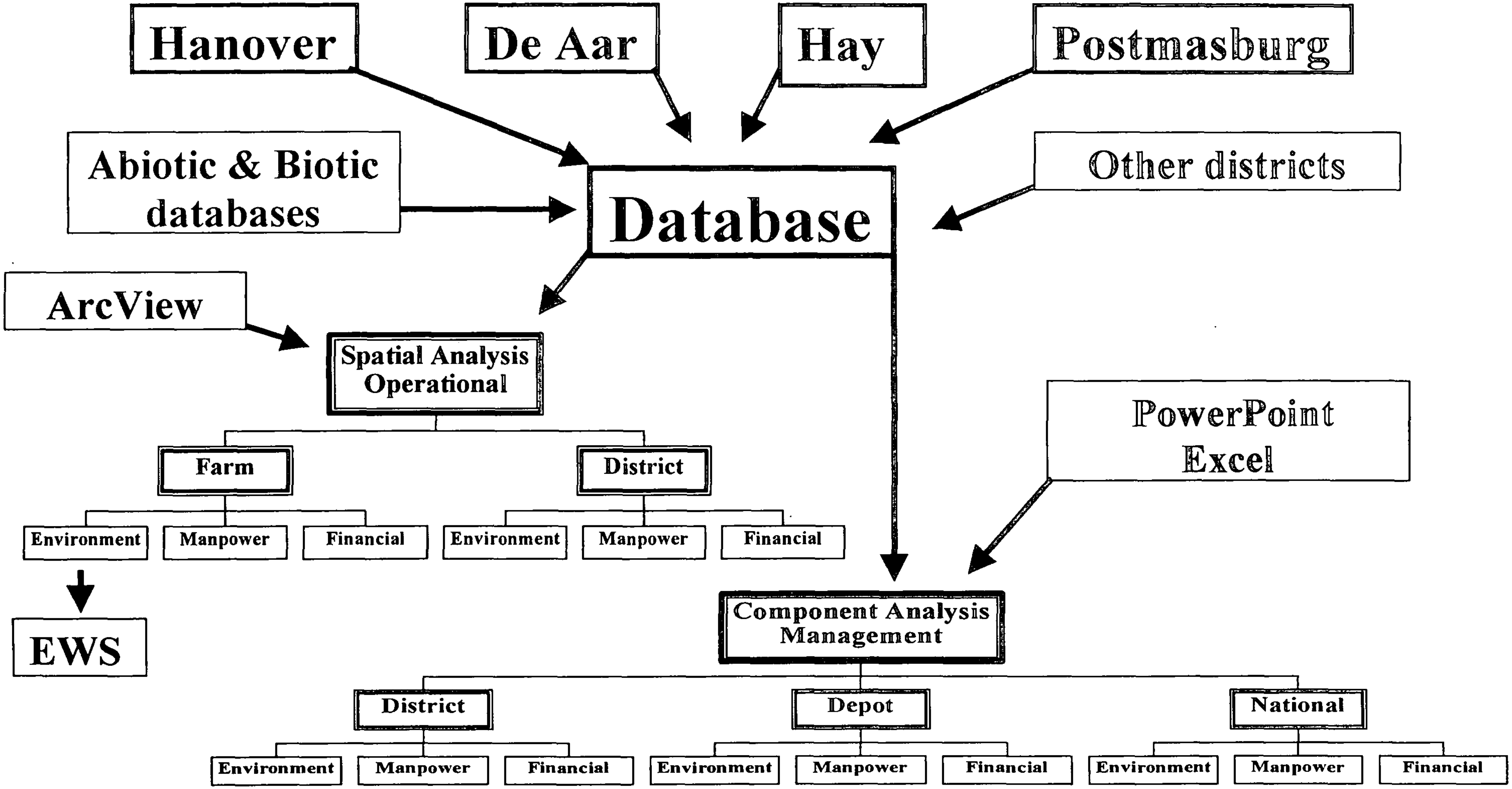


Figure 1.6 Flow diagram of all the components of the integrated information system.

Chapter 2

Material and methods

Data collection and data analysis.

At the end of each month, the supervisor submitted all the yellow and green forms (Ref. NR. AGR 102/002 and LEB 7/112, respectively, Heyns *et al.*, 1995) as well as other relevant log reports, to the district locust officer. The information was delivered to the administrative officer from where the data was collected for analysis.

The data is analysed with the use of a computer based geographic information system (GIS), namely Arcview, as well as with the aid of other computer programs. Polygons for the GIS were obtained from the National Department of Agriculture. The data was analysed in terms of three criteria for sustainable agriculture, namely the environmental, manpower and financial resources.

The primary objective is to develop a system for the easy analysis of locust control campaigns. This involved changing old data capturing forms to new more streamlined forms and setting up computer software for easy accessible analysis in future campaigns. Better management and better usage of data can lead to a reduction in the total control costs and a more effective utilisation of tax payer's money (Peters, Botha & Van der Westhuizen, 1997).

A new data sheet that can be seen in table 2.1 replaces the old yellow and green forms. The locust database used in this study was designed to resemble the new form, with a few added fields.

The information in table 2.1, as well as those in table 2.2, is available for each locust band or swarm controlled. The kilometres driven per supervisor and the wages (supervisor + assistants) were equally allocated to the number of bands or swarms controlled per day and is reflected in the fields *Mean Km* and *Wages (R)*. The *Wages*

(R) field was proportionately divided into the fields *Sup wages* and *Assistant wages* for the wages paid to the supervisors and assistants respectively. The district locust officer (DLO), supervisors and assistants earns respectively R139,40, R90,40 and R67,85 per day. The field *Travel cost (R)* was calculated as the product of the *Mean Km* for that particular band or swarm and the supervisor's travel subsidy per kilometre.

If no detailed figures were provided, the volume of pesticide sprayed per day was distributed relative to the size of each locust band or swarm controlled on the farm. This quantity was recorded in the field "Quan" under the heading "Formulation used" (table 2.1). Only the English headings of table 2.1 is used in the equations.

For the calculation of the field *Pesticide (R),* the value in the field "Quan" was multiplied by R12,00 per litre for all the locusts controlled in October 1996 and multiplied by R12,43 per litre for the locust controlled during the remainder of the period, up until May 1997.

The field *Man days* was calculated by dividing the total man days for the supervisor and his assistants (information on the previously used green form) by the total number of bands or swarms sprayed per month. If a farm was visited without spraying, for purposes of scouting etc., these farms were also included in the calculation, because it demanded time from these officials. This was proportionately divided into the fields *Supervisor days* and *Assistant days* for the supervisors and assistants respectively, on the grounds of the number of assistants employed by the supervisor.

The field *Hectare* was calculated by using the formula:

$$\frac{Length * Width}{10000} \qquad (2.1)$$

(The dimensions for *length* and *width* are in metre in table 2.1).

The fields *# Bands* and *# Swarms* was calculated (in Microsoft ® Excel 97) by using these respective formulas:

$$\# Bands = COUNTIF(Stage, \text{“<4”}) \qquad (2.2)$$

$$\# Swarms = COUNTIF(Stage, \text{“>3”}) \qquad (2.3)$$

“Stage” refers to the locust developmental stage: Stages 1, 2 and 3 refer to hoppers with respective sizes of small 10-15 mm, medium (20 mm) and “Rooibaadjies (25-30 mm). Stage 4 refers to mixed populations of hoppers and adults and stages 5 and 6 refer respectively to adults with eggs and without eggs. The stage and species code of each band or swarm is recorded under the heading “Locust” in table 1. These formulas determine whether a hopper band or an adult swarm was controlled on a farm.

The fields *Bands Ha* and *Swarm Ha* were calculated by the following formulas respectively:

$$\mathit{Bands\ Ha} = \mathit{IF(\#\ Bands{,}Hectare{,}0)} \tag{2.4}$$

$$\mathit{Swarm\ Ha} = \mathit{IF(\#\ Swarms{,}Hectare{,}0)} \tag{2.5}$$

These formulas calculate the surface area in hectare on which either a hopper band or adult swarm, according to equations (2.2) and (2.3) was sprayed.

The following fields calculate the specific expenses per band (Ba) or swarm (Sw) controlled and is calculated by using the following formulas:

$$\mathit{BaPest(R)} = \mathit{IF(\#Bands{,}Pesticide\ (R){,}0)} \tag{2.6}$$

$$\mathit{SwPest(R)} = \mathit{IF(\#Swarms{,}Pesticide\ (R){,}0)} \tag{2.7}$$

$$\mathit{BaT(R)} = \mathit{IF(\#Bands{,}\ Travel\ cost\ (R){,}0)} \tag{2.8}$$

$$\mathit{SwT(R)} = \mathit{IF(\#Swarms{,}\ Travel\ cost\ (R){,}0)} \tag{2.9}$$

$$\mathit{BaAsstW} = \mathit{IF(\#Bands{,}\ Asst.\ wages{,}0)} \tag{2.10}$$

$$\mathit{SwAsstW} = \mathit{IF(\#\ Swarms{,}\ Asst.\ wages{,}0)} \tag{2.11}$$

$$\mathit{BaSupW} = \mathit{IF(\#Bands{,}\ Sup\ wages{,}0)} \tag{2.12}$$

$$\mathit{SwSupW} = \mathit{IF(\#\ Swarms{,}\ Sup\ wages{,}0)} \tag{2.13}$$

The control details of each farm or codeset were linked with the ArcView attribute tables and thus farm polygons. The data obtained per band or swarm was analysed according to the flow diagram shown in figure 1.6.

The information in the database was subjected to the two main components of the system, namely the spatial analysis for operational purposes and the component analysis for management purposes. Within these two components, distinction is also made between information on farm, district and national level. Each of these levels is subdivided and analysed in terms of the environmental, manpower and financial criteria, according to figures 2.1 and 2.2.

Table 2.2 The following fields were added to the database in table 2.1 to facilitate the analysis. -

Depot	*Mean Km*	*Travel cost (R)*	*Wages (R)*	*Supervisor wages*
Assistant wages	*Pesticide (R)*	*Man days*	*Supervisor days*	*Assistant days*
Hectare	*# Bands*	*# Swarms*	*Bands Ha*	*Swarm Ha*
BaPest(R)	*SwPest(R)*	*BaT(R)*	*SwT(R)*	*BaAsstW*
SwAsstW	*BaSupW*	*SwSupW*		

The operational and managerial analysis can easily be extended from farm level to district, depot or even national level, by adding either farm, district or depot totals.

For the aim of this project the supervisors were only identified by codes and their names were not disclosed. Examples of the codes are as follows: "D1", a supervisor in De Aar, "H3" a supervisor in Hanover, "HY7" a supervisor in Hay and "P2" a supervisor in the Postmasburg district.

The system also enables the user to compare different campaigns in order to rule out inaccuracy and facilitate better planning among and within campaigns.

Table 2.1: Supervisors must record these details for each locust band or swarm controlled in South Africa.

Bladsy Nr:
Page Nr: 00001

Jaar:...........Maand:.............Naam van beampte:...................................Identiteitsnommer:...Distrik:..
Year:. ....Month:...............Name of official..Identity number:..Distict:..

Datum Date	Afstandsmeterlesing Amptelik(km) Odometer reading Official (km)		Afstand Gereis Distances travelled		Vertrek van Departed from	Gereis na (Plaasnaam en Kodestel) Travelled to (Farm name and Codeset)	Nr Ass Nr Ass	Groote van konsentrasie Size of consentration Tree / Paces		Sprinkane Locust		Middels gebruik Formulation used		Spuit Toerusting Spay Equipment	
	Begin Start	Einde End	Amptelik Official	Rrivaat Private				Lengte Length	Breedte Width	Tipe Type	Stdm Stage	Tipe Type	Hoev. Quan	Tipe Type	Hoev. Quan
Totale/Total:															

I certify that above mention information is correct, the official trips were necessary and that the arrangements made were the most
Ek sertifiseer dat bogenoemde inligting korrek is, die amptelike ritte noodsaaklik was en dat die reëlings getref in elke geval
economical in each instance.
die mees ekonomiese was.

....
Signature of reporting officer
Handtekening van verslaggewende beampte

I certify that this return has been examined and that all official trips undertaken were necessary and in the public interest.
Ek sertifiseer dat hierdie opgawe nagegaan is en dat alle amptelike ritte wat onderneem was noodsaaklik en in staatsbelang was.

....
Signature of controlling oficer
Handtekening van kontrolerende beampte

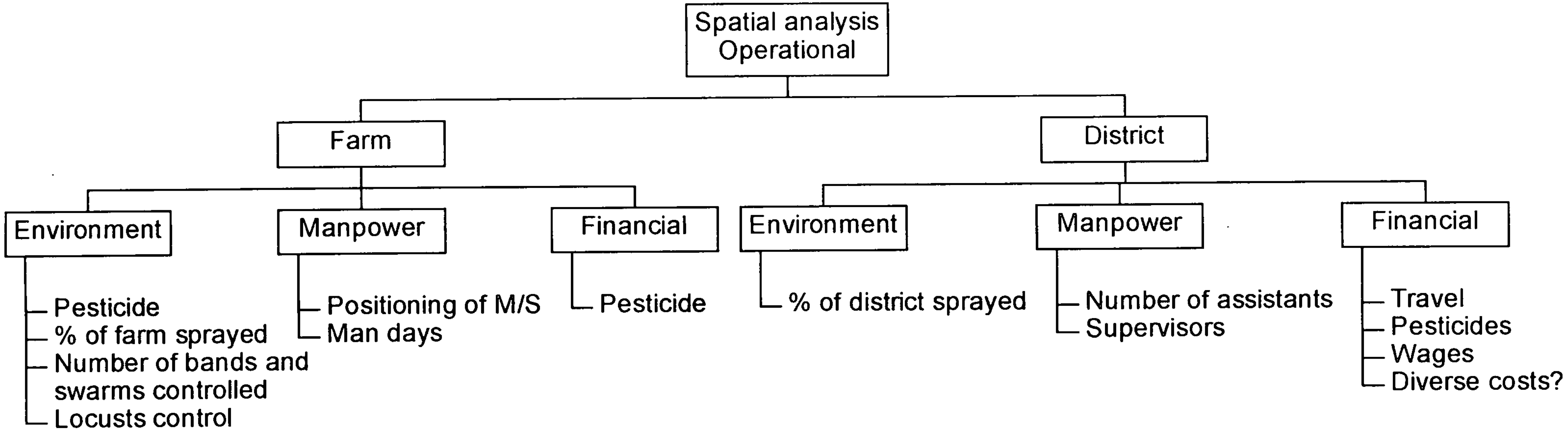


Figure 2.1: Diagrammatic presentation of the spatial analysis of the integrated information system

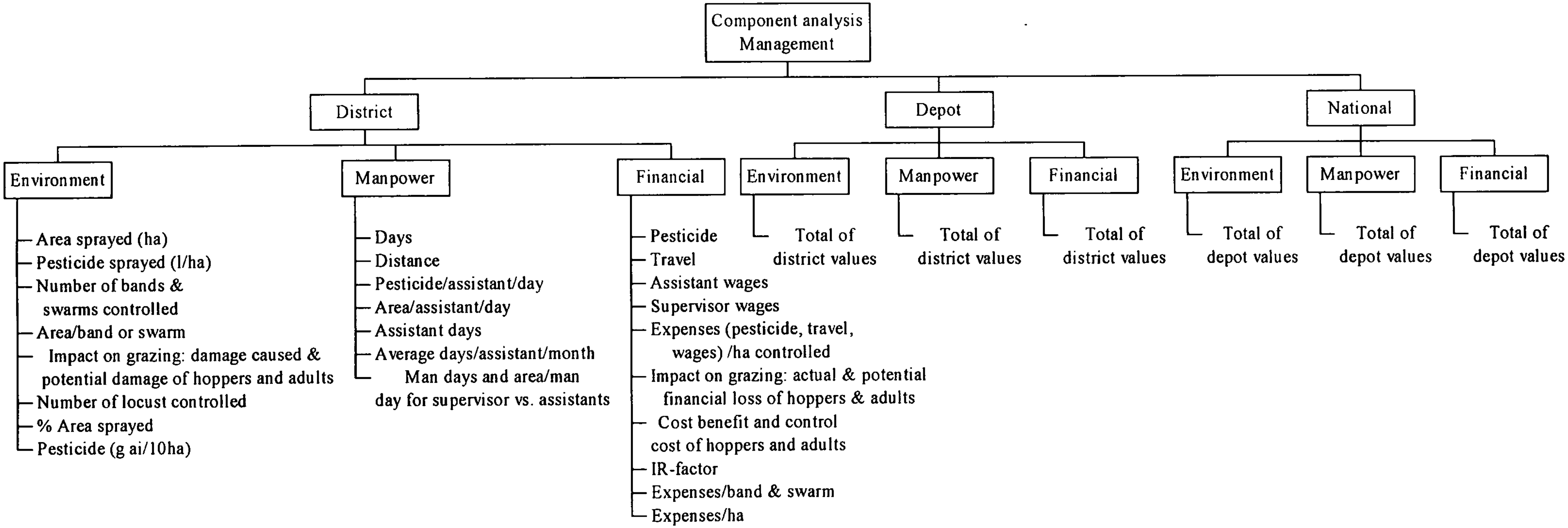


Figure 2.2: Diagrammatic presentation of the component analysis of the integrated information system.

Chapter 3

Criterion: Environment

Introduction

According to Heyns *et al.* (1995) the vast majority of the public and farmers are uninformed about the nature and extent as well as the economic threat that locusts hold for livestock farmers in the hatching and invasion areas. Brown locusts return only 5% of the nutrients (organic nitrogen) ingested in a certain area to the area of impact via their faeces. The rest is partially incorporated into the biomass of the locust and leaves the area. The latter is actually deposited on the farm where the locust is controlled.

Blickenstaff, Skoog & Daum (1974) stated that the effectiveness of grasshopper control can be measured in various ways: (1) immediate and long-term reduction in the population density, (2) control benefit and (3) the reduction in the area needing treatment.

A reduction in heavy infestations and a subsequent decrease in the outbreak area would be beneficial to the environment. According to Hewitt (1977) grasshoppers can damage rangeland in three ways: (1) the removal of forage in direct competition with livestock, (2) permanent damage to plants due to continued feeding by grasshoppers beyond accepted use factors and (3) destruction of seed heads, which prevents natural reseeding.

When grasshoppers feed on the top of plants they browse in direct competition with livestock and when they feed on plant material near the ground they contribute to overgrazing and weakening the root reserves in the stand, which may possibly lead to soil erosion (Nerney, 1958; Hewitt, 1977).

The ecological function of grasshoppers can be viewed from three different perspectives: (1) the proportion of the total energy in an ecosystem which is tied up in grasshopper biomass. (2) The amount of energy flow which passes through grasshoppers during a given time. (3) The influence or control a grasshopper population may exert on the dynamics or functions of other consumers, producers and decomposers in an ecosystem (Rodell, 1977).

Chapter 3 analyses the amount of pesticides deposited on natural grazing and the relative sizes of swarms and areas involved. It further analyses the impact the locusts had on the grazing in term of tons of grazing removed and the potential damage averted by control.

Results and discussion

Unless otherwise stipulated, "Avg." equals "average" for all the figures. Figures 3.1 to 3.4 compare the total area (ha) and the average rate (litre per hectare) sprayed per supervisor in the four districts. The *Hectares* histograms refer to the total area sprayed per supervisor (table 2.2). The series *l/ha* illustrates the amount of litres sprayed by the supervisor and his assistants, divided by the total number of hectare sprayed and was calculated by using the following formula (in Microsoft® Excel):

$$l/Ha = \frac{Quan}{Hectare} \qquad (3.1)$$

"Quan" and *Hectare* are fields in table 2.1 and 2.2 respectively. "Quan" is a field under the heading "Formulation used" and records the quantity of pesticide applied in litre. The campaign totals per supervisor were used in equation (3.1). The district averages of the various series were calculated by using the following formulas:

$$Avg.\ Ha = AVERAGE(HectareX{:}HectareY) \qquad (3.2)$$

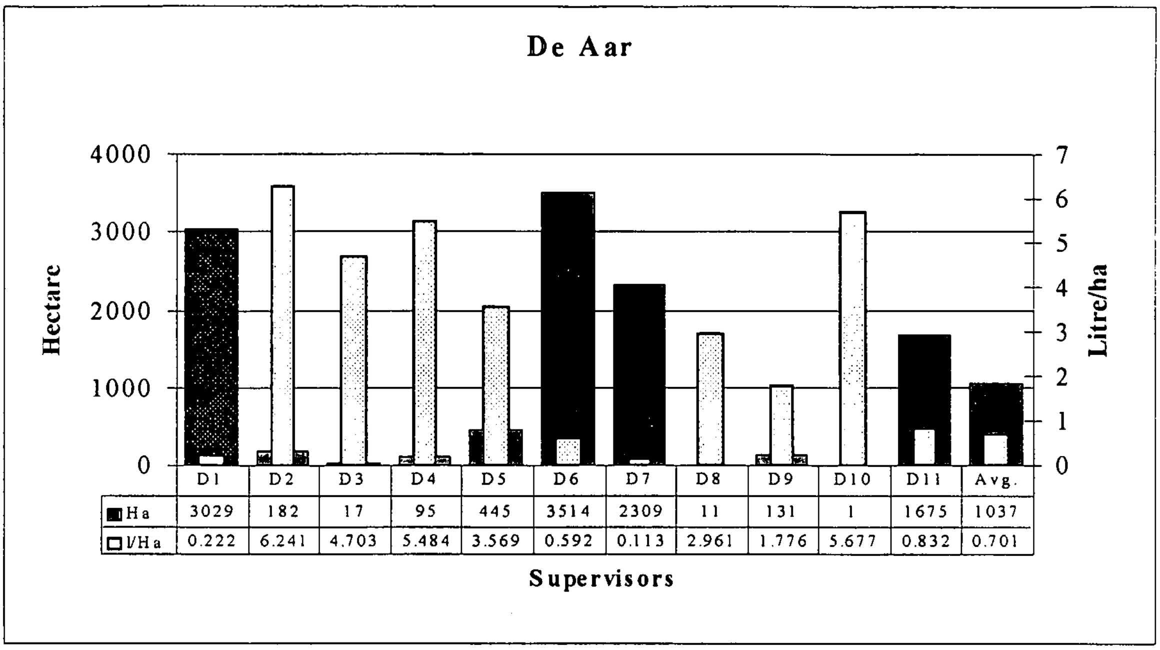
$$Avg.\ l/Ha = \frac{SUM(QuanX{:}QuanY)}{SUM(HectareX{:}HectareY)} \qquad (3.3)$$

Where *HectareX* and *HectareY* are the total number of hectares sprayed by all the supervisors in any given district and *QuanX* and *QuanY* are the total amount of pesticides applied by the same range of supervisors.

There was great variation between the supervisors in the districts regarding the number of hectares sprayed as well as the application rate (figures 3.1 to 3.4). The highest (3 514,025 ha) and lowest (0,664 ha) number of hectares were sprayed by supervisors D6 and D10 respectively, both in the De Aar district. The highest application rate (7,446 l/ha) was by supervisor HY7 in Hay and the lowest rate (0,007 l/ha) was by P1 in Postmasburg district. Deltamethrin is registered for use against locust at an application rate of 2 – 3 l/ha of a 6 g ai per litre ULV formulation (Heyns *et al.*, 1995; Krause *et al.*, 1996). From figures 3.1 to 3.4 it is clear that gross violations of the registration occurred. In each district only about two or three supervisors came close to the registered application rate. They were D8 (2,961 l/ha), H8 (2,733 l/ha), H10 (2,551 l/ha), HY16 (2,485 l/ha), HY19 (2,498 l/ha), HY24 (2,419 l/ha), HY26 (2,516 l/ha) and P6 (2,181 l/ha). In the chemical control of pests, it is important to obtain maximum effects on target species while keeping to a minimum the effects on non-target species and the environment (Chiang, 1973).

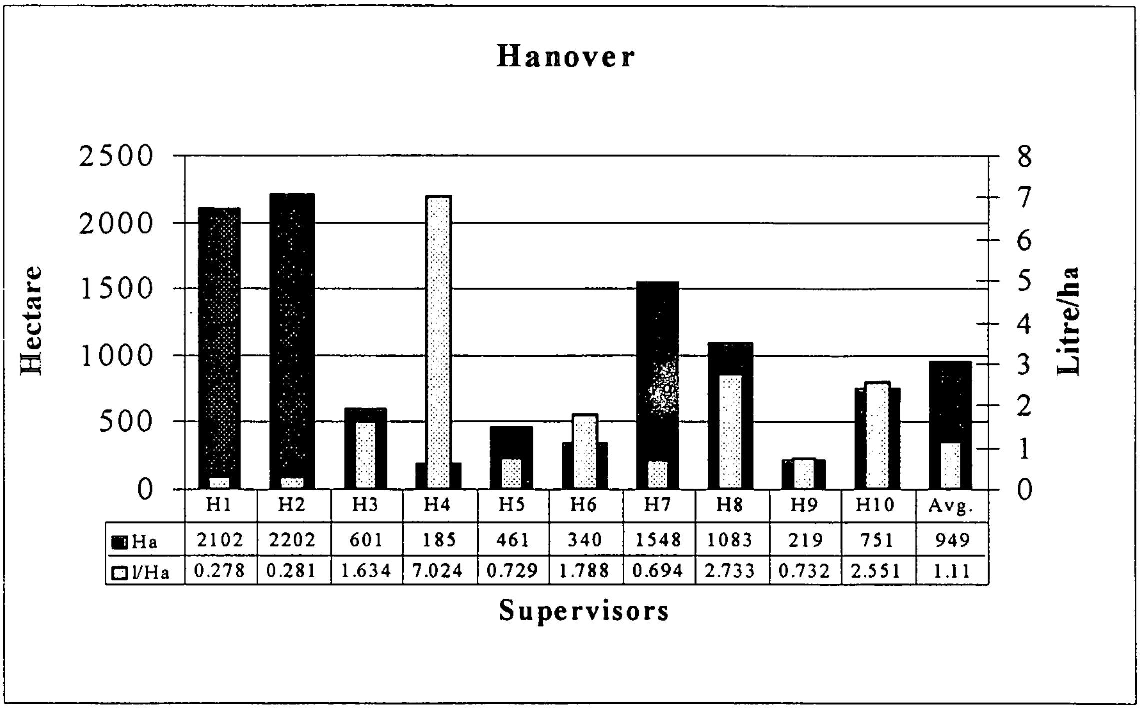
Supervisors HY11, P2 and P3 did not report the amount of pesticides used, consequently the application rate could not be calculated for them. D12, H11 and HY25 were the secretaries in the respective districts and did not control any locusts. They were consequently omitted from these figures, as well as D13 and H12 who acted as district locust officers (DLO) and also did not control locusts.

If the district average values in figures 3.1 to 3.4 are compared, it is clear that all the averages were well below the required application rate of 2,5 litres per hectare. The highest rate was in the Hay district at an average of 1,426 l/ha. The lowest rate, at 0,054 l/ha was found in the Postmasburg district. As stated previously, P2 and P3 did not report the amount of pesticide used. This could have had a profound effect on the average amount of pesticide sprayed per hectare in the district, because this implied that 33% of the supervisors did not report the amount of pesticides used. Furthermore, according to equation (3.3) the district average l/ha was calculated by dividing the sum of all the litres sprayed by the total number of hectares sprayed. The number of hectares sprayed for P2 and P3 were known, but not the amount of pesticide used. The average value is thus lower than it would have been if the amount of pesticide sprayed were known.



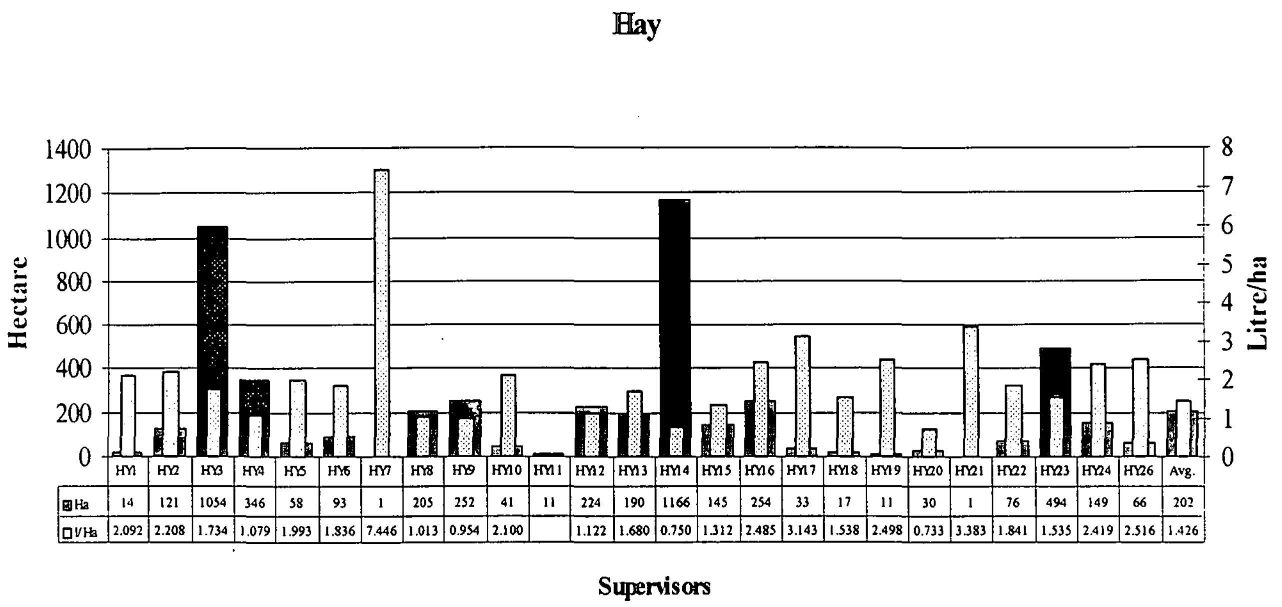
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
■Ha	3029	182	17	95	445	3514	2309	11	131	1	1675	1037
□l/Ha	0.222	6.241	4.703	5.484	3.569	0.592	0.113	2.961	1.776	5.677	0.832	0.701

Figure 3.1 Total number of hectares sprayed and the average application rate per supervisor in the De Aar district in the 1996/97 locust control campaign.



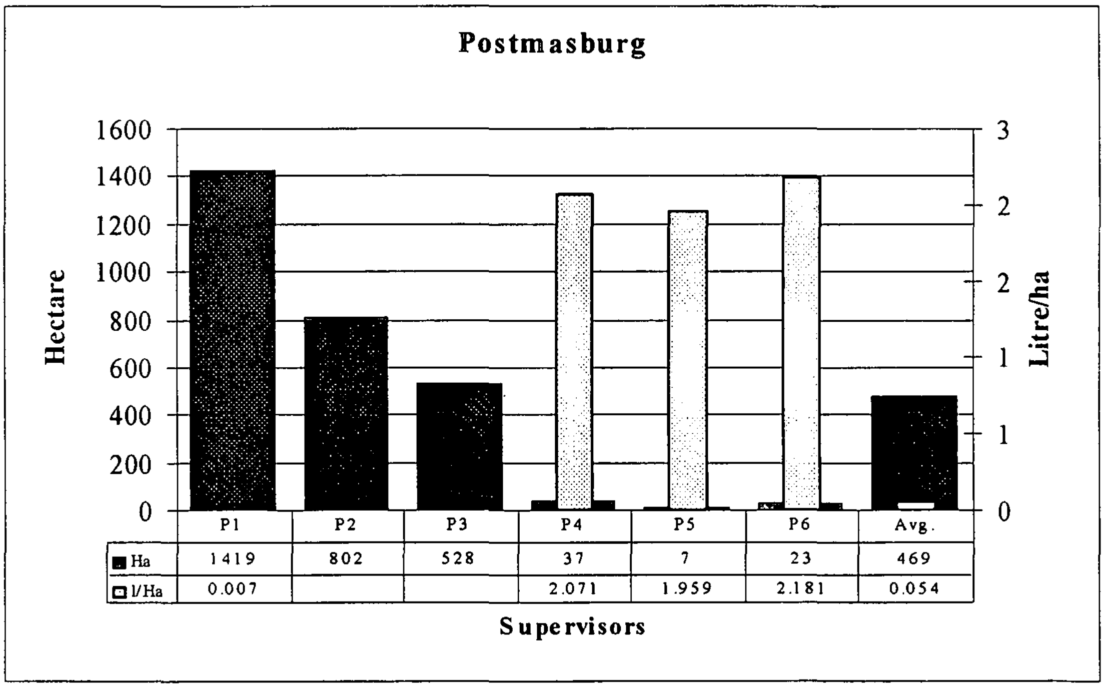
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Avg.
■Ha	2102	2202	601	185	461	340	1548	1083	219	751	949
□l/Ha	0.278	0.281	1.634	7.024	0.729	1.788	0.694	2.733	0.732	2.551	1.11

Figure 3.2 Total number of hectares sprayed and the average application rate per supervisor in the Hanover district in the 1996/97 locust control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY11	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY26	Avg.
▨ Ha	14	121	1054	346	58	93	1	205	252	41	11	224	190	1166	145	254	33	17	11	30	1	76	494	149	66	202
☐ l/Ha	2.092	2.208	1.734	1.079	1.993	1.836	7.446	1.013	0.954	2.100		1.122	1.680	0.750	1.312	2.485	3.143	1.538	2.498	0.733	3.383	1.841	1.535	2.419	2.516	1.426

Figure 3.3 Total number of hectares sprayed and the average application rate per supervisor in the Hay district in the 1996/97 locust control campaign.



	P1	P2	P3	P4	P5	P6	Avg.
■ Ha	1419	802	528	37	7	23	469
☐ l/Ha	0.007			2.071	1.959	2.181	0.054

Figure 3.4 Total number of hectares sprayed and the average application rate per supervisor in the Postmasburg district in the 1996/97 locust control campaign.

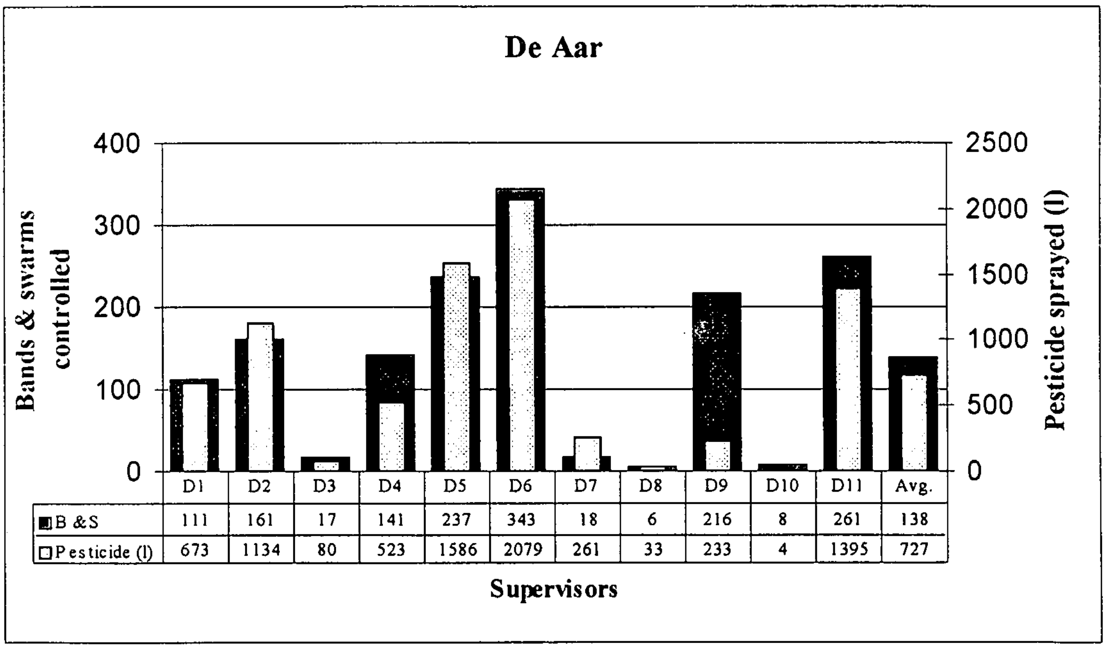
In figures 3.5 to 3.8 the number of bands and swarms controlled and the total amount of pesticide applied in doing so per supervisor in the four districts are compared. The series *Pesticide (l)* is the total per supervisor of the series "Quan" under the heading "Formulation used" in table 2.1 and records the pesticide applied per spraying action. The series *B & S* are the totals per supervisor of the fields (in table 2.2) *#Bands* and *#Swarms* and calculates the total number of bands and swarms controlled by a supervisor.

The district averages of these two series were calculated by using the following formulas:

$$\text{Avg. } B \,\&\, S = AVERAGE(B\&SX{:}B\&SY) \qquad (3.4)$$

$$\text{Avg. Pesticide } (l) = AVERAGE(QuanX{:}QuanY) \qquad (3.5)$$

B & S is the total number of bands and swarms controlled by a supervisor (totals of *#Bands +#Swarms*) and *B&SX* and *B&SY* are the supervisors in a range in any given district. *QuanX* and *QuanY* are the total number of pesticides applied by the supervisors in the district.



	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
■B &S	111	161	17	141	237	343	18	6	216	8	261	138
□Pesticide (l)	673	1134	80	523	1586	2079	261	33	233	4	1395	727

Figure 3.5 Total number of bands and swarms controlled and the pesticide applied (litre) per supervisor in the De Aar district in the 1996/97 locust control campaign.

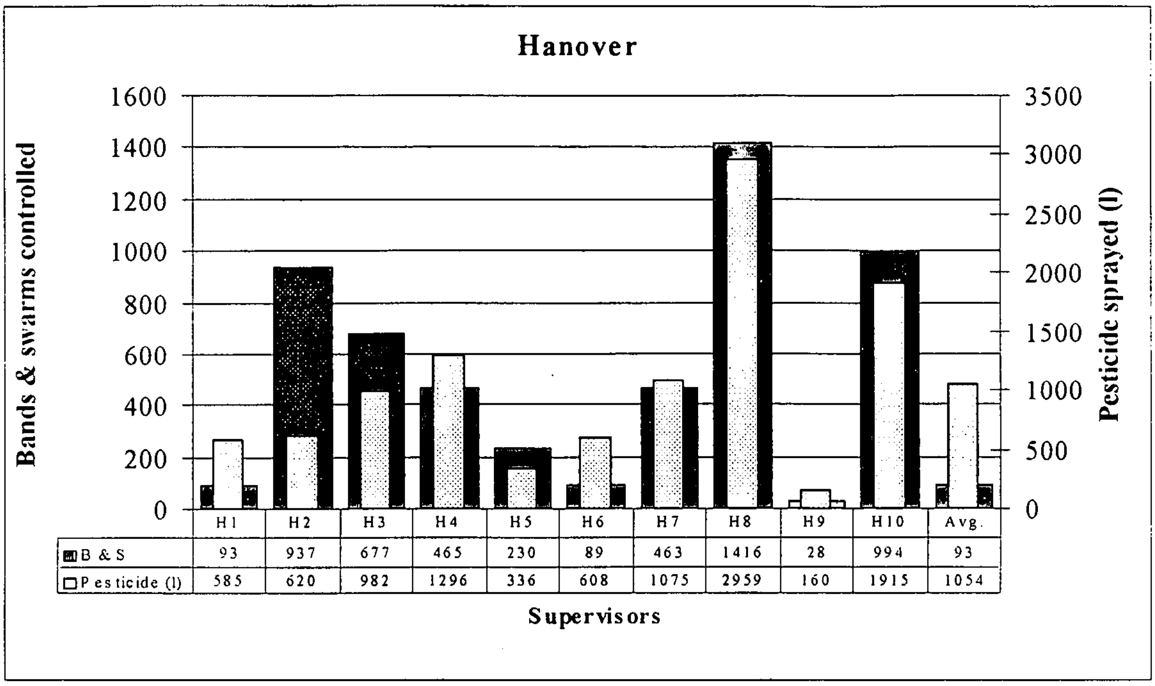


Figure 3.6 Total number of bands and swarms controlled and the pesticide applied (litre) per supervisor in the Hanover district in the 1996/97 locust control campaign.

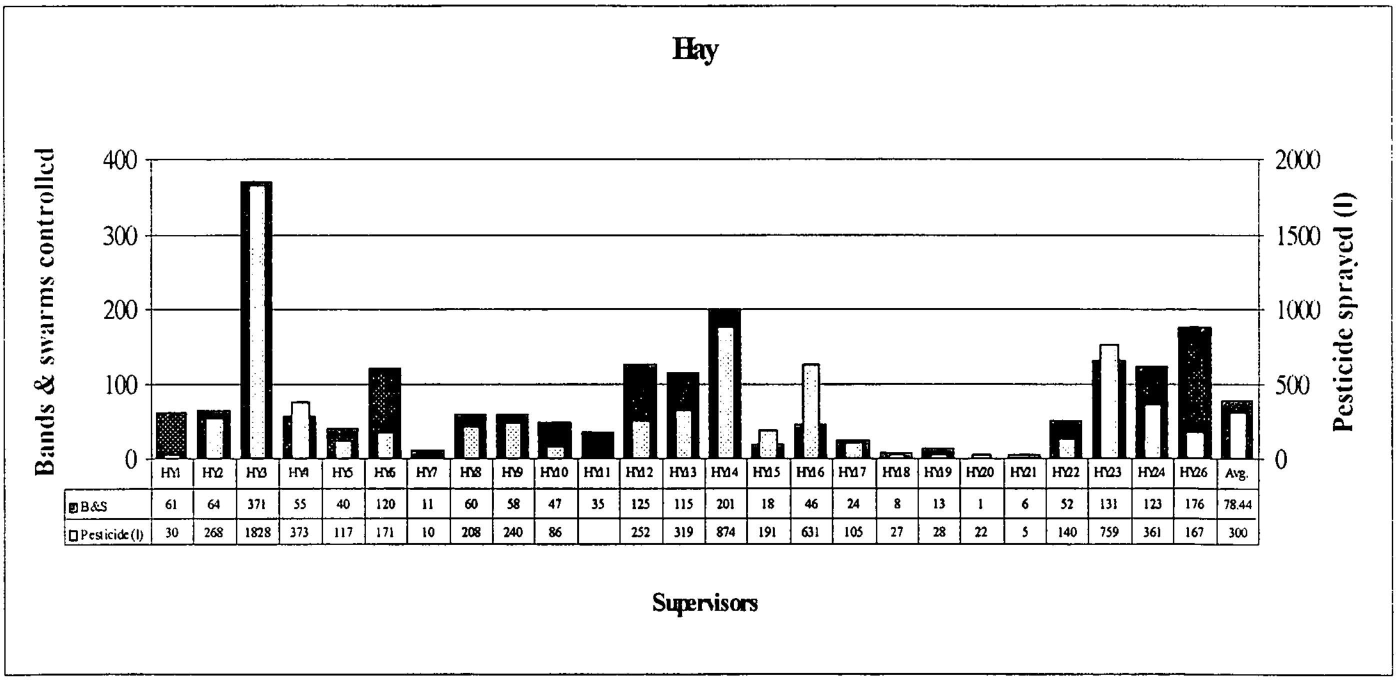
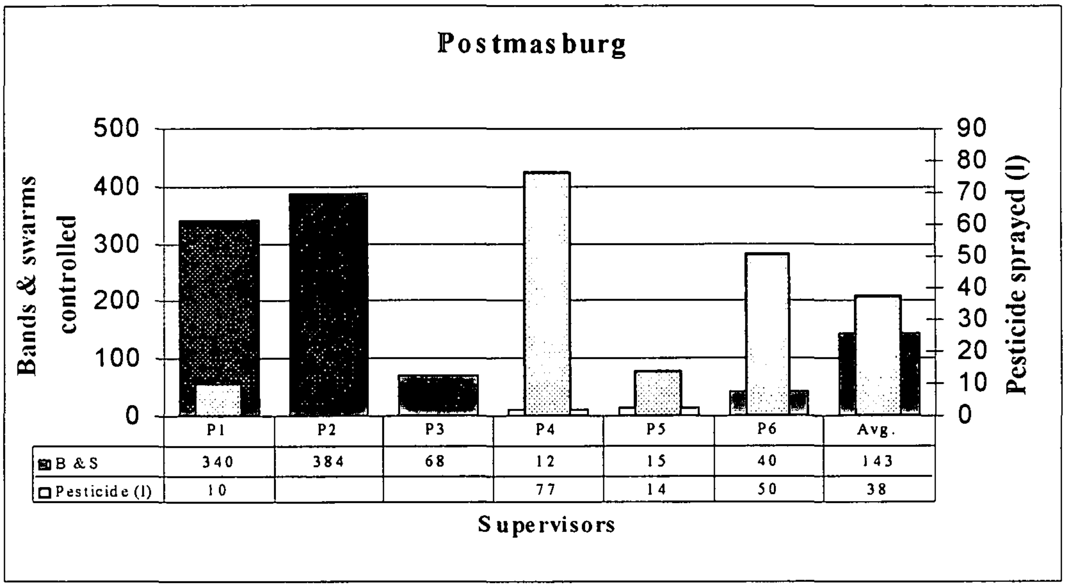


Figure 3.7 Total number of bands and swarms controlled and the pesticide applied (litre) per supervisor in the Hay district in the 1996/97 locust control campaign.



	P1	P2	P3	P4	P5	P6	Avg.
▨ B & S	340	384	68	12	15	40	143
☐ Pesticide (l)	10			77	14	50	38

Figure 3.8 Total number of bands and swarms controlled and the pesticide applied (litre) per supervisor in the Postmasburg district in the 1996/97 locust control campaign.

There were great differences between the supervisors in the various districts regarding both the numbers of bands and swarms controlled and also the amount of pesticide applied (figures 3.5 to 3.8). The number of bands and swarms sprayed by a supervisor were added and the relative sizes were not reflected in these figures. Figure 3.5 to 3.8 should therefore be viewed in association with figures 3.1 to 3.4. From figure 3.5 it would appear as if D1's pesticide application correlated with the number of bands and swarms controlled, but if this is viewed in conjunction with figure 3.1 it is evident that this supervisor did not spray at the correct application rate and applied far to little pesticide.

Supervisors P2 and P3 did not report the amount of pesticide sprayed and no *Pesticide (l)* value could be used in figure 3.8. The same is true for supervisor HY11 in figure 3.7. From the district average values the highest number of bands and swarms controlled per supervisor was in Hanover (539) and the lowest in Hay (78). The highest average amount of pesticide applied was in Hanover (1054) and the lowest in Postmasburg (38).

In figures 3.9 to 3.12 the relative percentages of hoppers vs. adults controlled by the different supervisors in the four districts are compared. The calculated numbers of each are compared and not the number of bands and swarms controlled. The formulas for calculating the total number of either hoppers or adults controlled are in columns N and O in table 5.3. Variables *Hoppers %* *vs. Adults %* were calculated by using the formulas in column references P and Q in table 5.3. The district averages were calculated by using the following formulas:

$$Avg.\ Hoppers = SUM(NX:NY)/SUM(NX:OY)*100 \qquad (3.6)$$

$$Avg.\ Adults = SUM(OX:OY)/SUM(NX:OY)*100 \qquad (3.7)$$

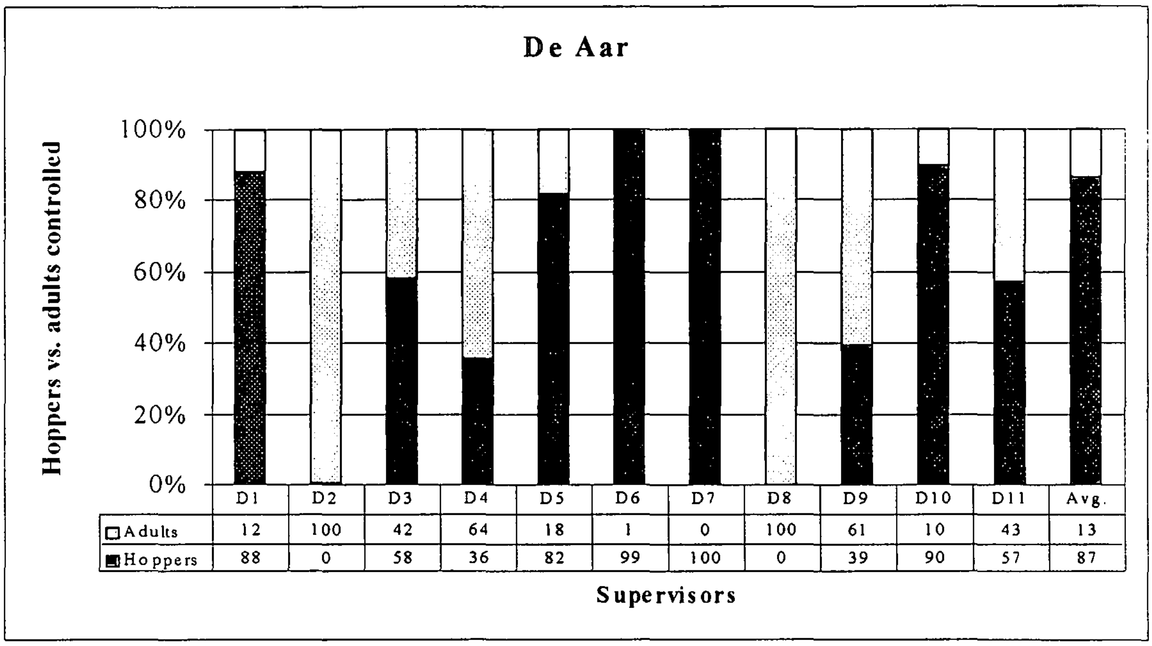
NX and *NY* are the total number of hoppers controlled by the range of supervisors in a district. In the same way is *OX* and *OY* the total number of adult locusts controlled by the range of supervisors in a district. N and O are column references in table 5.3.

Since it is more advantageous to control the locusts in the hopper stage (Quinn, Kepner, Walgenbach, Foster, Bohls, Pooler, Reuter & Swain, 1993; Coetzee, 1994; Heyns *et al.*, 1995; Van der Westhuizen & Botha, 1997; Roux, 1998), it would be more beneficial for a district to have controlled more hopper bands than adult swarms. This was true for De Aar (figure 3.9). In further comparing figures 3.9 to 3.12, it is apparent that all the other districts controlled a higher percentage adults than hoppers. The highest difference in percentages was in Hanover. The supervisors in Postmasburg controlled nearly equal amounts of hoppers and adults.

Two peak periods in locust control occurred in the 1996/97 campaign (Van der Westhuizen & Botha, 1997). The first was in December 1996 and the second in February 1997. At the same time a relative shift in position of locust control occurred from mid-Karoo to the northern-Cape. Escaping bands and swarms from the mid-Karoo, as well as new outbreaks, could have resulted in the relative high number of adults versus hoppers encountered in especially Hay and Postmasburg.

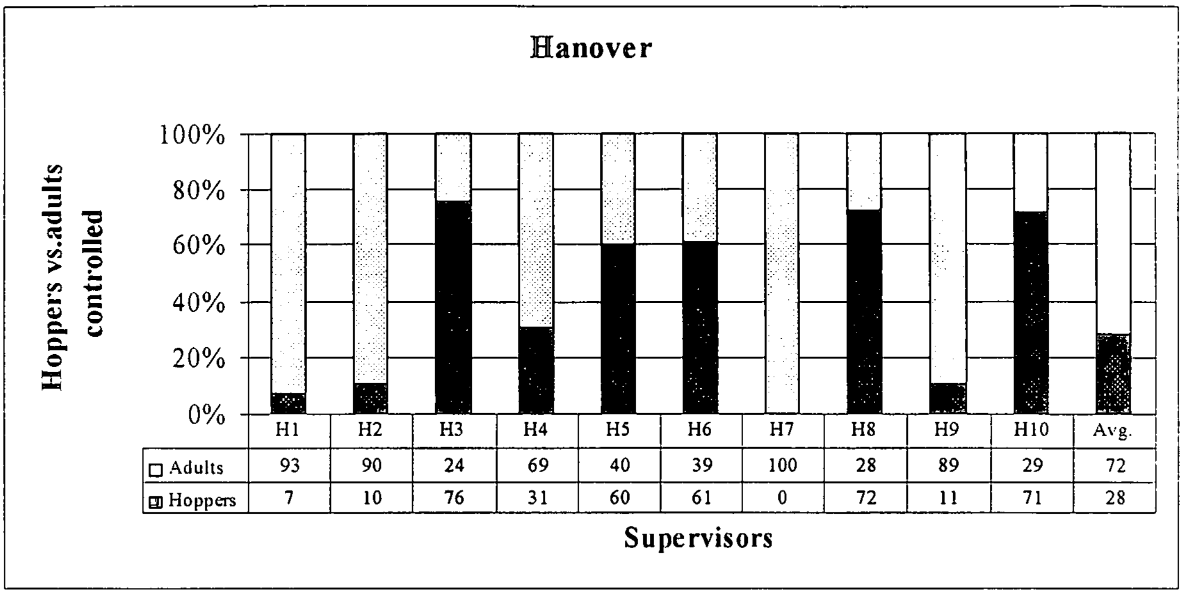
In figure 3.9 supervisor D8 only controlled adults and was employed in only one month (table 4.2). In contrast to him supervisor D7 controlled only hoppers and was employed for one month. When reviewing figures 3.9 to 3.12 in association with table 4.2, it would appear that in general, supervisors who were active through many months during the campaign had a better chance to combat both hoppers and adults.

Examples of these are supervisors D5, D11, H3, H8, H10, HY3, HY26, P1 and P4. In contrast with this, if a supervisor was employed for a short period of time, it is more likely that he only controlled either hoppers or adults. If he controlled both, then usually only a small percentage of the one and a high percentage of the other, but not necessarily 50:50. Examples of these are supervisors H1, H9, D7, D8, HY11, HY17, HY18, HY20, P5 and P6.



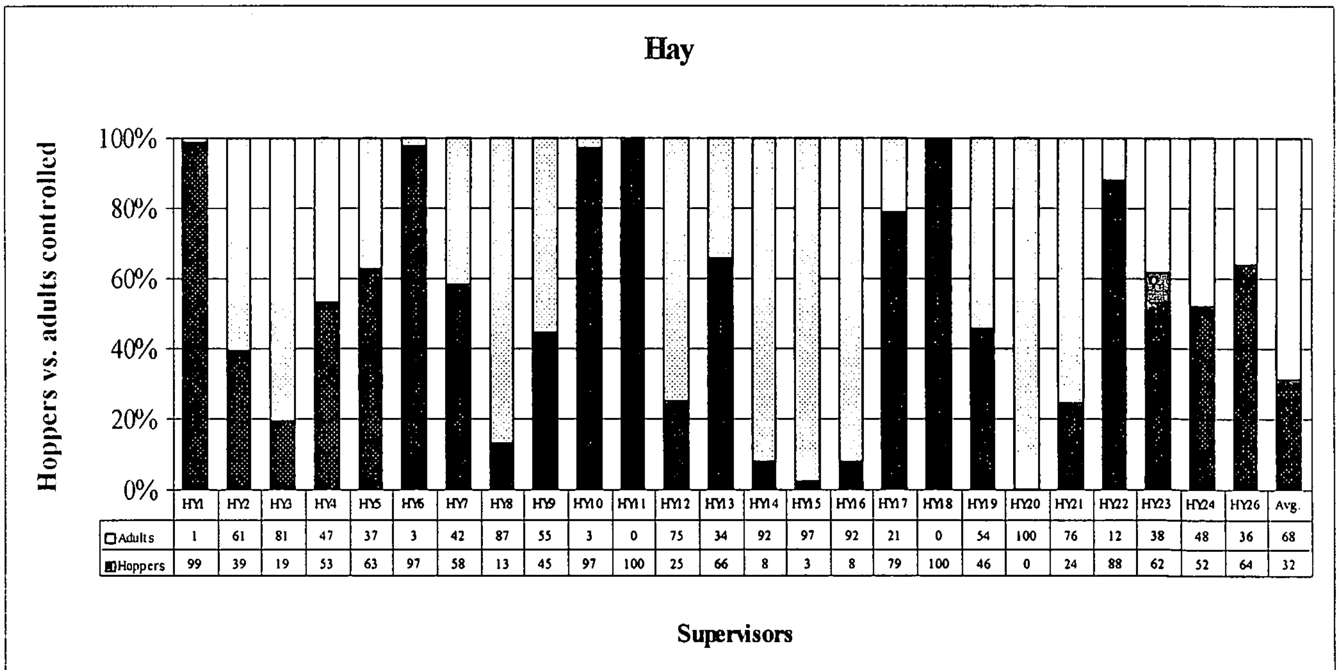
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
☐ Adults	12	100	42	64	18	1	0	100	61	10	43	13
▨ Hoppers	88	0	58	36	82	99	100	0	39	90	57	87

Figure 3.9 Percentage hopper versus adult locusts controlled by the supervisors in the De Aar district in the 1996/97 locust control campaign.



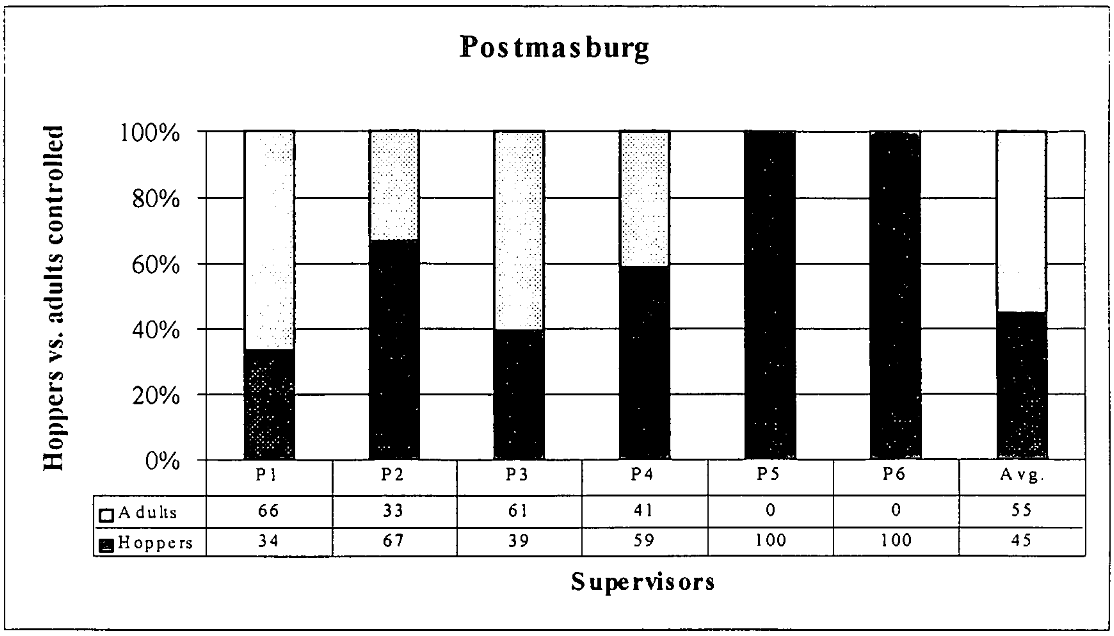
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Avg.
☐ Adults	93	90	24	69	40	39	100	28	89	29	72
▨ Hoppers	7	10	76	31	60	61	0	72	11	71	28

Figure 3.10 Percentage hopper versus adult locusts controlled by the supervisors in the Hanover district in the 1996/97 locust control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY11	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY26	Avg.
☐ Adults	1	61	81	47	37	3	42	87	55	3	0	75	34	92	97	92	21	0	54	100	76	12	38	48	36	68
▨ Hoppers	99	39	19	53	63	97	58	13	45	97	100	25	66	8	3	8	79	100	46	0	24	88	62	52	64	32

Figure 3.11 Percentage hopper versus adult locusts controlled by the supervisors in the Hay district in the 1996/97 locust control campaign.

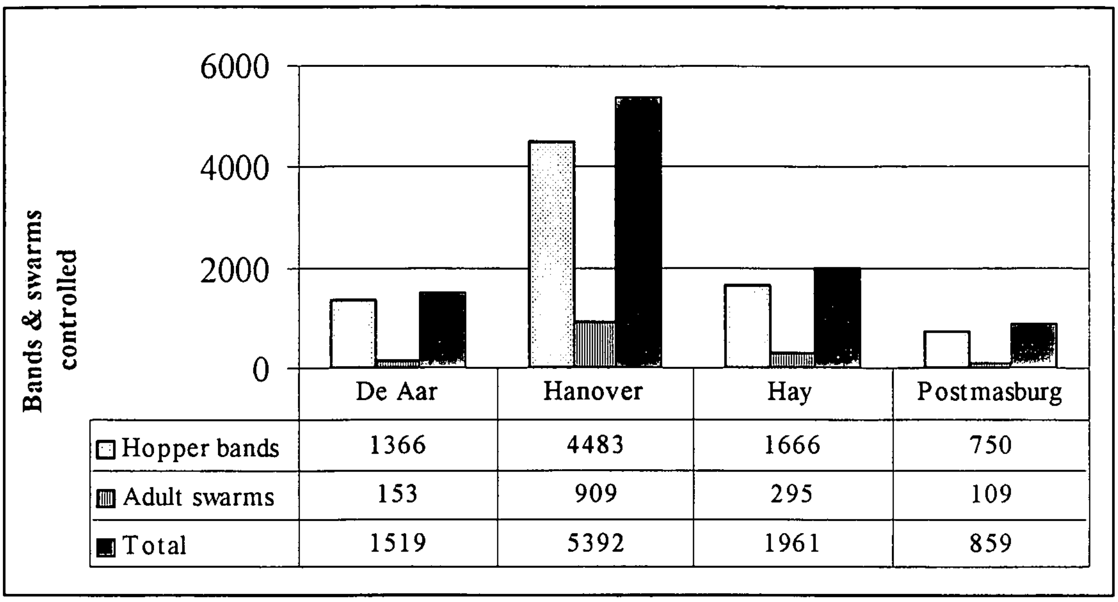


	P1	P2	P3	P4	P5	P6	Avg.
□ Adults	66	33	61	41	0	0	55
■ Hoppers	34	67	39	59	100	100	45

Figure 3.12 Percentage hopper versus adult locusts controlled by the supervisors in the Postmasburg district in the 1996/97 locust control campaign.

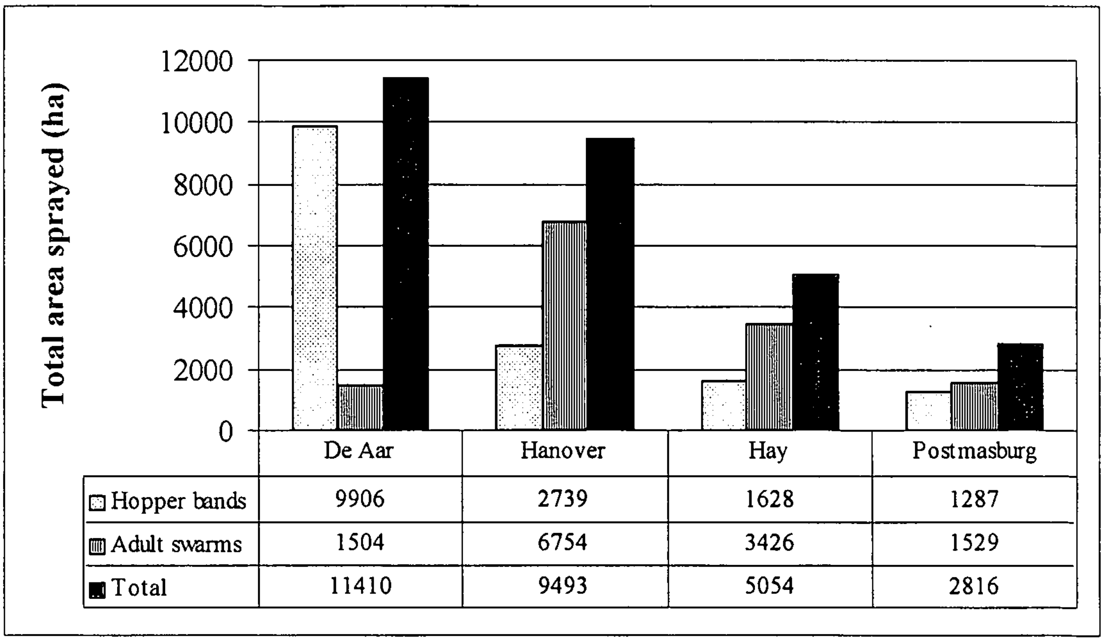
In figure 3.13 the relative numbers of bands and swarms controlled in the various districts are compared. The series are the campaign totals per district of the fields (in table 2.2) *#Bands* and *#Swarms*. In all the districts more hopper bands than adult swarms were controlled. Figure 3.13 only takes into account the number of bands and swarms controlled and do not take into account the actual sizes of the swarms or the number of locusts controlled per band or swarm. This is the reason for the apparent conflict among figures 3.9 to 3.12 where the number of locusts per bands or swarms was taken into account.

It is further evident from figure 3.13 that the highest number of bands plus swarms (total) was controlled in Hanover, followed by Hay, De Aar and Postmasburg. If this is compared with the number of bands or swarms per 100 hectare (table 4.1), Hanover still had the highest occurrence of locusts and Postmasburg the lowest. Due to the smaller size of De Aar district relative to that of Hay, De Aar had the second highest occurrence (or control action) of locusts in the four districts.



	De Aar	Hanover	Hay	Postmasburg
□ Hopper bands	1366	4483	1666	750
▥ Adult swarms	153	909	295	109
■ Total	1519	5392	1961	859

Figure 3. 13 The total number and number of hopper bands and adult swarms controlled in the four districts in the 1996/97 control campaign.



	De Aar	Hanover	Hay	Postmasburg
□ Hopper bands	9906	2739	1628	1287
▥ Adult swarms	1504	6754	3426	1529
■ Total	11410	9493	5054	2816

Figure 3.14 The total area sprayed and the area per hopper bands and adult swarms in the four districts in the 1996/97 control campaign.

In figure 3.14 the sum of the areas where bands and swarms were controlled in the four districts, as well as the combined areas are compared. In the De Aar district, hoppers were controlled on the largest area. This is in compliance with figures 3.9 to 3.12 where on average the number of hoppers controlled totalled a higher percentage than the number of adults controlled. In all the other districts the opposite was true. Figure 3.14 further emphasises that adult swarms were controlled on larger areas than hopper bands in Hanover, Hay and Postmasburg. The series are calculated by using the campaign totals per district of the fields (in table 2.2) *Bands Ha* and *Swarms Ha*. In Postmasburg the difference between the total areas of hoppers and adults controlled was the smallest. This is further emphasised in figures 3.9 to 3.12 where the difference in percentages between hoppers and adults controlled in Postmasburg was also the lowest of all districts.

From the total values in figure 3.14 it is evident that the largest total area (hopper areas + swarm areas) was in De Aar, followed by Hanover, Hay and Postmasburg.

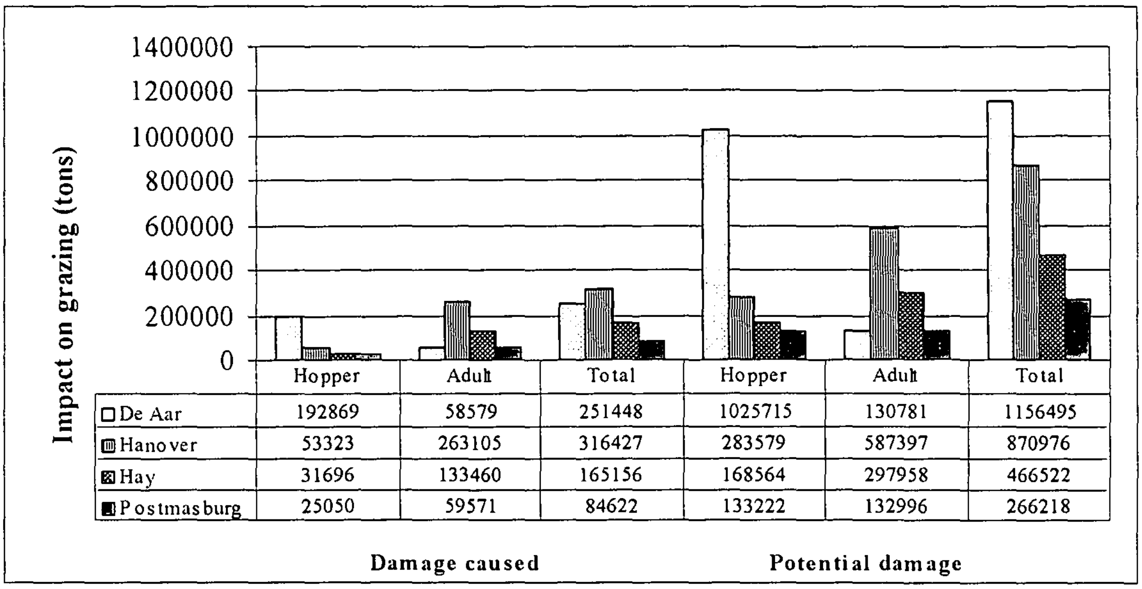
Table 3.1 Pesticide deposition criteria expressed as the amount of pesticide applied (g ai) per ten hectare in the four districts in the 1996/97 locust control campaign.

District	**g ai/10 Ha**
De Aar	1,602
Hanover	1,377
Hay	0,338
Postmasburg	0,005

The highest amount of active ingredient of deltamethrin per ten hectares was sprayed in De Aar, followed by Hanover, Hay and Postmasburg (table 3.1). The values were calculated by using the following formula:

$$g\ ai/10\ ha = \frac{\sum Quan * 6 * 10}{\sum DHa} \qquad (3.8)$$

"Quan" is the amount of pesticide applied in litre under the heading "Formulation used" in table 2.1 and summarises the total amount of pesticide applied in a particular district. This number is multiplied by 6, since deltamethrin is formulated at 6 g ai/l. This is divided by the total area of a district and multiplied by ten to produce the value: g ai/10 ha.



	Hopper	Adult	Total	Hopper	Adult	Total
□ De Aar	192869	58579	251448	1025715	130781	1156495
▥ Hanover	53323	263105	316427	283579	587397	870976
▩ Hay	31696	133460	165156	168564	297958	466522
■ Postmasburg	25050	59571	84622	133222	132996	266218

Figure 3.15 Impact on grazing in tons caused by the hoppers, adults and the total impact in the four districts in the 1996/97 control campaign.

In figure 3.15 the actual pasture damage caused by the locusts and the potential damage in the various districts are compared. The potential damage is the damage that could have been caused to grazing if the locusts were not controlled. To estimate the grazing impact, the hoppers were assumed to be in the late immature stages (instar five) and the swarms to be two weeks after maturity. This assumption works favourably in respect to damage caused, but conservatively in respect to the damage averted by control (Heyns *et al.* 1995; Van der Westhuizen & Botha, 1997).

The damage caused was calculated using column references R, S and T in table 5.3. The potential damage was calculated using column references U, V and W in table 5.3. From figure 3.15 the highest hopper impact was in De Aar, followed by Hanover, Hay and Postmasburg. The highest impact on grazing by adult locusts was in Hanover, followed by Hay, Postmasburg and De Aar. The exact same sequence can be found in figure 3.14 concerning the areas bands and swarms were sprayed on. This is due to the earliest parameter to have an effect on the actual or potential damage to grazing in table 5.3 (column references D and E), pertaining to the areas the bands and swarms were controlled on. Capiera (1987) and Pfadt & Hardy (1987), according to Legg, Lockwood, Kemp & Nolan (1993) stated that the damage done by grasshoppers to the forage resource is a function of the grasshopper community structure (species) and their density.

The potential damage to grazing in figure 3.15 is far greater than the actual damage caused. This further emphasises that it is more beneficial to the environment and the economy (column references X to AA in table 5.3) to control the locusts in the hopper stage.

Locusts are in direct competition with livestock (Schell, 1994). More grasshoppers were collected from fields heavily grazed by cattle than from lightly grazed fields (Nerney, 1960; Holmes, Smith & Johnston, 1979) and also on areas where shrub losses resulted from wildfires and other causes (Fielding & Brusven, 1993). Their presence thus further decreased the grazing capacity of the fields. Intraspecific and interspecific competition influence plant growth. The growth of plants after herbivory feeding would be relatively low in areas with abundant grass biomass (Quinn, Johnson, Butterfield & Walgenbach, 1993). The fact that the potential damage is greater than the actual damage also emphasises that the locusts are a real threat to the grazing in the Karoo and should therefore be controlled responsibly.

The data in the locust control database (table 2.1 and 2.2) was summarised per farm in each district and converted to a dBase ® format to be entered into ArcView® (Environmental Systems Research Institute). All the ArcView figures are imported and are unfortunately not on scale relative to the originals. The relative sizes of the districts as well as the codesets (identifying code) for each farm is displayed in appendices 1 to 4. In appendix 5 the relative sizes and positions of the four districts are displayed in relation to the other locust districts. Appendix 6 is a map of South Africa indicating the magisterial districts as well as the area involved in locust control in the 1996/97-locust campaign. The boundaries of the magisterial districts may differ somewhat from those of the locust districts. Figures 3.16 to 3.31 display locust associated criteria on farm level.

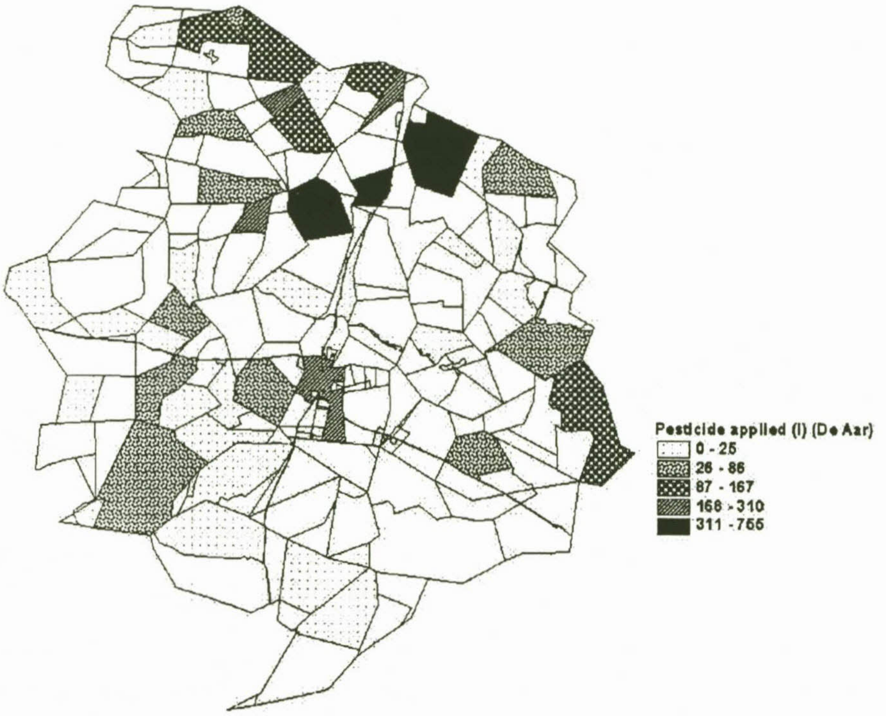


Figure 3.16 Pesticide applied per farm in the De Aar district during the 1996/97 locust campaign.

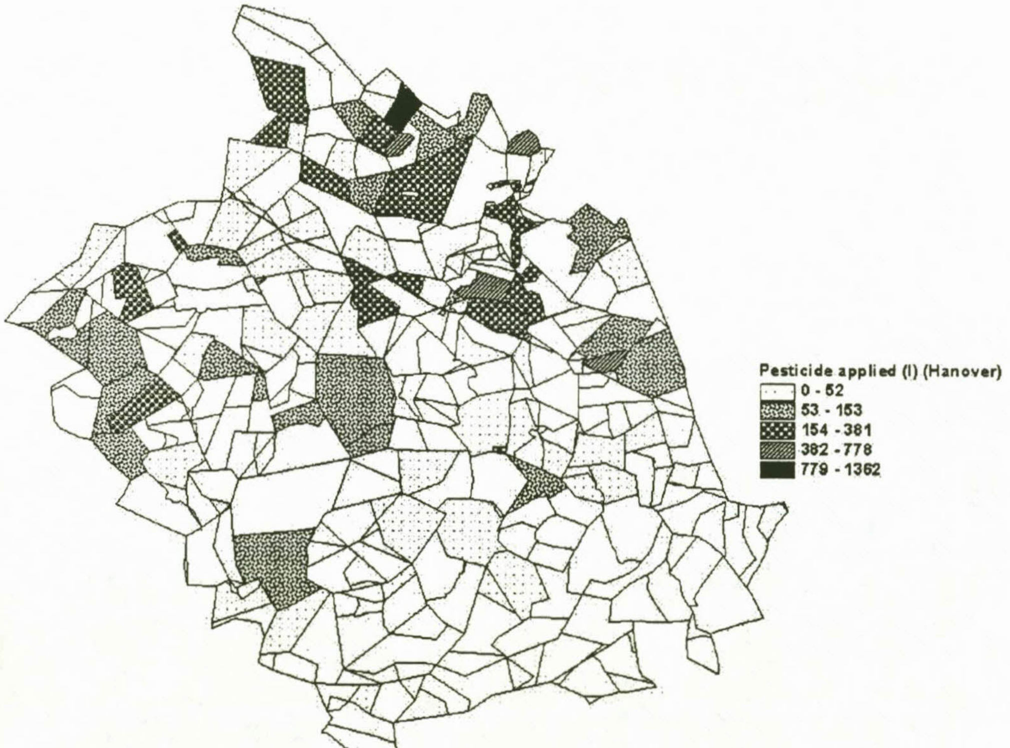


Figure 3.17 Pesticide applied per farm in the Hanover district during the 1996/97 locust campaign.

Figure 3.18 Pesticide applied per farm in the Hay district during the 1996/97 locust campaign.

The highest amount of pesticide applied in the different districts were recorded on the following farms. De Aar: PHI529 (755 litres), PHI503 (705 litres) and PHI484 (562 litres). Hanover: HAN49 (1362 litres). Hay: HAY956 (519 litres), HAY830 (239 litres), HAY1064 (236 litres), HAY762 (233 litres), HAY756 (221 litres). Postmasburg: HAY165 (41 litres). The highest amount of pesticide applied per farm was in the Hanover- and De Aar districts. Great differences in the amount of pesticides applied per farm occurred among districts (figures 3.16 to 3.19).

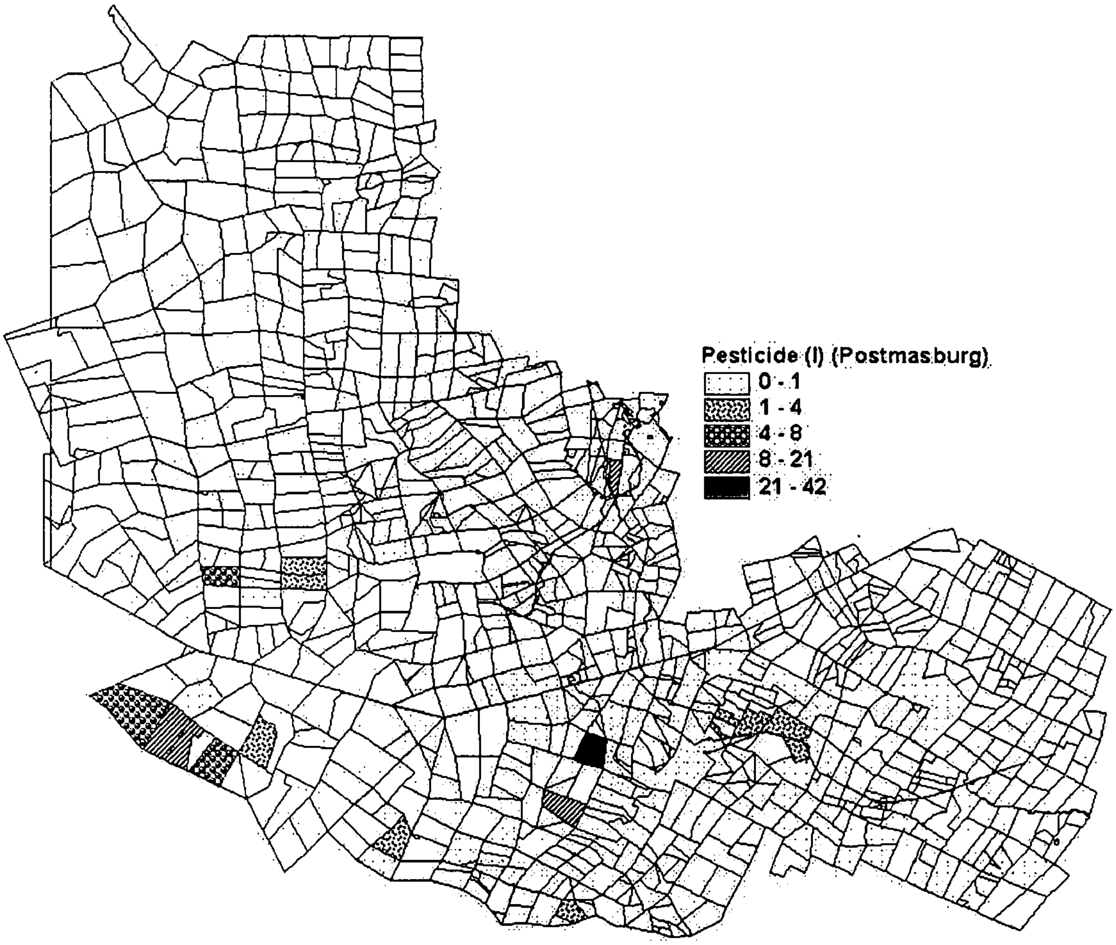


Figure 3.19 Pesticide applied per farm in Postmasburg during the 1996/97 locust campaign.

In figures 3.19 to 3.22 the percentages of the farms sprayed in the various districts is displayed. The farms on which the highest percentages in each district were recorded were as follows. De Aar: BRT298 (413,385). Hanover: HAN49 (231,05 %). Hay: HAY830 (24,94 %). Postmasburg: HAY258 (16,91 %). The highest values in Hay and Postmasburg were relative low in comparison with those in De Aar and Hanover.

The supervisors who recorded the control data used 1:250 000 topo-cadastral maps to obtain the positions of the swarms. These maps differed somewhat from the farm polygons in ArcView with respect to the most resent subdivisions of the farms. The old maps do not contain all the newest boundaries. When a supervisor allocated a

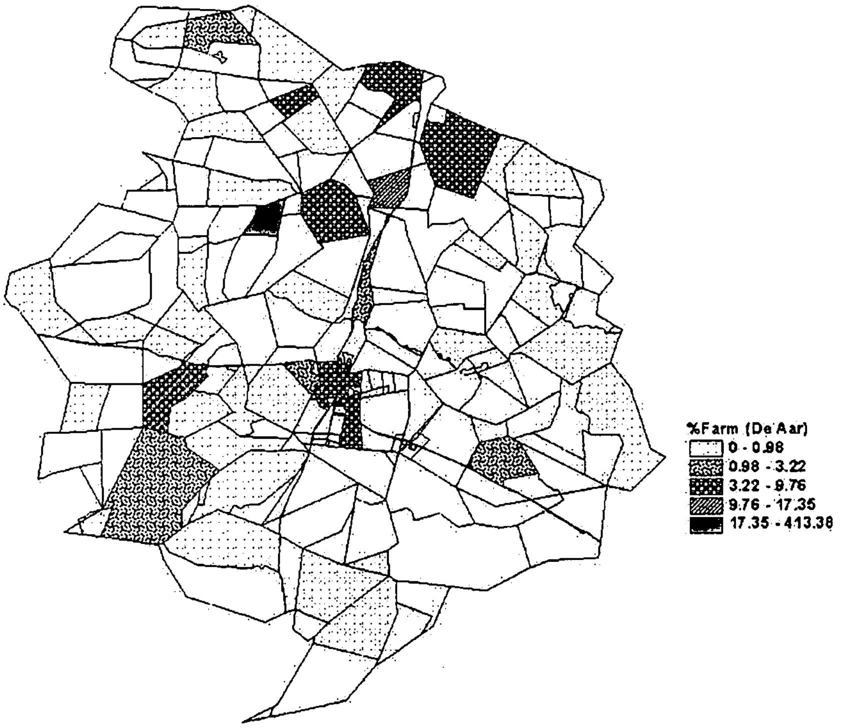


Figure 3.20 Percentage of the farms sprayed in De Aar in the 1996/97 campaign.

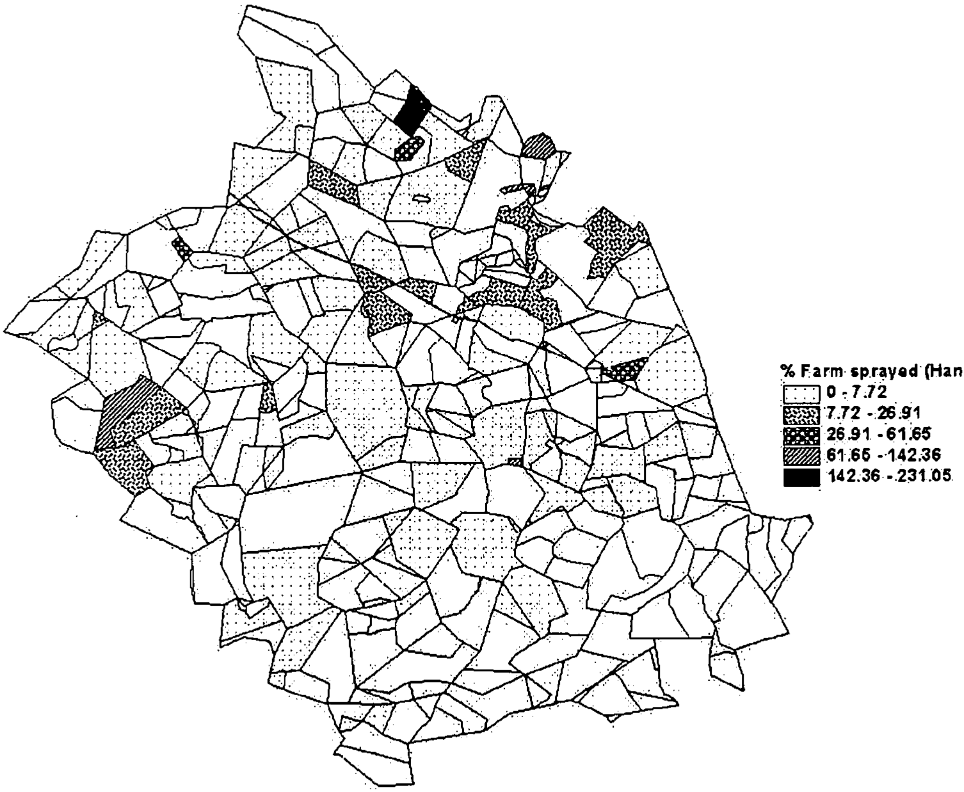


Figure 3.21 Percentage of the farms sprayed in Hanover in the 1996/97 campaign.

Figure 3.22 Percentage of the farms sprayed in Hay in the 1996/97 campaign.

swarm to a specific farm according to farm numbers on the old maps (1:250 000 topo-cadastral), that swarm could actually have been controlled on one of the adjacent subdivisions of the original farm. The recent ArcView maps were not available in 1996 and there was no way of knowing on exactly what subdivision the swarm was controlled. The swarms were in such cases allocated to the farm polygon on or to the nearest polygon the supervisor had indicated on the control information details. This could have resulted in the two farms in De Aar and Hanover having had such high percentages sprayed. In future campaigns supervisors will be equipped with the latest ArcView maps eliminating these discrepancies.

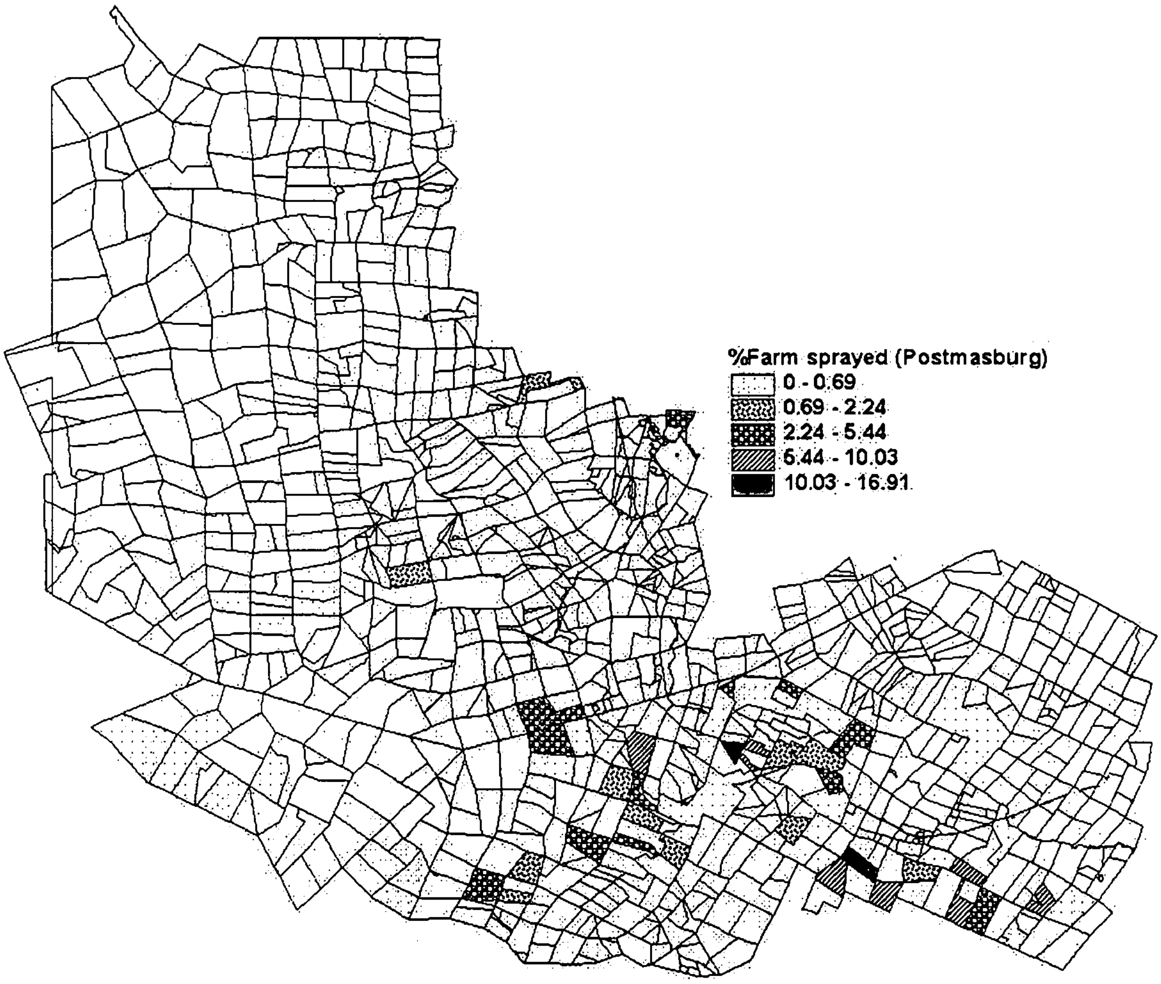


Figure 3.23 Percentage of the farms sprayed in Postmasburg in the 1996/97 campaign.

Figures 3.24 to 3.27 show the total number of bands and swarms controlled on each farm. Some of the highest numbers per district were as follows. De Aar: PHI503 (108). Hanover: HAN221 (443). Hay: HAY852 (101), HAY830 (78). Postmasburg: HAY70 (83).

In all the districts more hopper bands than adult swarms were controlled (figure 3.13). The highest number of bands and swarms were controlled in Hanover, followed by Hay, De Aar and Postmasburg.

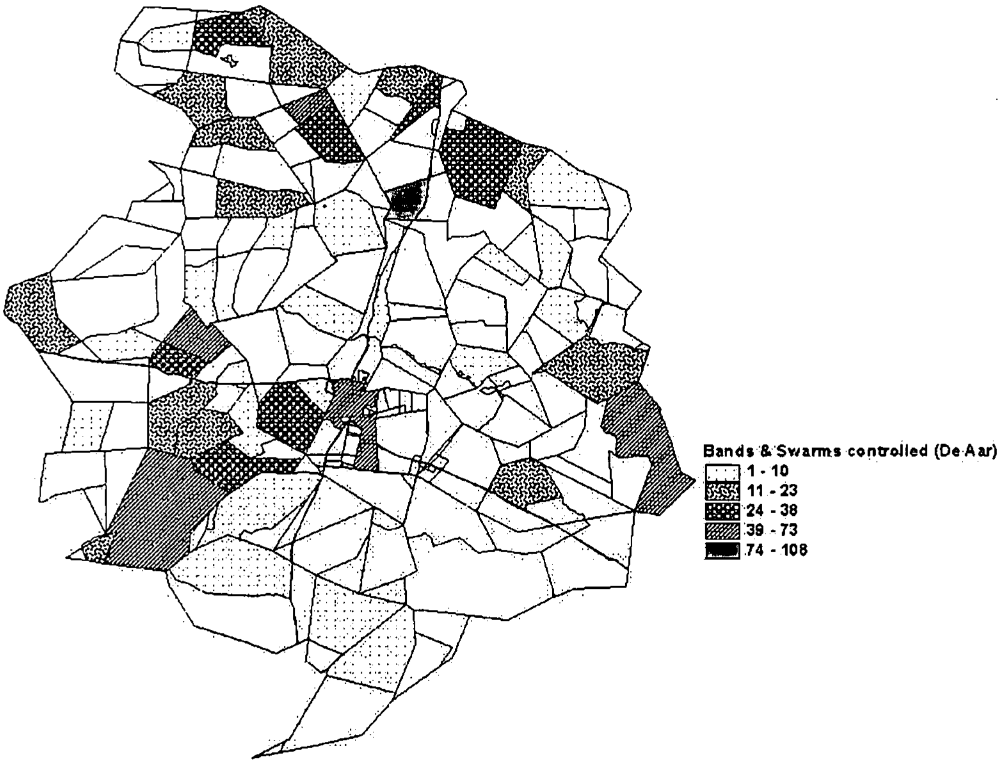


Figure 3.24 Total number of bands and swarms controlled per farm in De Aar in the 1996/97 campaign.

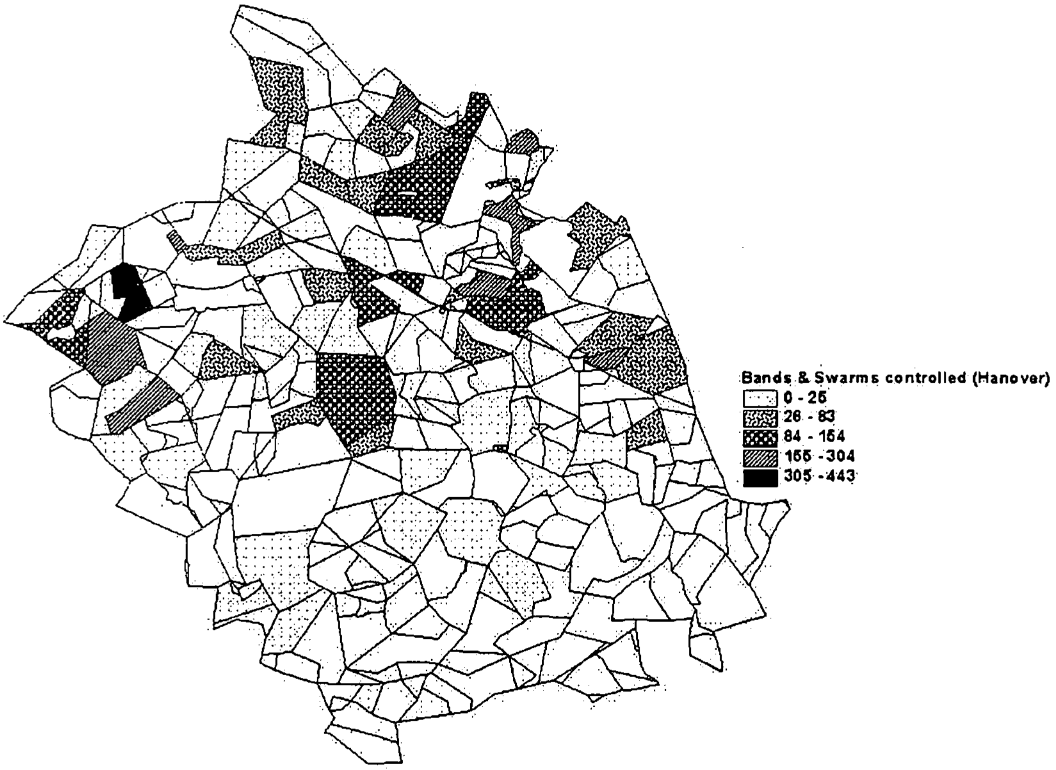


Figure 3.25 Total number of bands and swarms controlled per farm in Hanover in the 1996/97 campaign.

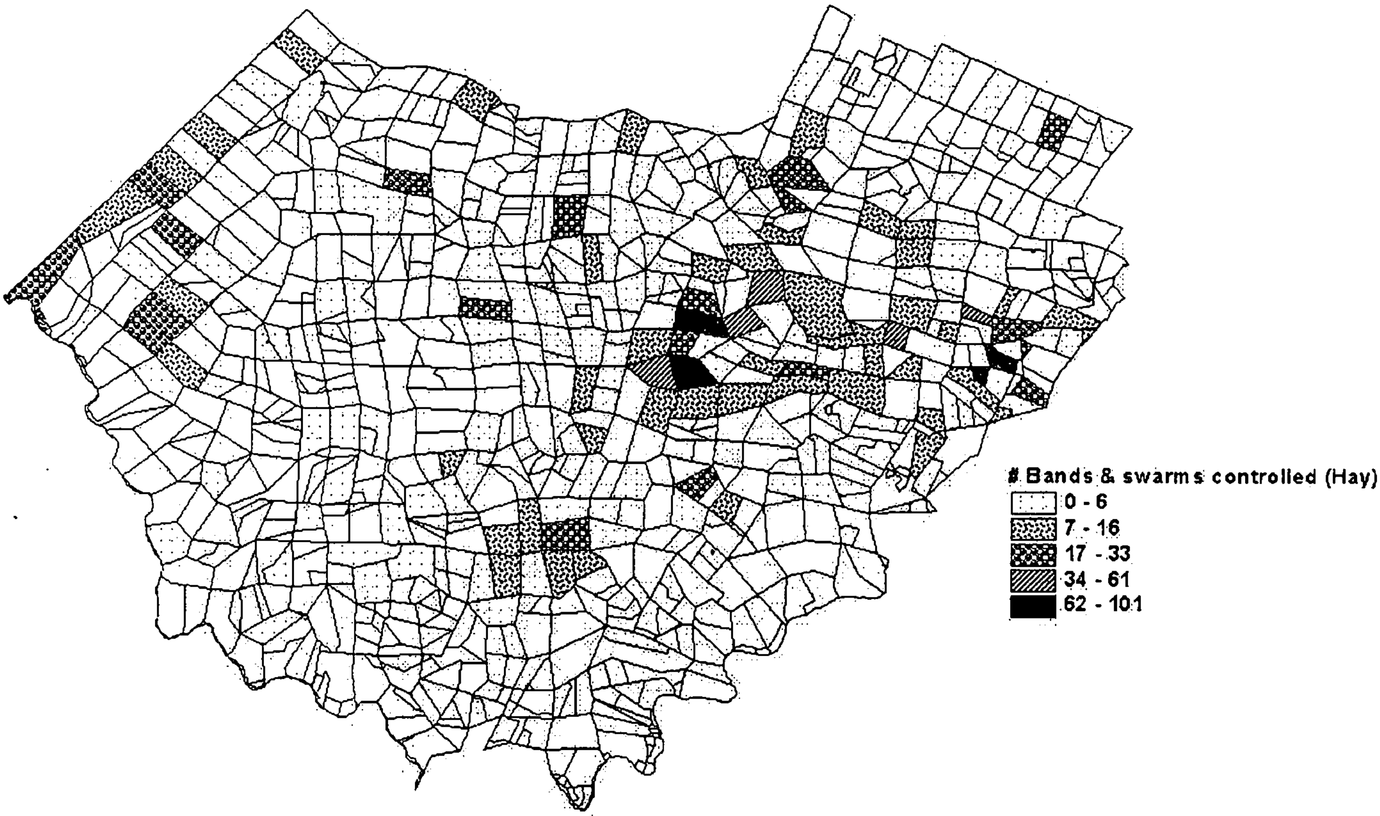


Figure 3.26 Total number of bands and swarms controlled per farm in Hay in the 1996/97 campaign.

In the De Aar, Hanover and Hay districts the control actions were distributed throughout the district, but in Postmasburg it was restricted to the southern parts. In all the districts some farms show heavy control activities with adjacent farms of no control at all. This is especially true for the De Aar and Hanover districts.

Due to the vastness of some districts and the inaccessibility of some terrain as well as the fact that huge areas are uninhabited (Anon, 1989; Hanrahan & Horne, 1997), it can be expected that some bands do escape control. By using control data from this and previous campaigns, these risk areas can easily be mapped and monitored for future reference.

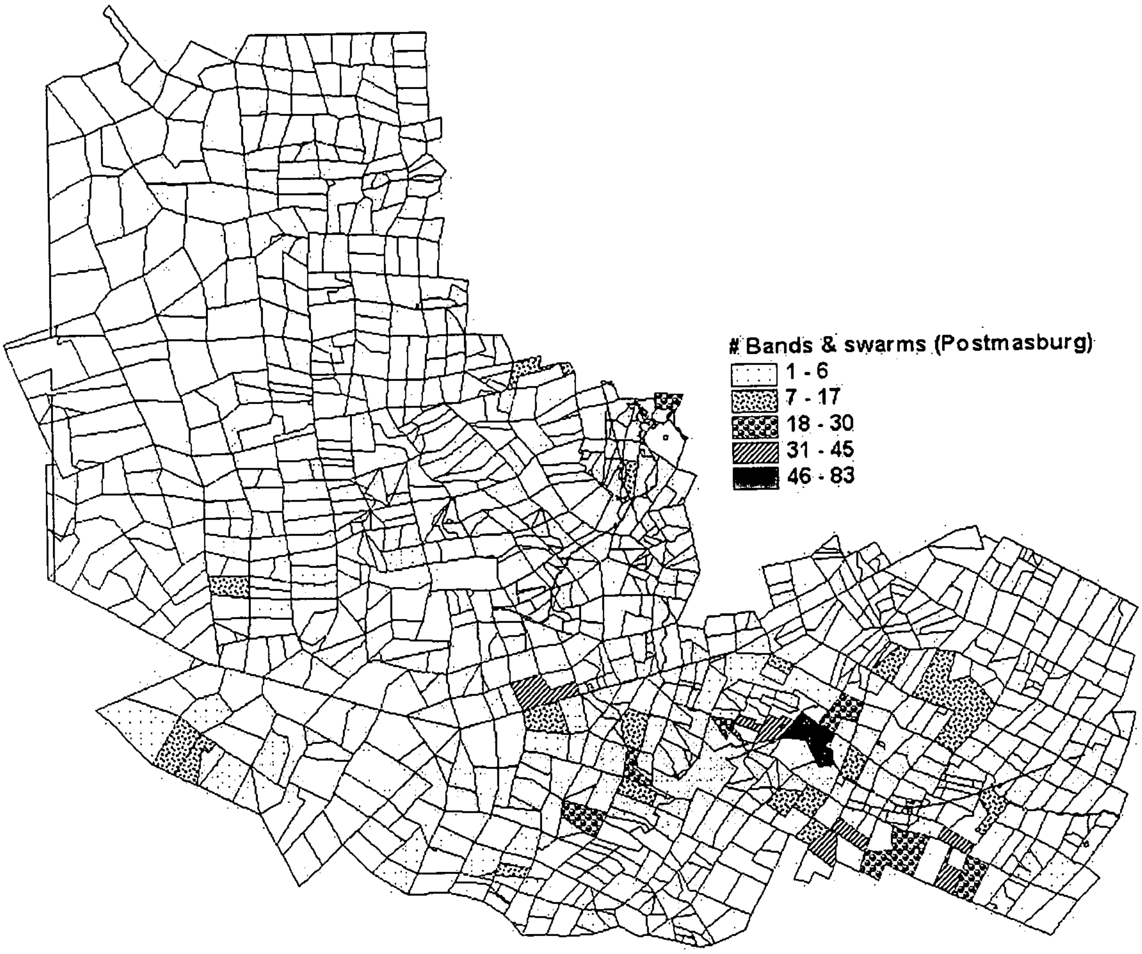


Figure 3.27 Total number of bands and swarms controlled per farm in Postmasburg in the 1996/97 campaign.

The number of locusts controlled per farm in each district (figure 3.28 to 3.31) was calculated taking into account the area sprayed and the number of locusts controlled per square metre. Van der Westhuizen & Botha (1997) used an average of 295 hoppers and 302 adults per square metre in their calculations of the total number of locusts controlled. These numbers can be calculated using column references N and O in table 5.3.

Some of the highest numbers of locusts controlled per district were as follows. De Aar: BRT298 (12 857 690 265). Hanover: HAN49 (9 697 979 791). Hay: HAY830 (872 390 630). Postmasburg: HAY258 (890 149 272), HAY49 (389 963 450).

Figure 3.28 Total number of locusts controlled per farm in De Aar in the 1996/97 campaign.

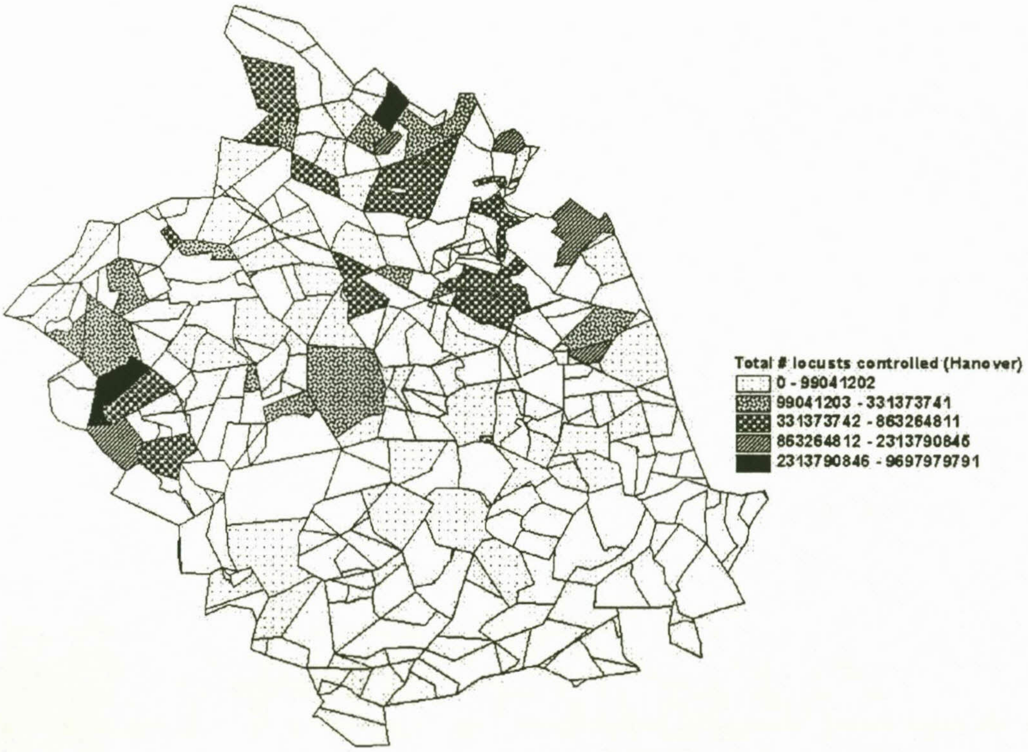


Figure 3.29 Total number of locusts controlled per farm in Hanover in the 1996/97 campaign.

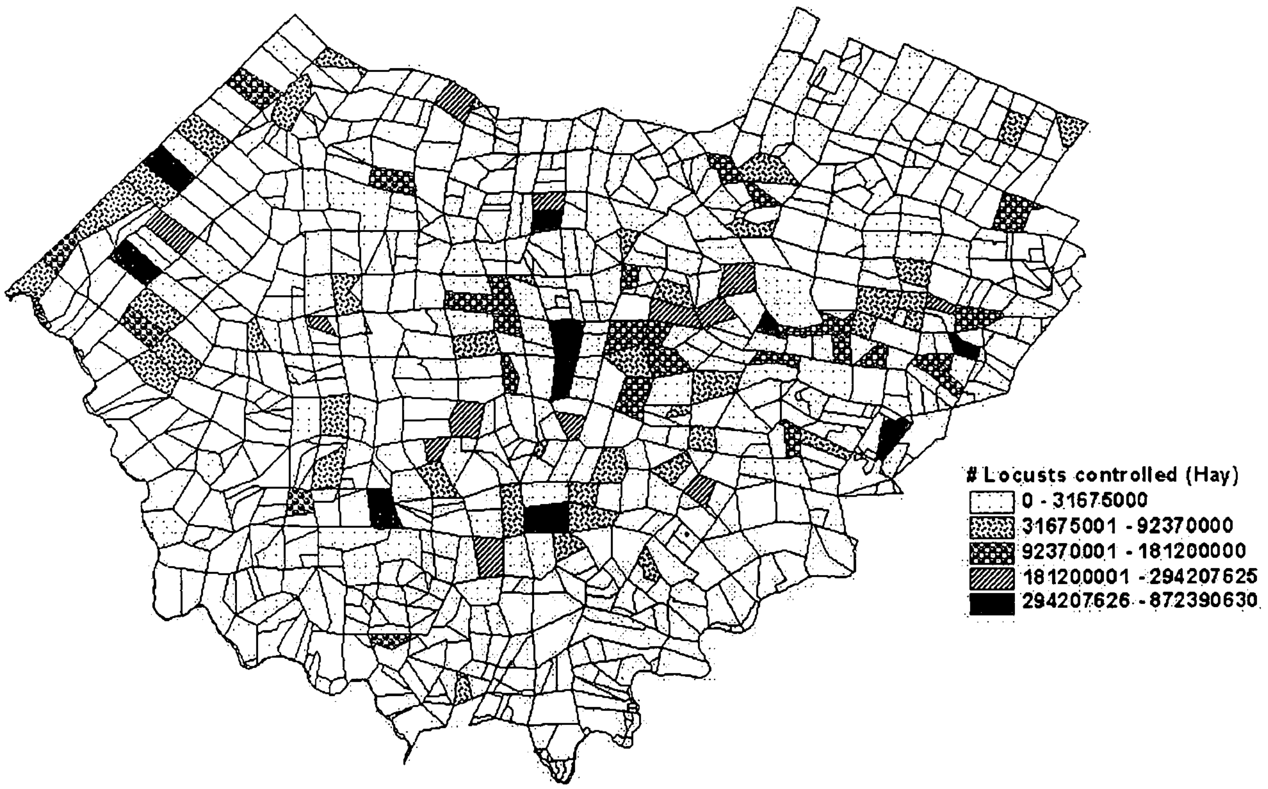


Figure 3.30 Total number of locusts controlled per farm in Hay in the 1996/97 campaign.

The highest number of locusts controlled on a single farm was over 12 000 million in De Aar. In Hay and Postmasburg lesser numbers were controlled per farm. This further emphasises the extent of the locust outbreaks in De Aar and Hanover districts (table 4.1).

The highest numbers of locusts were recorded on farms indicating the highest control activities (percentage of farm sprayed). This was true for all the districts. Farm HAY830 in the Hay district was also listed in the top class concerning the number of bands and swarms controlled.

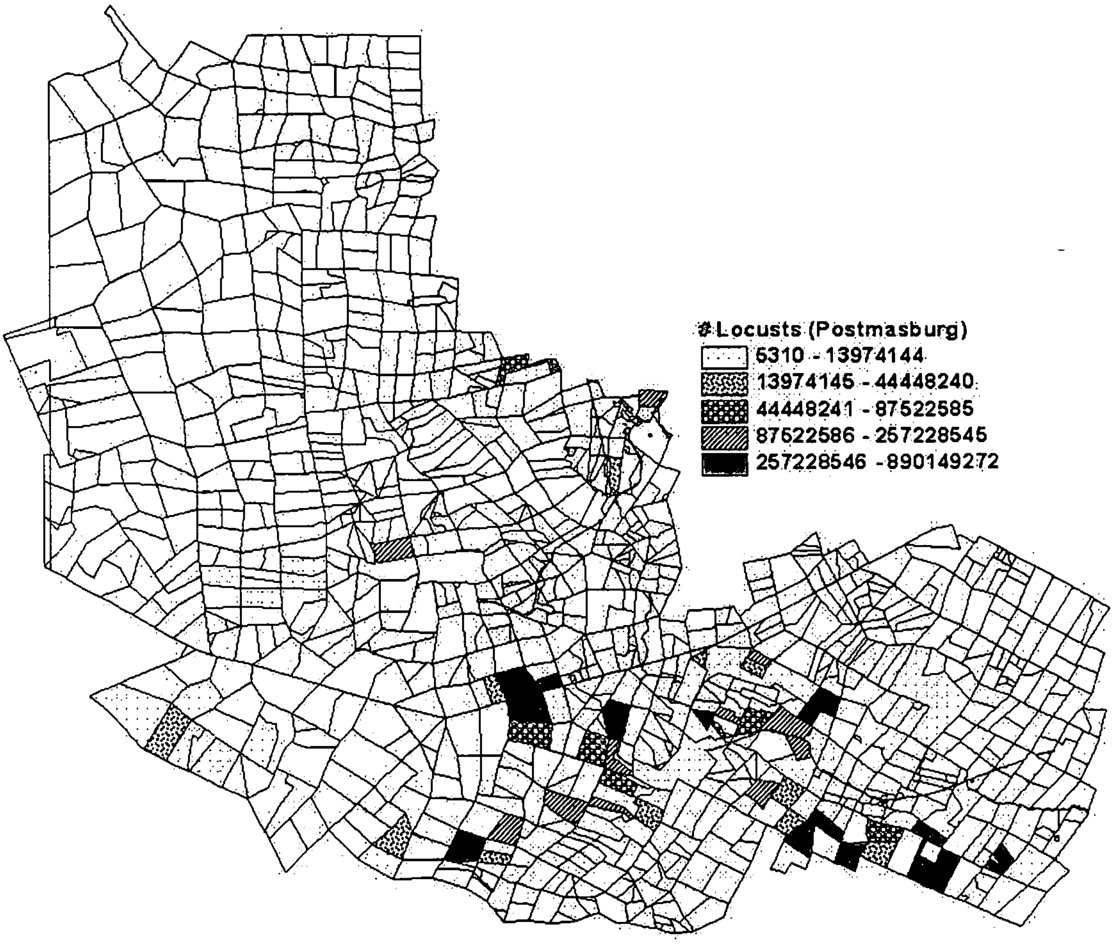


Figure 3.31 Total number of locusts controlled per farm in Postmasburg in the 1996/97 campaign.

The percentage of a district sprayed was calculated by dividing the total number of hectares sprayed in a district by the district area (ha) (x 100). The highest percentage of a district was sprayed in Hanover, followed by De Aar, Hay and Postmasburg (figure 3.32). The same order is indicated in table 4.1 with respect to the average number of bands or swarms controlled per 100 hectares of the district.

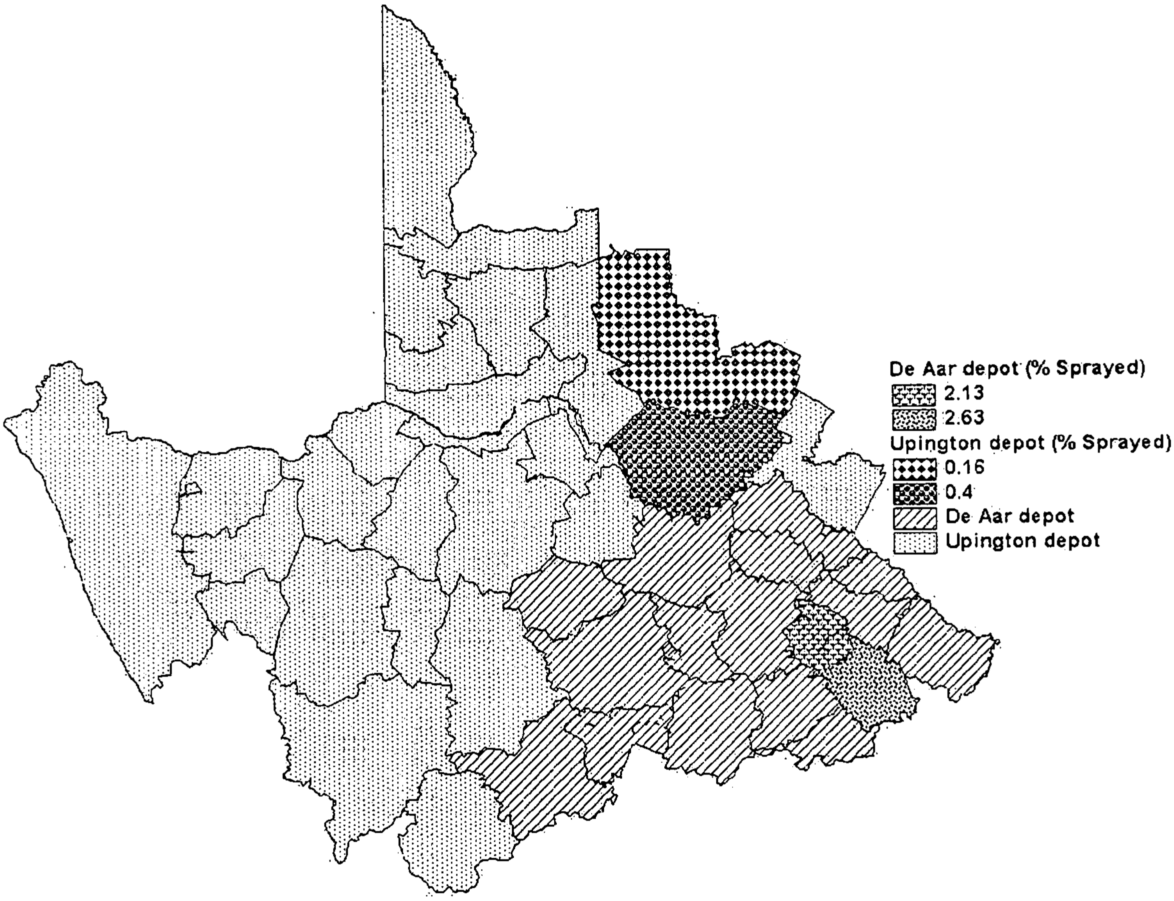


Figure 3.32 Total percentage of the four districts sprayed in the 1996/97 locust control campaign.

The lifestock carrying capacity (number of hectares per large stock unit) was calculated based on the Putu15 model which was developed to determine the production potential of *Themeda veld* in a semi-arid climate (Howard, 1997). Only the farms on which control actions occurred during November 1996 in the Hanover district, were indicated in figures 3.33 and 3.34. The damage by the hopper bands and adult swarms were calculated using column references R, S and T in table 5.3. These values were converted to the number of kilograms of grazing removed by the locusts per farm for the period of time.

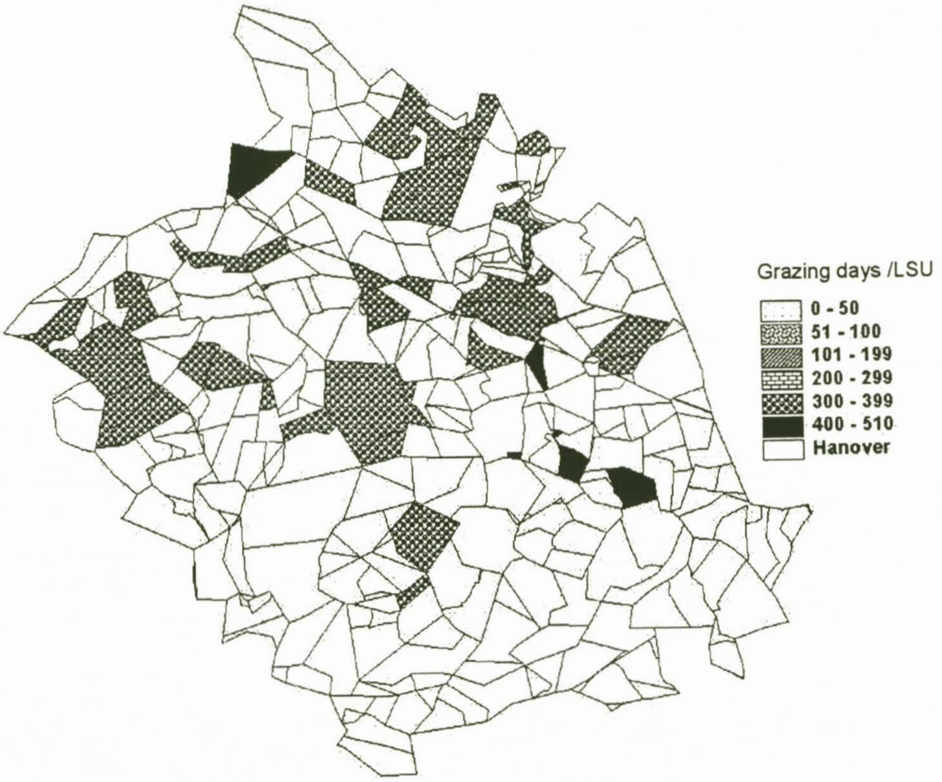


Figure 3.33 Grazing days per large stock unit (LSU) during November in the Hanover district before locust impact.

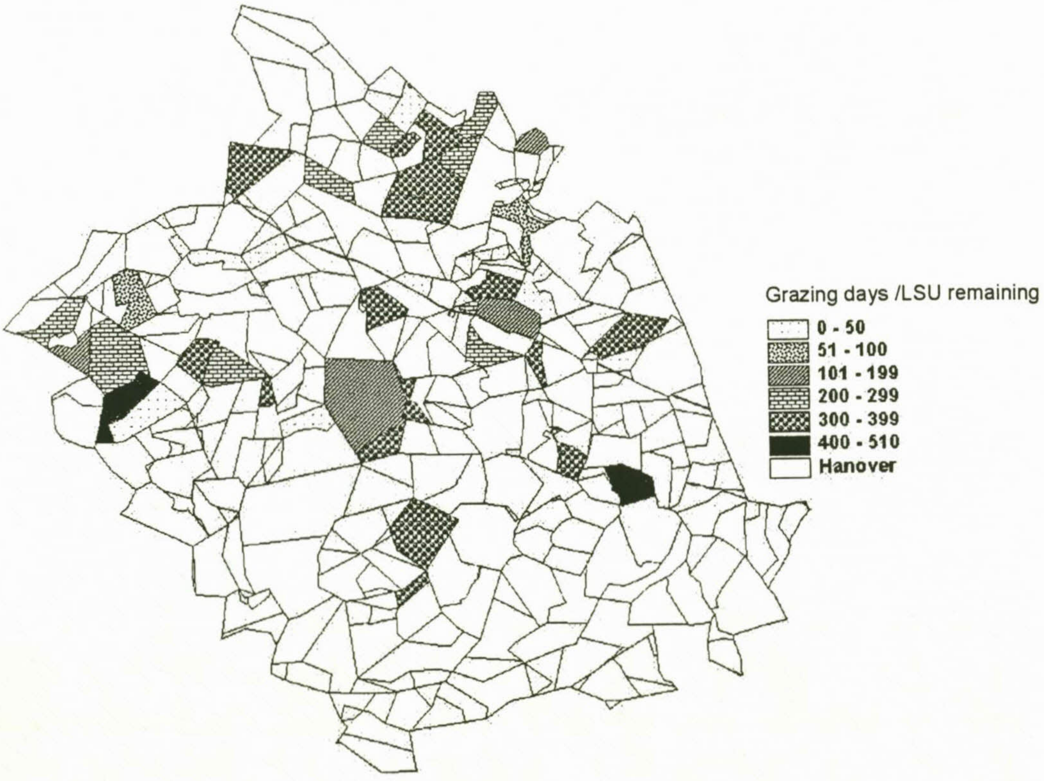


Figure 3.34 Grazing days per large stock unit (LSU) remaining after locust impact during November 1996 in the Hanover district.

The data obtained from the Putu 15 model was expressed as the amount of dry matter (kilogram) produced per hectare for each farm. This was multiplied by the total area (ha) for each farm to calculate the total amount of grazing available for any particular farm. The damage by the locusts (column reference T in table 5.3) was subtracted from this value to result in the amount of grazing remaining after locust damage. Division of this value by the total area (ha) of a farm resulted in the amount of dry matter (kg) per hectare left after locust damage. It was established that a large stock unit (LSU) requires 12 kg per day for maintenance and growth (Howard[2], pers. comm.). The amount of dry matter per hectare left was divided by 12 kg/day to determine the number of grazing days/ha left after locust impact. The grazing capacity of the Hanover district is 18 hectares per LSU (Fouche,[3] pers. comm.). By multiplying the number of grazing days/ha left after locust damage by 18 ha/LSU, the number of grazing days per LSU for each farm was estimated (figure 3.34). The number of grazing days per LSU before locust damage was calculated using the same procedure as explained, with the exception that no locust damage was subtracted (figure 3.33).

The severe damage caused by the locusts is furthermore illustrated (figures 3.33 and 3.34) with the emphasis on the number of grazing days per LSU. The impact of the locusts was more intense on some farms than other. It depended on the number and sizes of the swarms controlled. Some of the farms had implicitly no grass cover left after the locust damage. For the majority of the farms the number of grazing days/LSU was greatly reduced. This implies that the farmers probably had to resort to alternative and more expensive feed to sustain their livestock. This should be considered as very serious, especially in the light of the fact that locusts were controlled until March 1997 in the Hanover district (table 4.2).

Although the commando system of locust combat is very efficient, it would still be valuable to have an appropriate early warning system for future outbreaks. The brown locust is capable of laying both diapause and non-diapause eggs which do not hatch simultaneously after rain in favourable conditions. This then causes the delayed hatching of the eggs which makes predictions of outbreaks very difficult (Smith,

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[3] Dr. H.J. Fouché, ARC. RGI, Bloemfontein.

1964). Predicting outbreaks is furthermore hampered by the cyclic nature of brown locust outbreaks where the cycles can vary from seven to eleven years (Smith, 1964, Botha & Lea, 1970b and Anon, 1998d).

During this study no data on egg-pod deposition during previous seasons as well as egg bed depletion was available. These in combination with climatic and historical data are important factors in establishing a possible early warning system for locust control. This system however aims to demonstrate that with the incorporation of such mentioned data with basic data, an early warning system with a relatively high level of accuracy can be established.

Bryceson and Wright (1986) used satellite data in conjunction with a locust simulation model to detect areas suitable for locust breeding. Remote sensing of soil moisture within the natural outbreak area of the brown locust in conjunction with a potential breeding activity factor could provide a general assessment of potential breeding conditions. This could play an important role in predicting and controlling these insects (Nailand, 1993). Monitoring needs to take more account of satellite-based surveys of rainfall and growth of vegetation (Pedgley, 1987). A number of early warming systems taking these factors into account and operating on a huge scale is currently been researched by some scientists (Hanrahan & Tilch, 1996; Cressman, 1997; Hanrahan & Horne, 1997; Magor & Pender, 1997; Anon, 1998c; Anon, 1999b).

Outbreaks occur during years of plenteous rain after periods of drought (Smith 1939; Lea 1958; Smith 1964; Mattson & Haack 1987; Nailand & Hanrahan; 1993). As little as 6,25 to 10 mm of rainfall is needed to induce the hatching of eggs (Smith, 1941; Anon, 1998d). At least 25 mm of effective rainfall per month is required for complete and general hatching of eggs (Du Plessis, 1939). Considering the whole biology of the locusts, there seems to be no simple relation between rainfall and swarming (Botha & Lea, 1970b; Annecke & Moran, 1982). The brown locust is remarkably well adapted to the irregular rainfall and temperature extremes found in the Karoo. Much of its success is related to the physiology and development of the egg stage (Nailand & Hanrahan, 1993).

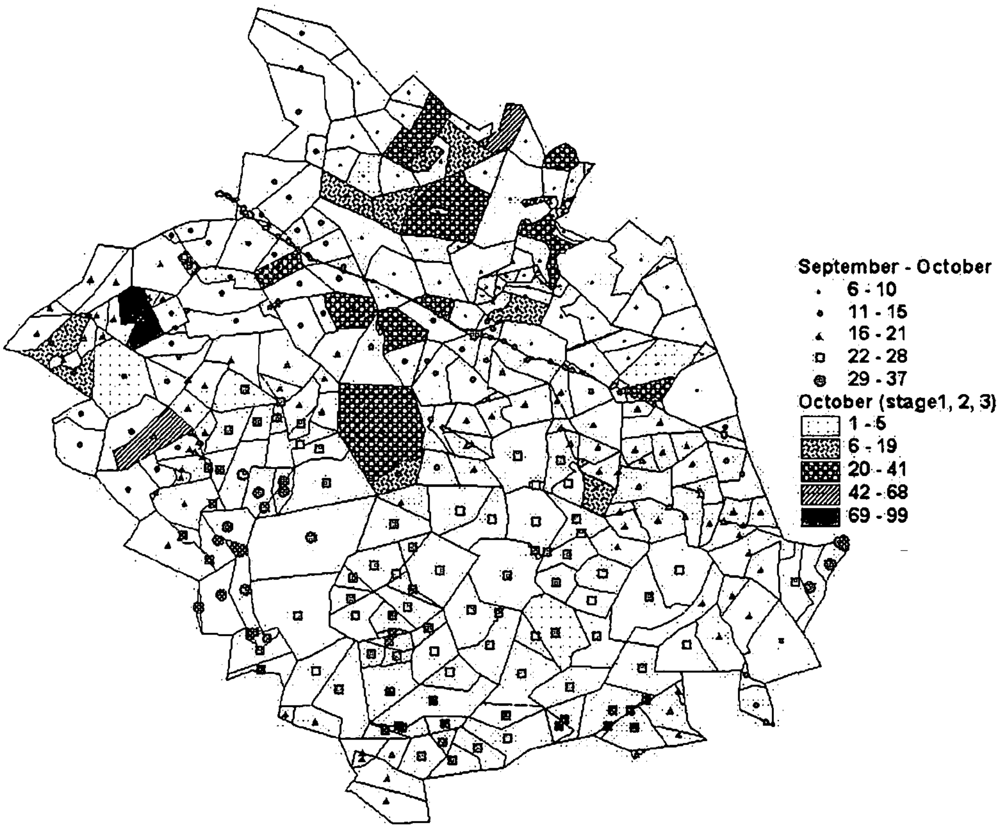

Figure 3.35 Cumulative rainfall (mm) during September and October 1996 and the number of hopper bands (in stages 1, 2 and 3) controlled in the Hanover district.

With this problem in mind, but with the realisation that rain is needed for the eggs to hatch, rainfall data (obtained from Howard[4]) was linked with control data (table 2.1 and 2.2) to visualise any resemblance (figure 3.35). After sufficient rainfall and with the right temperatures, eggs hatch in about nine days (Smith, 1964).

Each of the hopper instars last an average of about eleven days (Faure, 1923; Heyns *et al.*, 1995). To incorporate the effect of delayed hatching (Smith, 1964), the cumulative rainfall for September and October 1996 was viewed in conjunction with the control actions in October 1996 in the Hanover district. Hopper stage 1 comprised of instars 1, 2 and 3. Stage 2 is represented by instar 4 and stage 3 is hopper instar 5.

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[2] Dr. M.D. Howard, Department of Agrometeorology, UOFS, Bloemfontein.

Most of the bands (stages 1 to 3) were controlled on farms that only received little rainfall (6–10 mm). These numbers were however sufficient for the eggs to hatch (Anon, 1998d). Some of the bands were also controlled on farms that received rainfall with numbers belonging to the higher of the five rainfall classes.

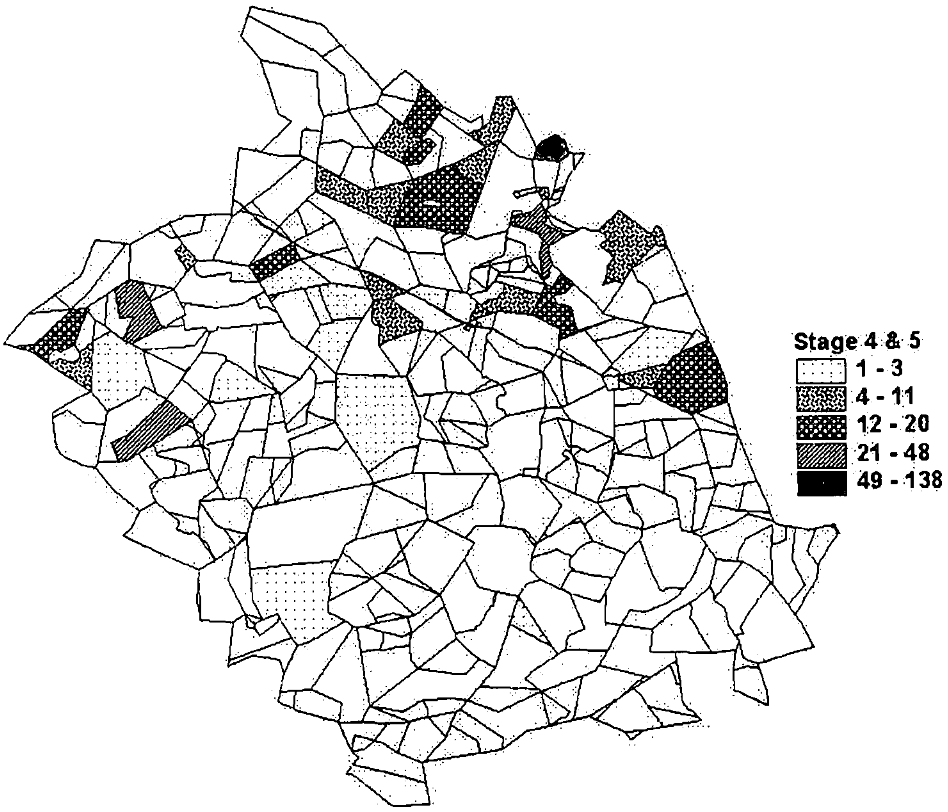


Figure 3.36 Farms showing locusts (stages 4 and 5) controlled close to the end of the 1996/97 campaign in the Hanover district.

According to Lea (1958), locust increases and decreases are closely related to the amount of early summer rainfall (July to December) and not to that of the late summer or the season as a whole. Locust increases most often follow a season in which the early summer rainfall was low.

Stage 4 locusts are transitional swarms in which both fifth instar hoppers and young adults occur. Stage 5 locusts are the adults with eggs. This is the most dangerous instar with regards to future campaigns. Stage 6 is the adult locusts without eggs which probable already have laid their eggs. Adult swarms might have been missed the attentive eyes of the supervisors in the cases of stage 4 locusts. For this reason the farms on which both stage 4 and the very important stage 5 locusts were controlled during the 1996/97 campaign in Hanover, is displayed in figure 3.36.

These are the farms that should receive special attention in future campaigns, because they are the most probable farms with locust eggs and potential of egg hatching under optimal conditions. Attention should be given to the five classes the stages were classified in. The higher the number of swarms controlled on a farm, the higher the probability that eggs were laid. This of course increases the possibility for future outbreaks on that farm.

It should be kept in mind that gregarious brown locusts lay mostly non-diapause eggs, which can survive in the soil for up to two years (Faure, 1923 & Botha, 1969b; Anon, 1998d). This, combined with the delayed hatching of the eggs (Smith, 1964) makes specific predictions of future outbreaks very difficult. Botha (1970c) stated that "......it seems unlikely to find any short cuts to the control of the brown locust. We shall periodically be faced with extensive outbreaks that will have to be attacked with poisons."

The use of vehicle in the combating of locusts can also be regarded as an environmental impact on grazing. At the same time it can be used as a measurement of control efficiency. In an attempt to analyse the relationship between control input (distance travelled) and control output (bands and swarms controlled) Zar's multiple regression analysis (Zar, 1974) was conducted on the data obtained for the four districts (table 3.2) Zar's method of multiple regression analysis compares the slopes and elevations of the linear regressions (Zar, 1974).

Table 3.2 Statistical analysis of the number of kilometres driven to control the bands and swarms in the four districts, where x = number of bands & swarms controlled, y = kilometres driven, n = number of co-ordinates and b = slope.

District	Regression nr.	SUM X^2	SUM XY	SUM Y^2	n	b	Residual SS	Residual DF	R	R^2
De Aar	1	74684	1327433	45328570	42	17.8	21734725	40	0.72	0.52
Hay	2	95139	2084871	116382412	67	21.9	70694718	65	0.63	0.39
Postmasburg	3	62709	1190378	26012574	15	19.0	3416129	13	0.93	0.87
Combined	1, 2, 3	242227	4603319	187790909	124	19.0	100308735	122	0.68	0.47
Hanover	4	929424	6331055	52506499	30	6.8	9380575	28	0.91	0.82
Pooled regression							105226147	146		
Common regression		1161956	10933738	240230057		9.4	137346090	149	0.65	0.43
Total regression		1677718	15110961	274766923	154		138664675	152	0.70	0.50

Slopes

	Hay	Postmasburg	De Aar
Hanover	▨	▨	▨
De Aar	☐	☐	
Postmasburg	☐		

Elevations

	Hay	Postmasburg	De Aar
Hanover	☐	☐	☐
DeAar	☐	☐	
Postmasburg	☐		

▨ Significant difference ($p < 0,05$)

☐ No significant difference ($p \geq 0,05$)

The values were tested at $\alpha = 0,05$. There were statistical differences between the slopes (F = 14,9), but no statistical difference was found between the elevations (F = 0,5) of the four districts. Hanover was the only district that differed statistically from the others with regards to the slopes (table 3.2). Since there were no statistical difference between De Aar, Hay and Postmasburg, these three districts were also represented in a combined regression (figure 3.37).

Supervisors in the Hanover district drove on average 6,8 kilometres to control a band or swarm, while supervisors in the other districts drove 19 kilometres (b-value of the combined regression) to control the locusts. The analysis was done taking in account only those kilometres driven where actual control took place. Kilometres driven for scouting of the locusts were not taken into account.

According to the analysis the distance driven by the supervisors within the Hanover district differed significantly from the remaining, indicating a either better positioning of the supervisors relative to the locusts or a saving in travelling by rather using knapsacks for application purposes.

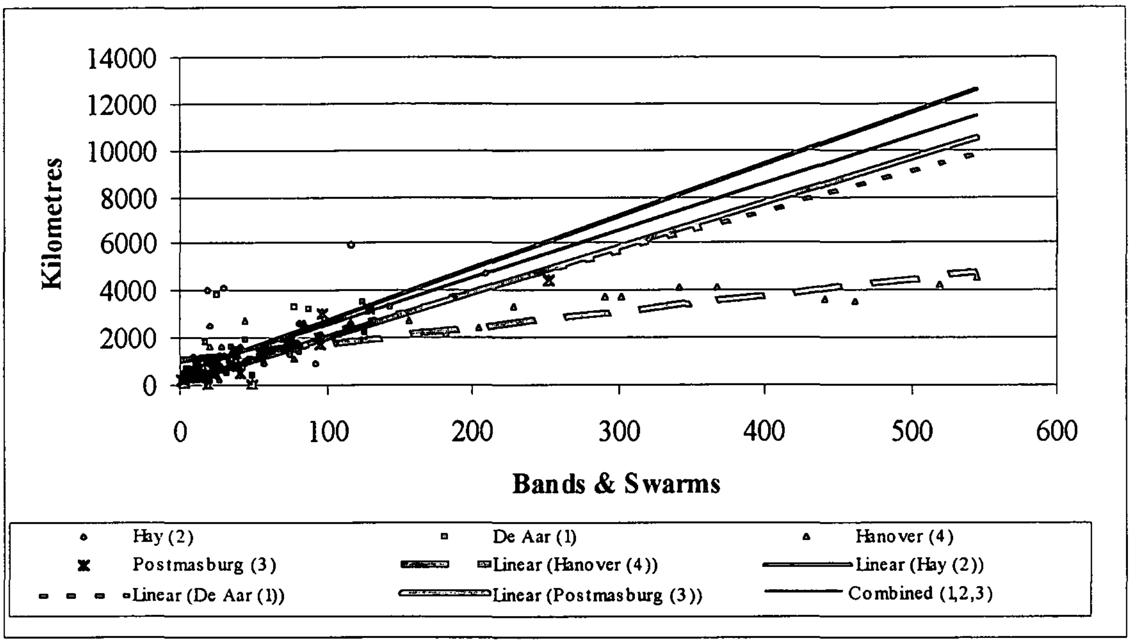


Figure 3.37 Relationship between kilometres driven and number of hopper bands and adult swarms controlled in the De Aar, Hanover, Hay and Postmasburg districts in the 1996/97 locust control campaign.

Chapter 4

Criterion: Manpower

Introduction

The periodic nature of the locust problem in South Africa excludes die existence of a permanent control infrastructure (Brown, 1988) and temporary labourers are employed in seasons of locust outbreaks. Strict rules should be applied to prevent the exploitation of the matter. The temporary labourers can easily be exploited or under utilised.

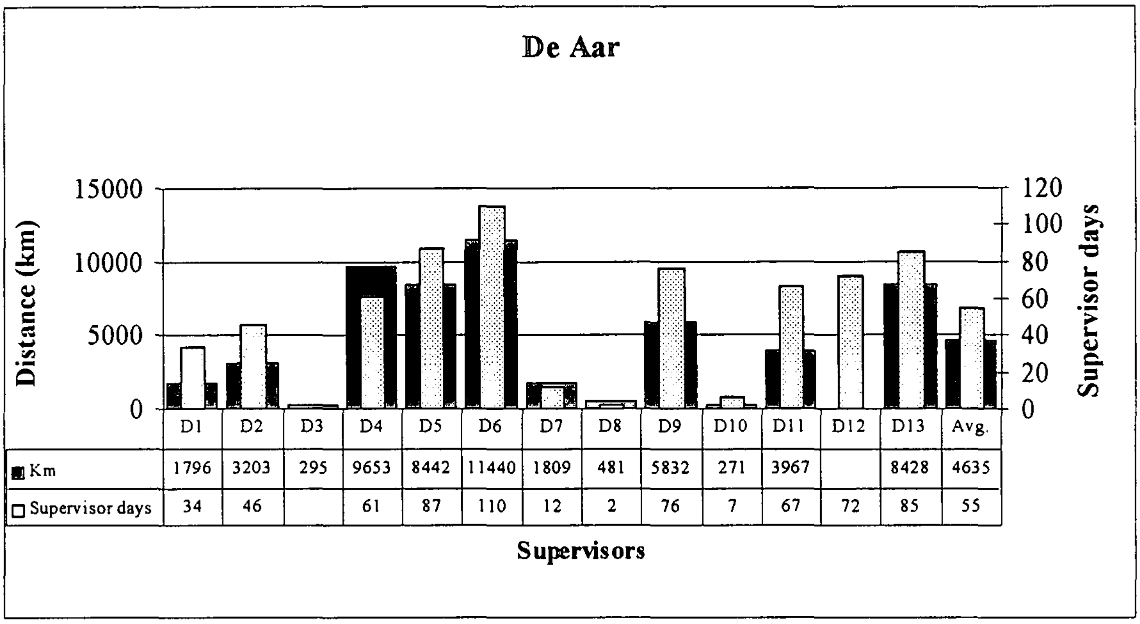
A ranking system exists where the district locust officer (DLO) administers the campaign in his appointed locust district. Several supervisors are appointed by the DLO to conduct the campaign in the district and reports directly to him. The supervisors normally employ from zero to five assistants to help them combat the locusts. The supervisors and assistants are not necessarily employed for the total duration of the campaign and are appointed as needed.

Since the areas of the various locust districts within the endemic region differ considerably in size and locust infestation rates, great care should be taken in analysing the manpower utilisation.

The aim of chapter 4 is to analyse the utilisation of manpower in the 1996/97 campaign and to develop guidelines for effective manpower utilisation in future campaigns.

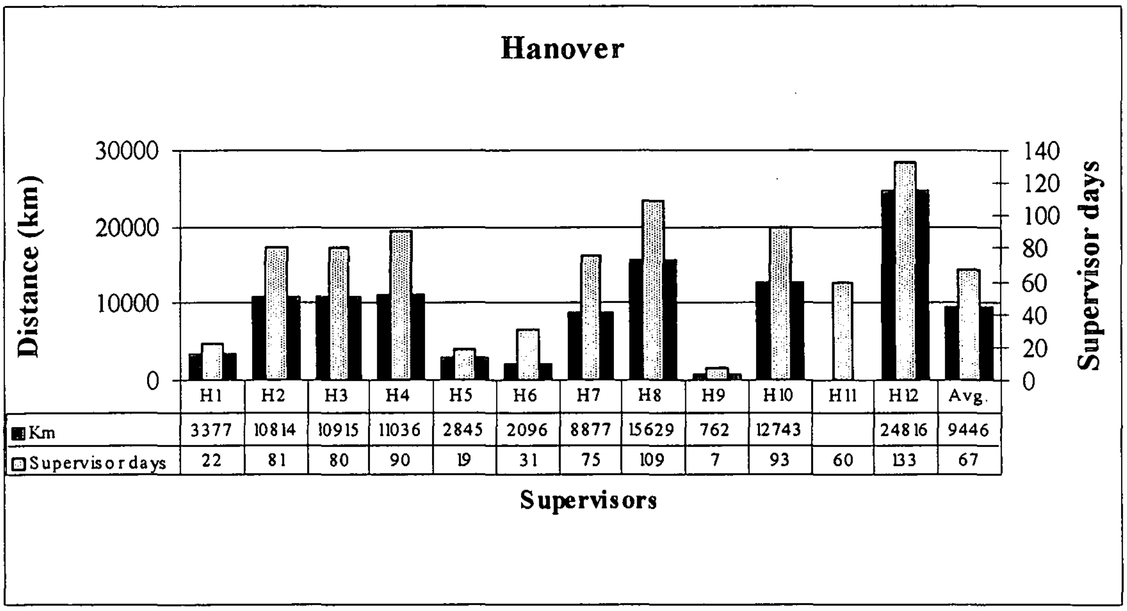
Results and discussion

Figures 4.1 to 4.4 show the distance travelled per supervisor and the number of days involved in the control of locusts in the De Aar, Hanover, Hay and Postmasburg districts. The values of the different series in the figures are obtained by adding the *Mean Km* and *Supervisor days* in the locust database (table 2.2) for each supervisor.



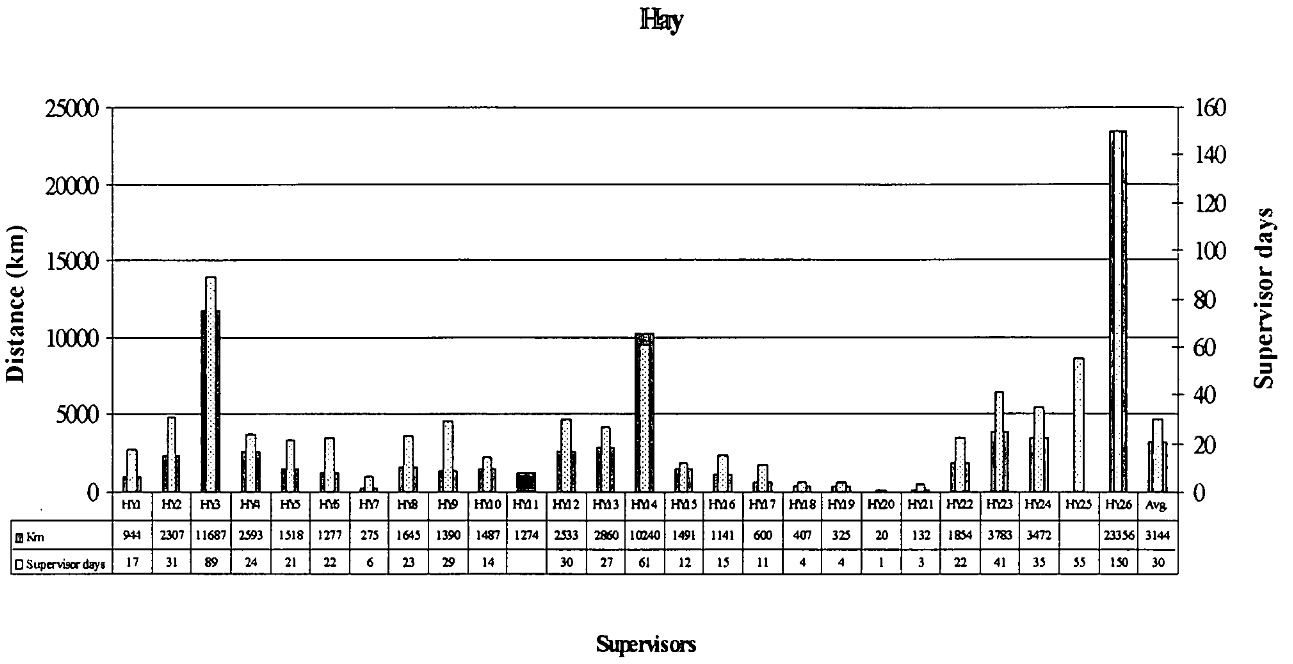
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	Avg.
■ Km	1796	3203	295	9653	8442	11440	1809	481	5832	271	3967		8428	4635
☐ Supervisor days	34	46		61	87	110	12	2	76	7	67	72	85	55

Figure 4.1 The total distance travelled (km) and total number of supervisor days involved in the De Aar locust district during the 1996/97 locust season.



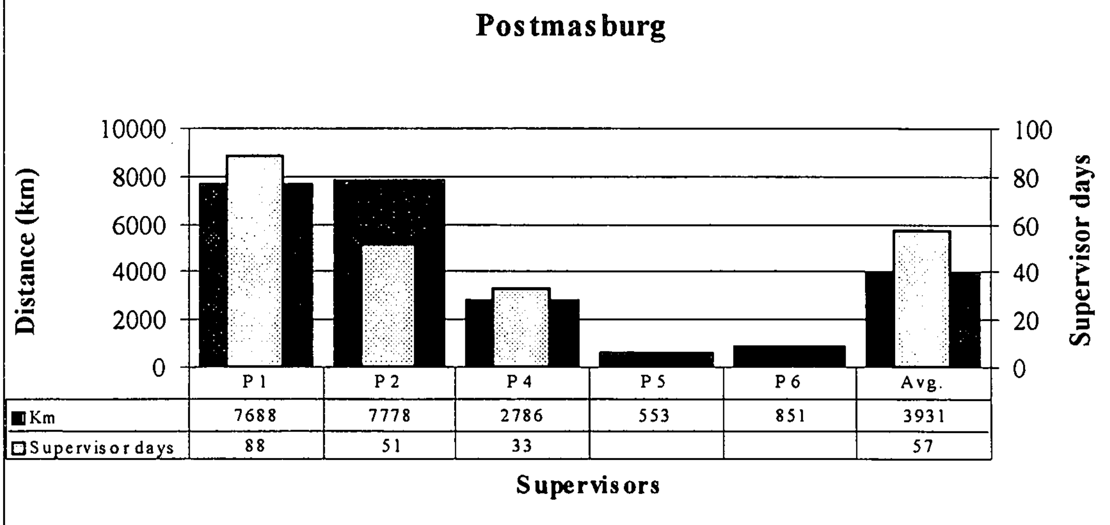
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	Avg.
■ Km	3377	10814	10915	11036	2845	2096	8877	15629	762	12743		24816	9446
☐ Supervisor days	22	81	80	90	19	31	75	109	7	93	60	133	67

Figure 4.2 The total distance travelled (km) and total number of supervisor days involved in the Hanover locust district during the 1996/97-locust season.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY11	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY25	HY26	Avg.
▨ Km	944	2307	11687	2593	1518	1277	275	1645	1390	1487	1274	2533	2860	10240	1491	1141	600	407	325	20	132	1854	3783	3472		23356	3144
☐ Supervisor days	17	31	89	24	21	22	6	23	29	14		30	27	61	12	15	11	4	4	1	3	22	41	35	55	150	30

Figure 4.3 The total distance travelled (km) and total number of supervisor days involved in the Hay locust district during the 1996/97 locust season.



	P1	P2	P4	P5	P6	Avg.
■ Km	7688	7778	2786	553	851	3931
☐ Supervisor days	88	51	33			57

Figure 4.4 The total distance travelled (km) and total number of supervisor days involved in the Postmasburg locust district during the 1996/97 locust season.

The number of supervisors employed, distance travelled and days involved varied dramatically among districts. The blank kilometre values refer to either the DLO or secretary, who did not combat any locusts. Furthermore, some supervisors combated locusts free of charge and did not record all the control details (table 5.1). The supervisors were limited in the number of kilometres they could have travelled per day and the limit was set on 150 km. All the averages were within that limit (table 4.1).

Table 4.1 The average distance in kilometre travelled per day by a supervisor to combat the locusts in that given district, the average number of bands or swarms controlled per 100 hectares of the total district area and the total district area (ha).

Locust district	**Avg. distance (km) per day**	**Avg. # of bands or swarms per 100 ha**	**District area (ha)**
De Aar	84	0.51	299 741
Hanover	142	1.17	459 067
Hay	105	0.15	1 278 030
Postmasburg	69	0.05	1 828 212

There were vast differences between the district averages. The occurrence of locusts was the highest in the Hanover district (table 4.1). Although Hanover is the second smallest of these four districts, the high kilometres were travelled per day by the supervisors. Opposed to this, Postmasburg is the largest district and the occurrence of locusts was the lowest. Effective organisation and planning by the DLO and supervisors can result in relative low distances travelled in combating locusts. Most of the supervisors did not control locusts for the full duration of employment (table 4.2).

Table 4.2 Months in which the supervisors were employed and the number of days in each month they sprayed locusts from October 1996 until May 1997.

Supervisors	1996			1997					
	10	11	12	1	2	3	4	5	Total
D1		1	15	7	11				34
D2		4	25	7	2	8			46
D3			▨						
D4	14	17	21	5		4			61
D5	13	24	27	8	10	5			87
D6	14	24	30	22	5	13	2		110
D7				12					12
D8				2					2
D9	24	13	24		7	8			76
D10			7						7
D11	9	12	31	10	1	4			67
D12	15	15	15	10	8	9			72
D13	19	19	17	8	8	14			85
H1			12	10					22
H2	3	28	24	12	14				81
H3	15	26	29	10					80
H4	23	29	30	8					90
H5			16	3					19
H6			17	14					31
H7	10	30	30	5					75
H8	25	30	30	19		5			109
H9				7					7
H10	20	29	30	14					93
H11	15	15	15	15					60
H12	30	30	30	20	17	6			133
HY1					14	3			17
HY2				5	15		11	▨	31
HY3		2	8	24	27	24	4		89
HY4					9	15			24
HY5					7	12	2		21
HY6				4	13	5			22
HY7						6			6
HY8				1	18	2	2		23
HY9					16	4	9		29
HY10					4	10	▨		14
HY11						▨			
HY12				5	17	8			30
HY13				2	14	11			27
HY14				17	24	10	10		61
HY15						10	2		12
HY16					14	1			15
HY17					11				11
HY18						4			4
HY19				▨	4				4
HY20				1					1
HY21						3			3
HY22				5	11	6			22
HY23				9	19	13			41
HY24				8	24	3			35
HY25				14	28	13			55
HY26		10	18	28	30	27	26	11	150
P1		3	16	12	21	18	18		88
P2				3	23	25			51
P3				▨	▨				
P4		1	2	8	13	9			33
P5							▨		
P6							▨		
▨	Months in which the supervisors controlled locusts.								

Supervisors D3, HY11, P3, P5 and P6 controlled locusts free of cost during the 1996/97 campaign (table 5.1) and supervisors HY2, HY10 and HY19 worked for free in some of the months.

The highest average supervisor-days were recorded in the Hanover district and can be explained by the high occurrence of locusts. The Hay district had the lowest supervisor-days and the highest number of supervisors. The other two districts had about the same average. The De Aar district had twice as many supervisors as the Postmasburg district and about ten times as many bands or swarms to control. The exact opposite is true for Hanover and Hay. Hay had about twice as many supervisors than Hanover, but the occurrence of locusts were about ten times less than in Hanover. It has to be remembered that trained volunteers from the community control locusts and that availability varies from district to district.

Peak numbers of locusts were controlled during December 1996 and again in January 1997. The intensity of the campaign simultaneously shifted from mid-Karoo to the northern-Cape (Van der Westhuizen & Botha, 1997). This pattern is further illustrated in table 4.2 by the activities of the supervisors in De Aar and Hanover, whom were more active at the end of 1996, compared to the increase in activity of the supervisors in Hay and Postmasburg in the beginning of 1997.

Figures 4.5 to 4.8 compare the total number of assistant days, as well as the hectares and litre sprayed per assistant day of each supervisor in the four districts.

The series *Assistant days* was calculated as the sum of the field *Assistant days* (table 2.2) for each supervisor. Corresponding series *Ha/Assistant day* and the series *l/Assistant day* were calculated by using the following formulas (Microsoft ® Excel):

$$\mathit{Ha/Assistant\ day} = \frac{\mathit{Hectare}}{\text{Assistant\_days}} \tag{4.1}$$

$$\mathit{l/Assistant\ day} = \frac{\mathit{Quan}}{\text{Assistant\_days}} \tag{4.2}$$

Hectare and *Assistant days* are fields in table 2.2. “Quan” is a field in table 2.1 under the heading “Formulation used” and records the quantity of pesticide applied in litre. The supervisor campaign totals were used in equation (4.1) and (4.2).

The supervisors D3 HY11, P3, P5 and P6 controlled locusts free of charge and therefore no assistant days were recorded for them. Supervisor HY20 only combated locusts for one day (figure 4.3) and did not employ any assistants, consequently the total number of assistant days and equations (4.1) and (4.2) could not be calculated. Secretaries D12, H11 and HY25 as well as DLO D13, did not control any locusts, therefore the series *Ha/Assistant day* and *l/Assistant day* could not be calculated ($\frac{x}{0}$ →where x represents any value, is impossible to calculate). The district locust officer of Hanover (DLO H12) employed an assistant, but did not control any locusts resulting in zero values of both series. The district averages for the various series were calculated by using the following formulas:

$$Avg.\ Assistant\ days\ = AVERAGE(Assistant\ daysX{:}Assistant\ daysY) \qquad (4.3)$$

Where *Assistant daysX* is the number of assistant days the first supervisor reported and *Assistant daysY* the number of assistant days the last supervisor in a range from a given district reported. If the number of assistant days for a supervisor was zero, then no value was entered into the equation to prevent artificial lowering of the average.

$$Avg.\ Ha/Assistant\ day = \frac{SUM(HectareX : HectareY)}{SUM(\text{Assistant\_days}X : \text{Assistant\_days}Y)} \qquad (4.4)$$

Where *HectareX* and *HectareY* are the total number of hectares sprayed per supervisor in a district, *Assistant daysX* and *Assistant daysY* are the total number of assistant days reported by the range of supervisors in the district.

$$Avg.\ l/Assistant\ day = \frac{SUM(QuanX : QuanY)}{SUM(\text{Assistant\_days}X : \text{Assistant\_days}Y)} \qquad (4.5)$$

Where *QuanX* and *QuanY* are the quantity of pesticide applied per supervisor in litre (see equation 4.2) and *Assistant daysX* and *Assistant daysY* are similar to equation (4.4).

In comparing the district averages of figures 4.5 to 4.8, it is evident that great differences occur within manpower utilisation. The lack of the series *Assistant days* for the above mentioned supervisors had a profound influence on both the series

Ha/Assistant day and *l/Assistant day*. According to equations (4.4) and (4.5) the total number of hectares sprayed and the total litre of pesticide applied for those supervisors without recorded assistant days were included in the equations. This resulted in the *Avg. Ha/Assistant day* and the *Avg. l/Assistant day* –values being higher than it would have been if those supervisors were not taken into account. If all the supervisors recorded assistant days, the district average would have been lower. In a district with many supervisors who work for free, this calculation benefit higher avg. *Ha/Assistant day*-value which, within limits, reflects on high productivity in the particular district. A high *avg. l/Assistant day*-value on the other hand can be detrimental to a district, because it reflects on the assistants having had a high exposure to pesticides.

There were great differences between the districts concerning the *Ha/Assistant day*-values. The Hay and Hanover districts had the lowest average values of 3,75 and 4,972 respectively, followed by De Aar at 11.873 and Postmasburg at 21,827 *Ha/Assistant day*. The high value in the Postmasburg district is due to the fact that half the number of supervisors worked for free and their number of hectares sprayed were added to the district total without adding assistant days.

Vast differences also occurred within any given district, regarding the *Ha/Assistant day*-values. Having used data from the old yellow forms, it was impossible to distinguish between swarms sprayed with the pick-up truck (bakkie) and knapsack Solo pumps. The new data sheets however make provision for the various application equipment (table 2.1). The high *Ha/Assistant day*- and high *l/Assistant day*-values probably correspond with supervisors making use of the bakkie pumps rather than knapsack pumps. In each case the total number of hectares sprayed was equally divided between all the assistants involved. Since a far greater area can be sprayed with the bakkie pump than a knapsack pump in any given time, this could account for those high values.

Equations (4.1) and (4.2) divide hectare and litre respectively by the number of assistant days reported by a supervisor. Since the denominator for these two equations is the same, equation (4.1) and (4.2) considers the relation of litres sprayed to hectare controlled. Figures 4.5 to 4.8 are thus further explained by figures 3.1 to

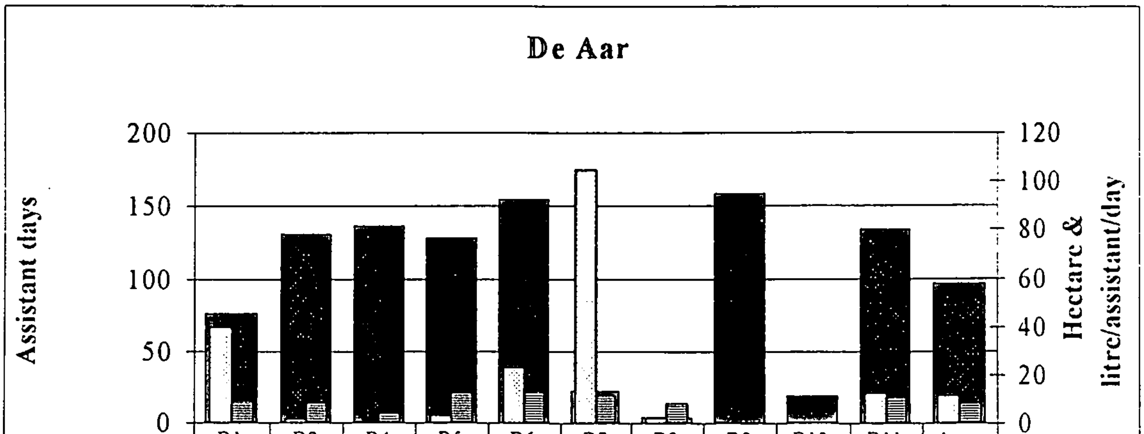
3.4. Deltamethrin (Decis ® UL 6) is used against locusts at a registered application rate of approximately 2,5 l/ha (Worthing & Hance, 1991; Heyns *et al.*, 1995; Krause *et al.*, 1996; Tomlin, 1997). The relation between the amount of pesticide applied per assistant per hectare should be close to 5:2. Figures 3.1 to 3.4 clearly illustrate that very few of the supervisors came close to that prescribed application rate.

If supervisors HY1 and HY15 are compared (figure 4.7), it can be seen that their numbers of assistant days were almost the same and can be seen as a constant for the sake of this argument. Supervisor HY1 sprayed 14 hectares and HY15 sprayed 145 hectares (figure 3.3), which is more than ten times that of HY1. It is thus expected that supervisor HY15 also applied more than ten times the amount of pesticide. If the pesticide applied (l) by these two supervisors are compared in figure 3.7, it is clear that HY15 applied far less than the expected ten times more. This is furthermore evident by comparing the *litre/hectare (l/ha)* applied by these supervisors in figure 3.3. From this it can be seen that HY15 applied the pesticide at an average rate of 1,312 l/ha, which is almost half the registered rate. Supervisor HY1 applied the pesticide at a rate of 2,092 l/ha and closer to the recommended application rate of 2,5 l/ha. If the pesticide was applied correctly, the relation between litre and hectare should be 2,5:1 in equation (4.1) and (4.2).

Supervisor H10 applied the pesticide at a rate of 2,551 l/ha, which is near perfect (figure 3.2). His value for *Ha/Assistant day* is 2,503 (figure 4.6). If this value is multiplied by the application rate, a value of 6,38 *l/Assistant day* is obtained.

$$\frac{l}{\text{Assistant\_day}} = \frac{Ha}{\text{Assistant\_day}} * \frac{l}{Ha} \tag{4.6}$$

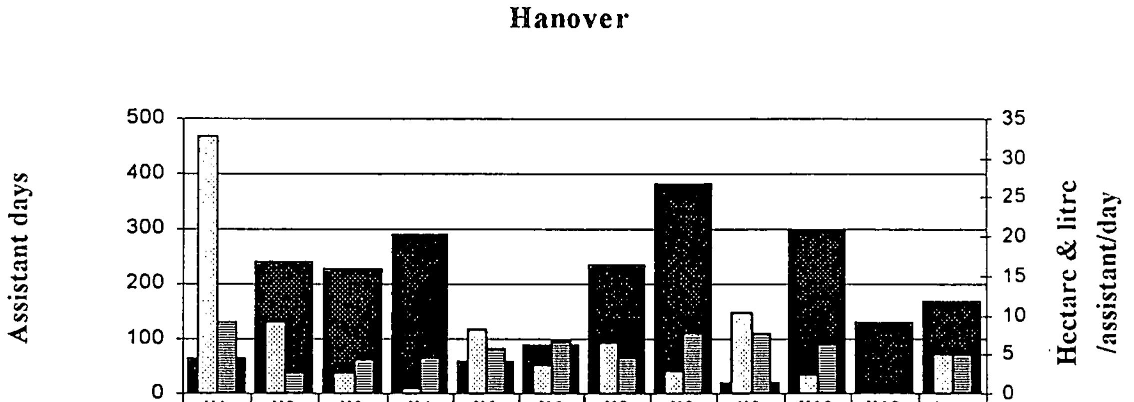
Equations (4.6) and (4.2) resulted in similar parameters and values. Since the relation between litre and hectare should be in the vicinity of 2,5:1, the Ha/Assistant day-value can be multiplied by 2,5 to have a comparable value with the correspondent *l/Assistant day*-value. The deviation from the recommended application rate can easily be determined in this manner.



	D1	D2	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
▨Assistant days	76	131	137	128	154	22	4	159	19	134	96.4
☐Ha/Assistant day	39.856	1.388	0.697	3.473	22.818	104.966	2.761	0.827	0.035	12.502	11.836
▤l/Assistant day	8.859	8.660	3.821	12.394	13.499	11.864	8.175	1.468	0.198	10.407	8.301

Supervisors

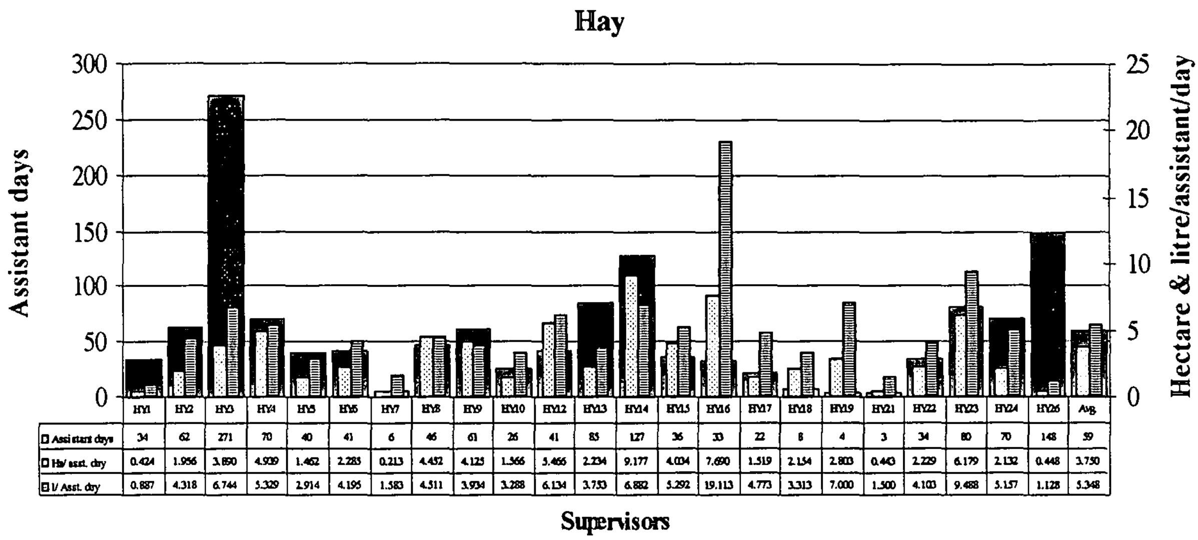
Figure 4.5 The total number of assistant days, hectares controlled and litres sprayed per assistant per day of the different supervisors within the De Aar district in the 1996/97 locust control campaign.



	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H12	Avg.
▨Assistant days	64	243	228	289	57	91	234	382	21	300	130	170
☐Ha/Assistant day	32.850	9.063	2.637	0.638	8.089	3.737	6.617	2.834	10.412	2.503		4.972
▤l/Assistant day	9.148	2.550	4.309	4.484	5.895	6.681	4.594	7.746	7.624	6.383		5.168

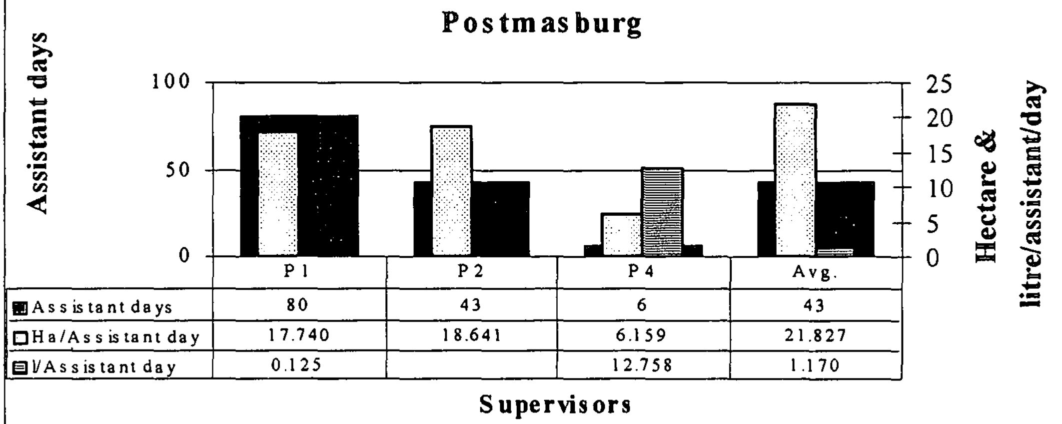
Supervisors

Figure 4.6 The total number of assistant days, hectares controlled and litres sprayed per assistant per day of the different supervisors within the Hanover district in the 1996/97 locust control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY21	HY22	HY23	HY24	HY26	Avg.
■ Assistant days	34	62	271	70	40	41	6	46	61	26	41	83	127	36	33	22	8	4	3	34	80	70	148	59
□ Ha/ asst. day	0.424	1.956	3.890	4.939	1.462	2.283	0.213	4.452	4.125	1.366	5.466	2.234	9.177	4.034	7.690	1.519	2.154	2.803	0.443	2.229	6.179	2.132	0.448	3.750
▤ l/ Asst. day	0.887	4.318	6.744	5.329	2.914	4.195	1.583	4.511	3.934	3.288	6.134	3.753	6.882	5.292	19.113	4.773	3.313	7.000	1.500	4.103	9.488	5.157	1.128	5.348

Figure 4.7 The total number of assistant days, hectares controlled and litres sprayed per assistant per day of the different supervisors within the Hay district in the 1996/97 locust control campaign.



	P1	P2	P4	Avg.
■ Assistant days	80	43	6	43
□ Ha/Assistant day	17.740	18.641	6.159	21.827
▤ l/Assistant day	0.125		12.758	1.170

Figure 4.8 The total number of assistant days, hectares controlled and litres sprayed per assistant per day of the different supervisors within the Postmasburg district in the 1996/97 locust control campaign.

The series in figure 4.9 compare the number of assistant days vs. supervisor days in a district as well as the average hectare either sprayed or managed by them. The series were calculated by using the following formulas:

$$\textit{Assistant days} = \textit{SUM(Assistant daysX : Assistant daysY)} \qquad (4.7)$$

$$\textit{Supervisor days} = \textit{SUM(Supervisor daysX : Supervisor daysY)} \qquad (4.8)$$

Where *Assistant daysX*, *Supervisor daysX* and *Assistant daysY*, *Supervisor daysY* are the total number of assistant days and supervisor days reported by the supervisors in a particular district. Avg. Ha/Assistant day is obtained from equation (4.4)

Equation (4.1) calculates the *Ha/Assistant day* parameter. The series *Ha/Supervisor day* is obtained in a similar manner by replacing the *Assistant days* with *Supervisor days* as denominator (table 2.2):

$$\textit{Ha/Supervisor day} = \frac{\textit{Hectare}}{\textit{Supervisor\_days}} \qquad (4.9)$$

$$\textit{Avg. Ha/Supervisor day} = \frac{SUM(HectareX : HectareY)}{SUM(Supervisor\_daysX : Supervisor\_daysY)} \qquad (4.10)$$

Where *HectareX* and *HectareY* are the total number of hectares sprayed per supervisor in the district and *Supervisor daysX* and *Supervisor daysY* are the total number of supervisor days reported by the respective supervisors.

The highest number of assistant days as well as supervisor days was reported from the Hanover district, followed by Hay, De Aar and Postmasburg (figure 4.9). This sequence corresponds with figures 3.13 to 3.16 concerning the total number of bands and swarms controlled.

Table 4.3 was obtained from the data in figure 4.9 and compares the ratio of assistant days to supervisor days in the four districts. According to this the Hanover district had the highest ratio which means that on average the supervisors employed significant more assistants. Comparing the four districts, the Hanover district was also the district of the highest locust outbreaks (figure 3.13). In the Postmasburg district more supervisor days than assistant days were reported. This simply means that some of the supervisors controlled certain bands or swarms without the use of assistants. This is mainly possible where the outbreaks are not that severe. The smallest number of bands and swarms were controlled in the Postmasburg district (figure 3.13).

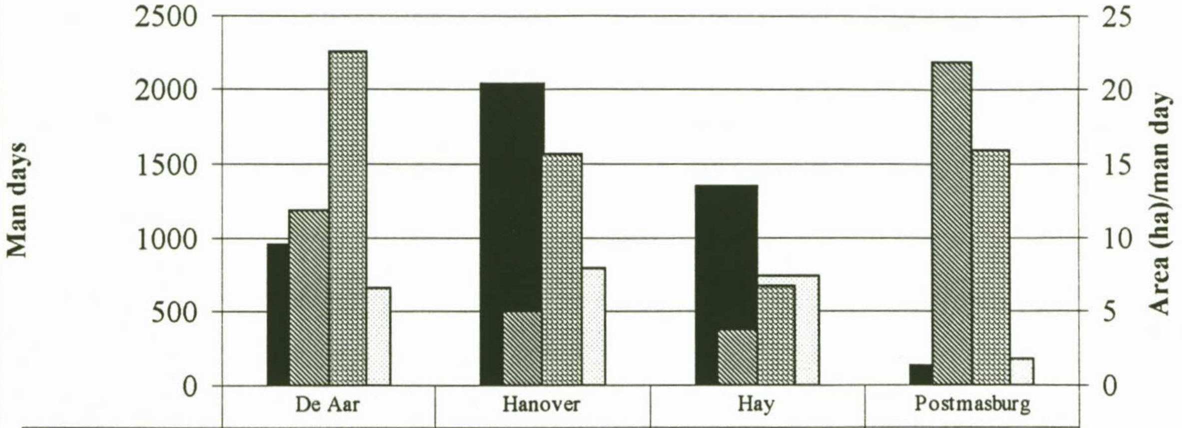
Table 4.3 The ratio of the number of assistant days to supervisor days in the four districts.

District	Assistant days : Supervisor days
De Aar	1,46 : 1
Hanover	2,55 : 1
Hay	1,80 : 1
Postmasburg	0,75 : 1

Figure 4.9 further illustrates the differences in the average area sprayed per man day. The average area per supervisor day is usually higher than the average area per assistant day (figure 4.9), because the supervisor manages the total area sprayed for that day, but can also partake in the actual spraying. On the other hand the total area sprayed is equally divided among all the assistants involved (see "Nr Ass", table 2.1).

In comparing equation (4.4 and 4.10) it is clear that the only difference is the use of the series supervisor days in equation (4.10), instead of the series assistant days in (4.4). Since it has earlier been established that the number of supervisor days in the Postmasburg district was more than the number of assistant days, it is evident why the average area per supervisor day is less then the average area per assistant day.

Furthermore, these values were rather high because of the fact that half the number of supervisors in the Postmasburg district worked for free and therefore did not report any assistant or supervisor days. As stated in equation (4.4 and 4.10) the total number of hectares sprayed by all the supervisors, regardless of whether they reported days or not, were entered into the equation.



	De Aar	Hanover	Hay	Postmasburg
■ Assistant days	961	2039	1347	129
☐ Supervisor days	662	800	747	172
▨ Ha/Assistant day	11.873	4.972	3.75	21.827
▩ Ha/Supervisor day	22.593	15.637	6.769	16

Figure 4.9 The number of man days and hectares sprayed per assistant and supervisor day in the four districts in the 1996/97 locust control campaign.

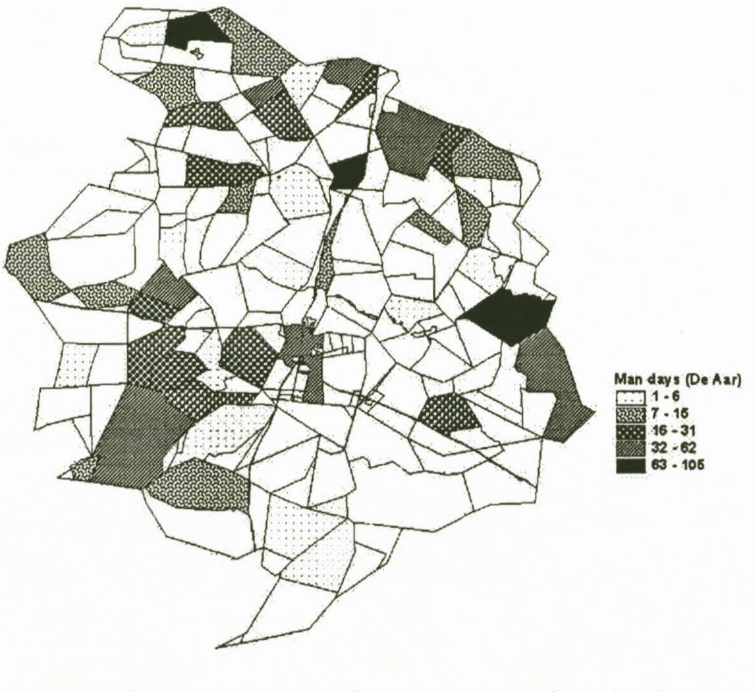


Figure 4.10 The total number of man days per farm in the De Aar district at the end of the 1996/97 locust control campaign.

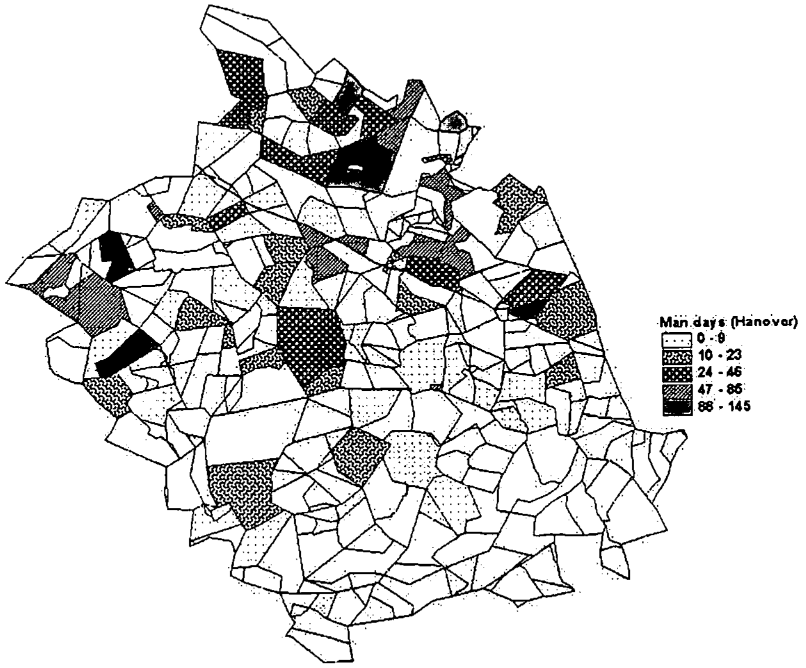


Figure 4.11 The total number of man days per farm in the Hanover district at the end of the 1996/97 locust control campaign.

The campaign totals of the locust database (table 2.1 and 2.2) were, in stead of per supervisor, summarised for every farm where locust control took place. These values were saved in dBASE file format and imported into ArcView® (Environmental Systems Research Institute) for spatial analysis. GIS provides a powerful tool for combining data from different sources related to the same geographic area (Zhou, MacDonald & Moore, 1991). Figures 4.10 to 4.13 visualises the total number of man-days reported per farm in these four districts.

The man-days reported referred to the number of supervisor and assistant days involved in the control of locusts on the respective farms. Days on which locusts were controlled were reported, as well as days on which only scouting took place. The man-days in figures 4.10 to 4.13 were grouped into five classes by default, but any number of classes as well as a unique value could have been chosen.

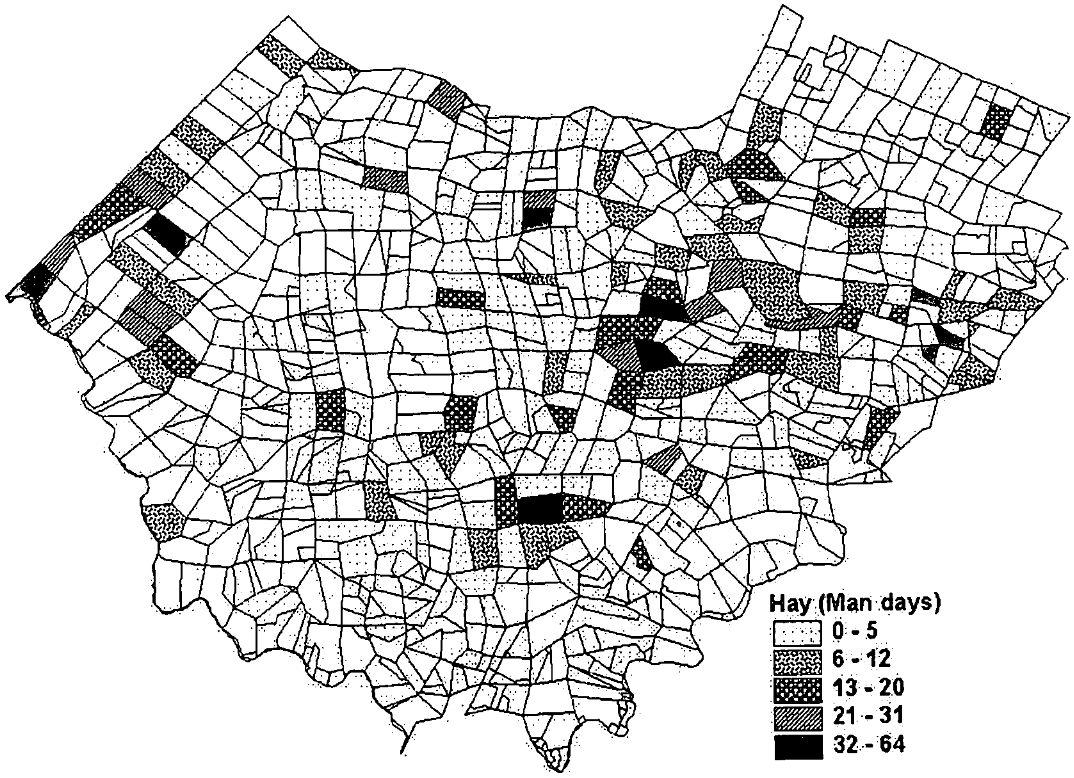


Figure 4.12 The total number of man days per farm in the Hay district at the end of the 1996/97 locust control campaign.

The highest number of man-days was reported from the Hanover district. Again, the Postmasburg district reported the lowest number of man days, which coincides with the fact that, within these four districts, the lowest number of locusts were also reported in Postmasburg (figure 3.13). With this system it is possible to visually monitor job creation and manpower utilisation with regard to the number of control teams implemented in the affected areas (Peters, Botha & Van der Westhuizen, 1997). The progress of the locust outbreaks and consequential socio-economical implications can be monitored (Peters, Lindeman & Van der Westhuizen, In Press).

Locust control was conducted on only some of the farms in a district (figure 4.10 to 4.13). Landowners are forced by law (Agricultural Pests act, 1983; Act No. 36 of 1983) to report the presence of brown locusts on their land (Botha & Lea: 1970b; Hanrahan & Horne, 1997; Hockey, 1988; Anon, 1998d) and they consequently scout for these locusts. If these scouting efforts are successful in even a severe outbreak, it would result in effective combating of the locusts in only small parts of the district.

The National Department of Agriculture also aims to contain the locusts within the outbreak areas and by doing so to deposit pesticides on as little land as possible.

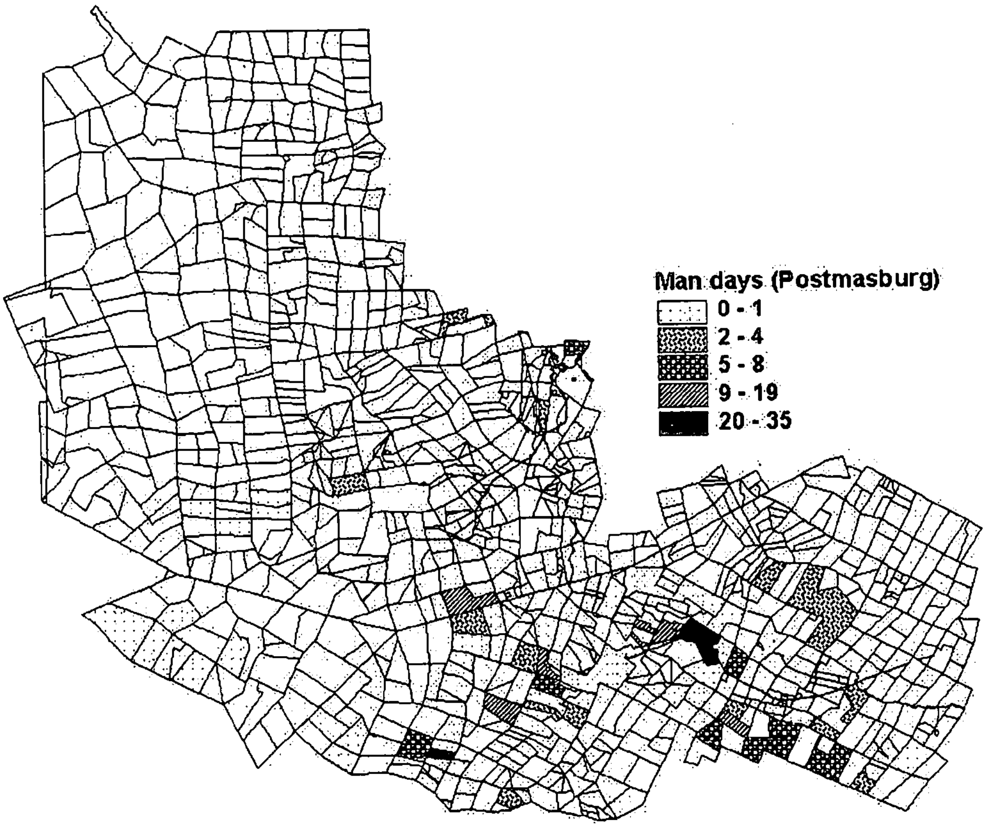


Figure 4.13 The total number of man days per farm in the Postmasburg district at the end of the 1996/97 locust control campaign.

A spatial analysis of farms visited by supervisors relative to their residence of the Hanover district was done. The farms visited and treated by supervisors were identified. The residential farm per supervisor is also displayed (figure 4.14 to 4.23). This was only done for the supervisors who stayed within the Hanover district. Supervisors H5 and H7 did not stay within the Hanover locust district, they actually stayed within the Colesberg district and were thus displayed outside the Hanover district border. The other supervisors resided in the Hanover locust district. Vast differences occurred among the parameters of the different supervisors. Most of the supervisors combated locusts on their own and neighbouring farms, but some travelled far distances to control locusts on the outer reaches of the district. In Hanover locust control prevailed for about 5 months (table 4.2) and all the supervisors were not employed simultaneously. This could explain why some supervisors had to travel into an area closer to another supervisor, because the latter probably was not activated for locust control at that time. This could have resulted in overlapping spraying pattern at the end of the campaign. A lower level of overlapping exists on a monthly basis. The spraying pattern of supervisors H7, H5 and H6 overlapped (figures 4.18, 4.19, 4.20). Supervisor H7 was employed for four months and H5 and H6 for two months. The same overlapping is evident for supervisor H2 (figure 4.15) who controlled locusts in five months and H1 (figure 4.14) who only controlled locusts in two months. The same tendency applies to the remaining supervisors (figures 4.14 to 4.23).

The supervisors sprayed varied numbers of farms. Supervisor H9 sprayed the lowest number of farms (6) and the highest number of 42 farms was sprayed by H8. The number of farms treated correlates well ($F = 5,90$; $p < 0,05$) with the period of supervisor employment. Supervisor H9 was only employed for one week, but supervisor H8 was employed for five months (table 4.2).

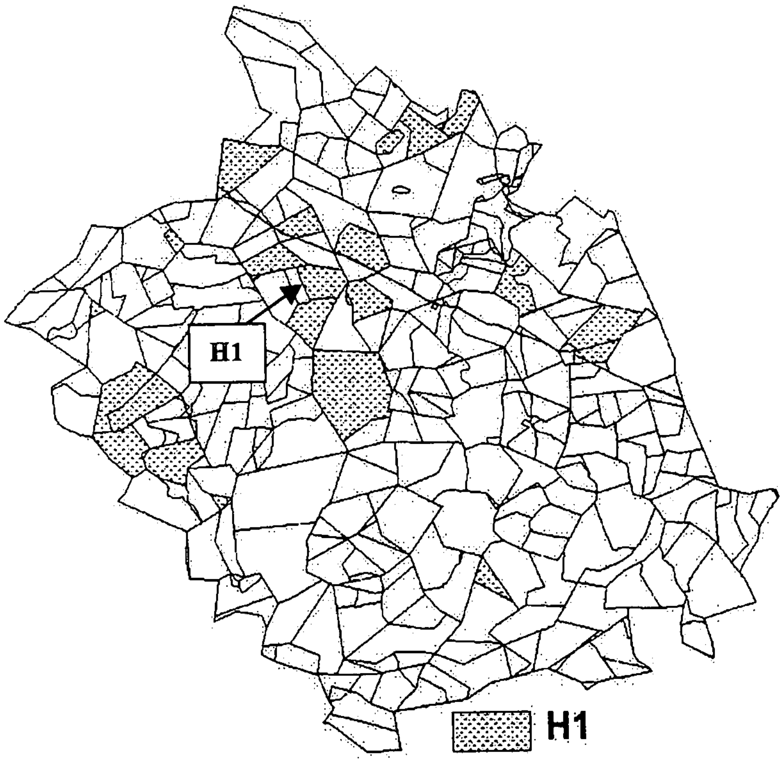


Figure 4.14 Farms in Hanover district treated by supervisor H1. The square and arrow indicates the residential farm of the supervisor.

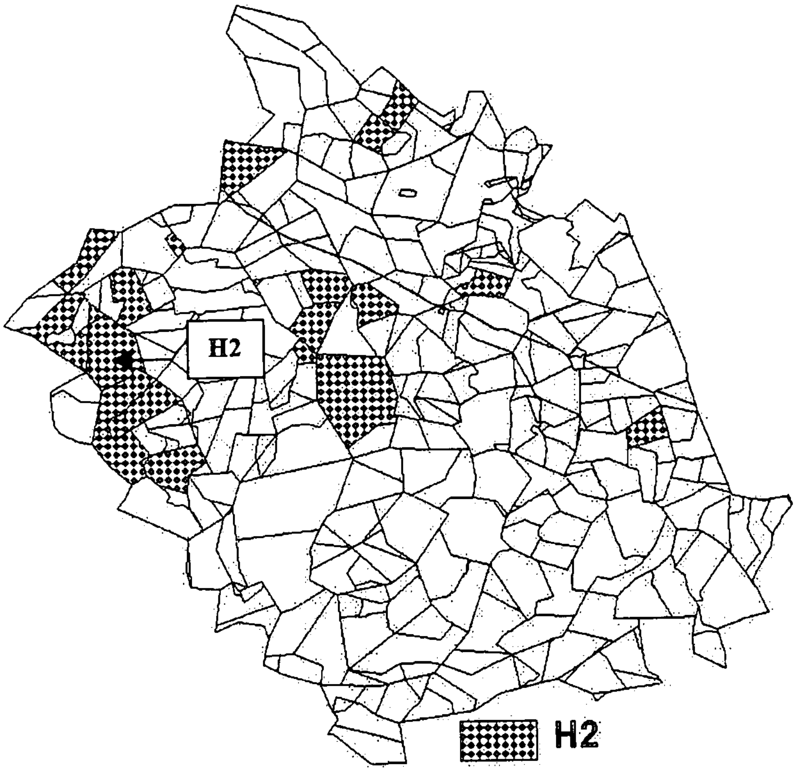


Figure 4.15 Farms in Hanover district treated by supervisor H2. The square and arrow indicates the residential farm of the supervisor.

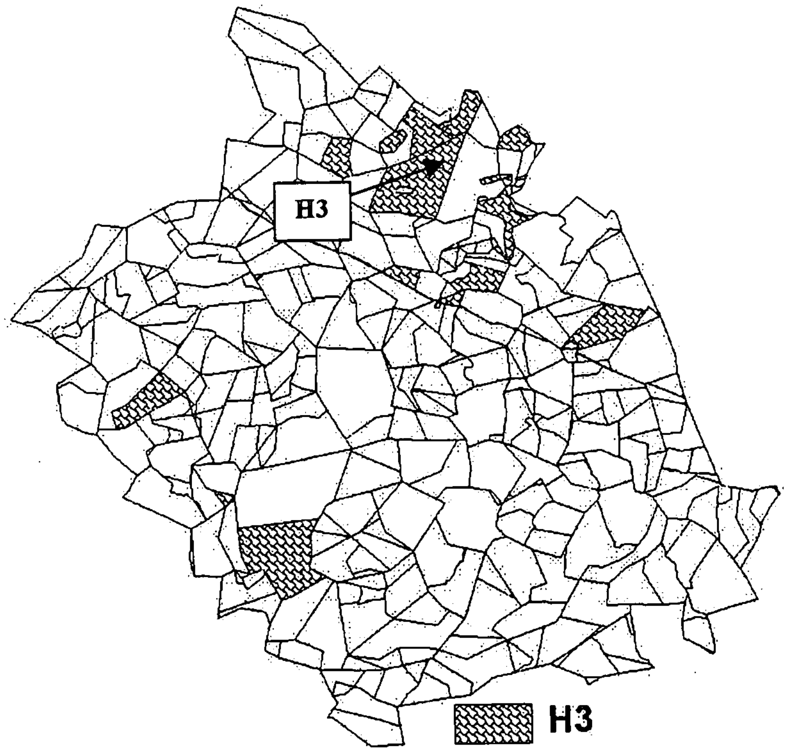


Figure 4.16 Farms in Hanover district treated by supervisor H3. The square and arrow indicates the residential farm of the supervisor.

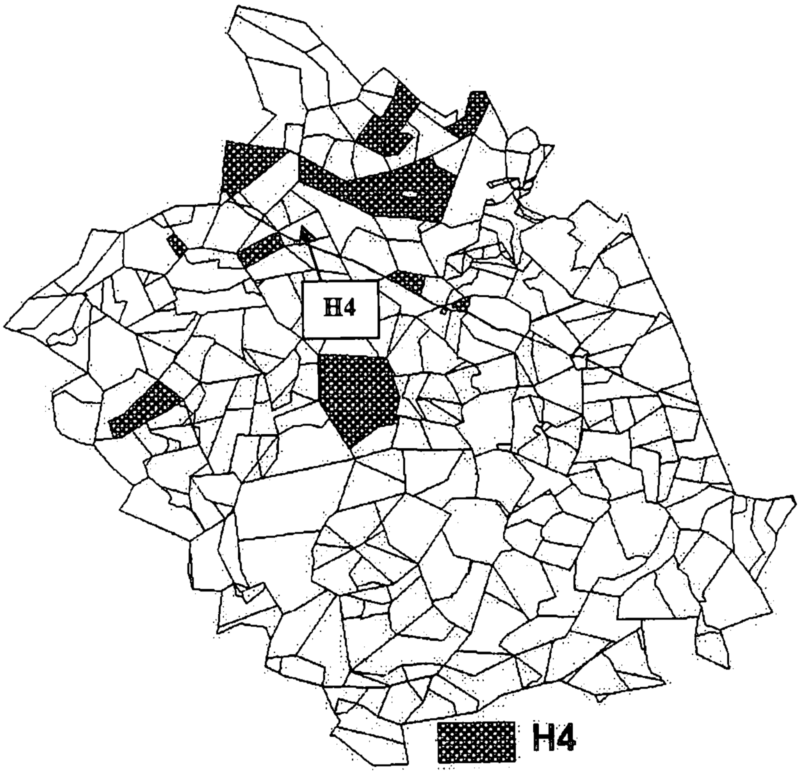


Figure 4.17 Farms in Hanover district treated by supervisor H4. The square and arrow indicates the residential farm of the supervisor.

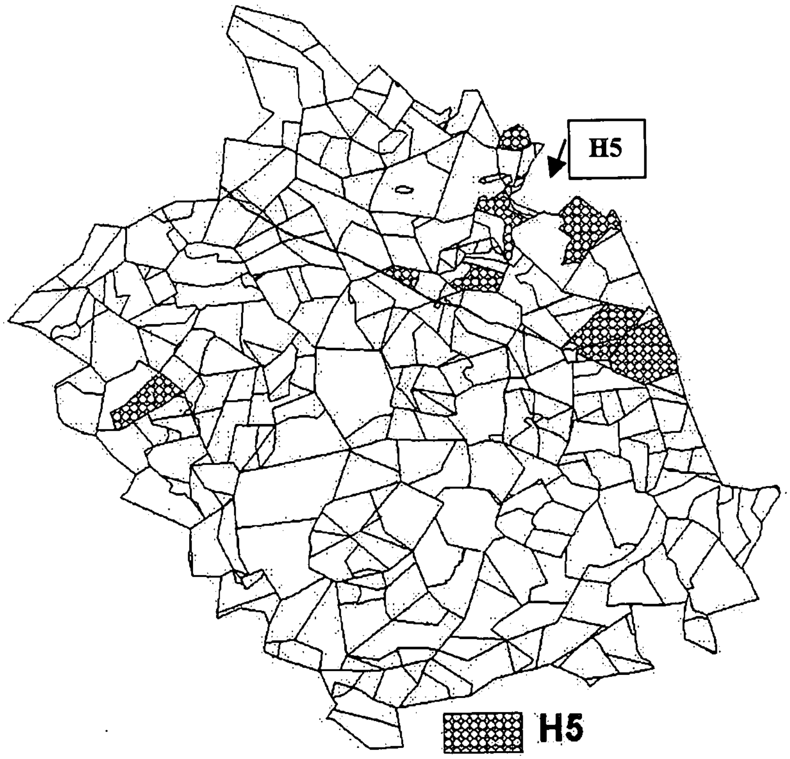


Figure 4.18 Farms in Hanover district treated by supervisor H5. The square and arrow indicates the residential farm of the supervisor.

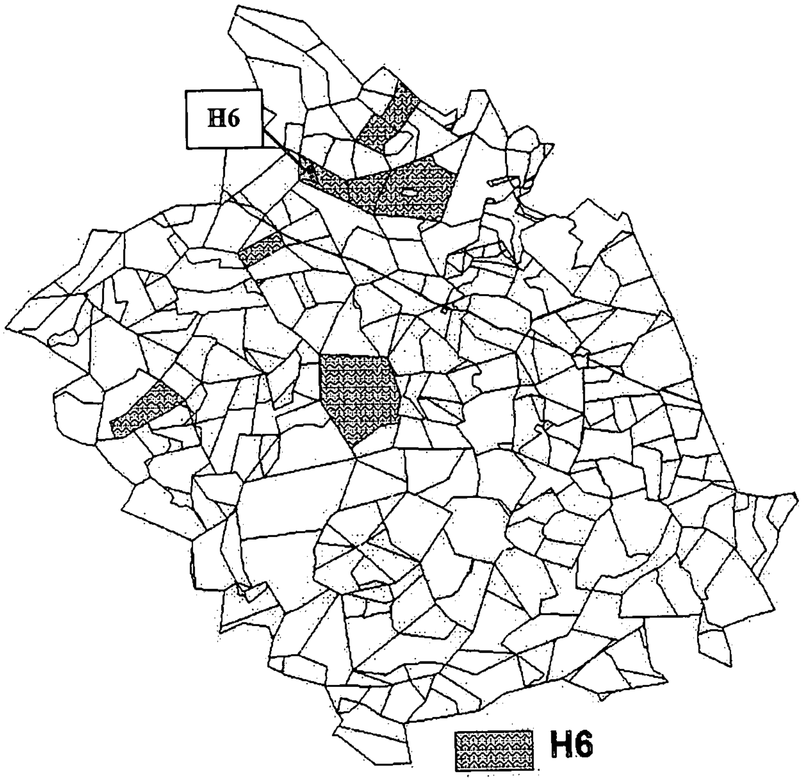


Figure 4.19 Farms in Hanover district treated by supervisor H6. The square and arrow indicates the residential farm of the supervisor.

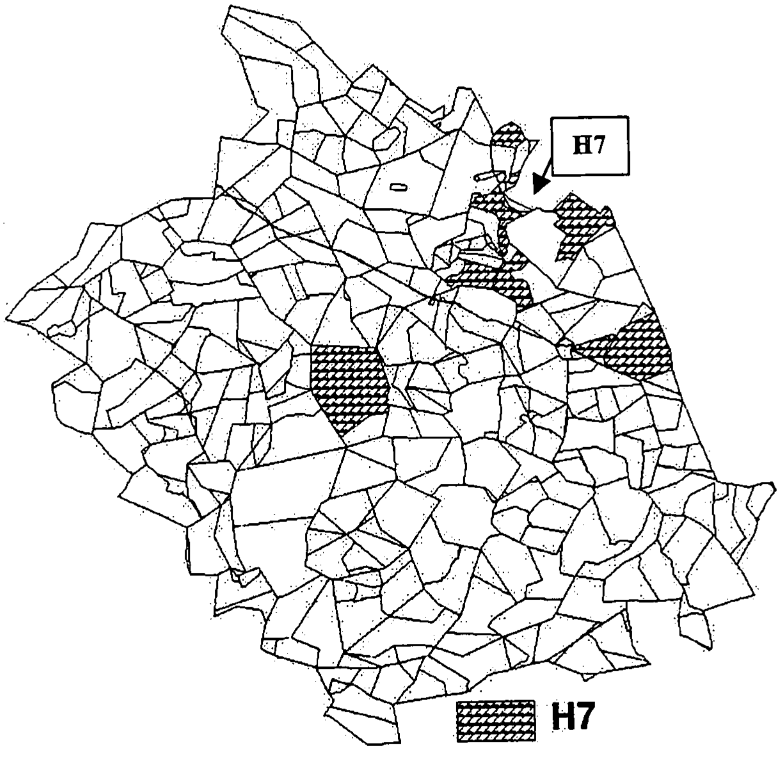


Figure 4.20 Farms in Hanover district treated by supervisor H7. The square and arrow indicates the residential farm of the supervisor.

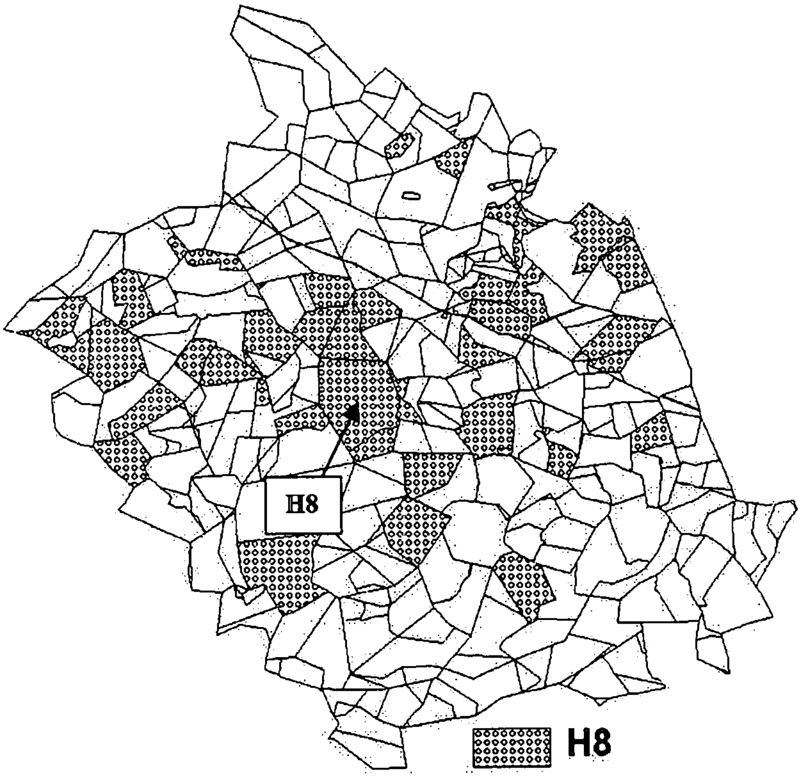


Figure 4.21 Farms in Hanover district treated by supervisor H8. The square and arrow indicates the residential farm of the supervisor.

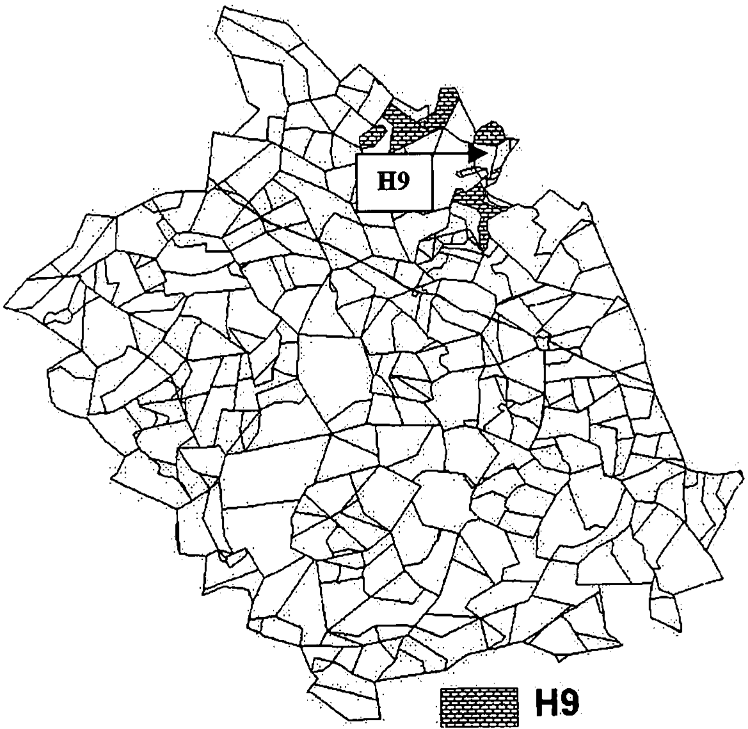


Figure 4.22 Farms in Hanover district treated by supervisor H9. The square and arrow indicates the residential farm of the supervisor.

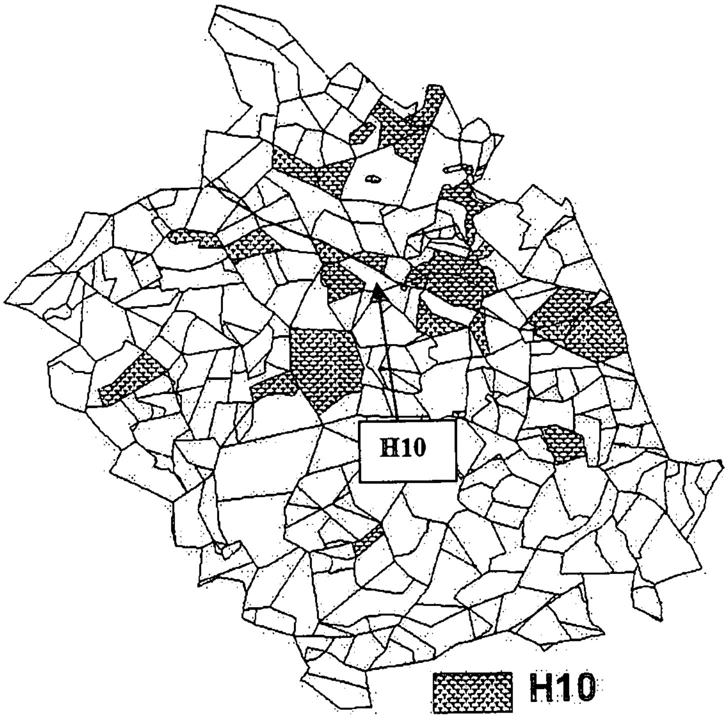
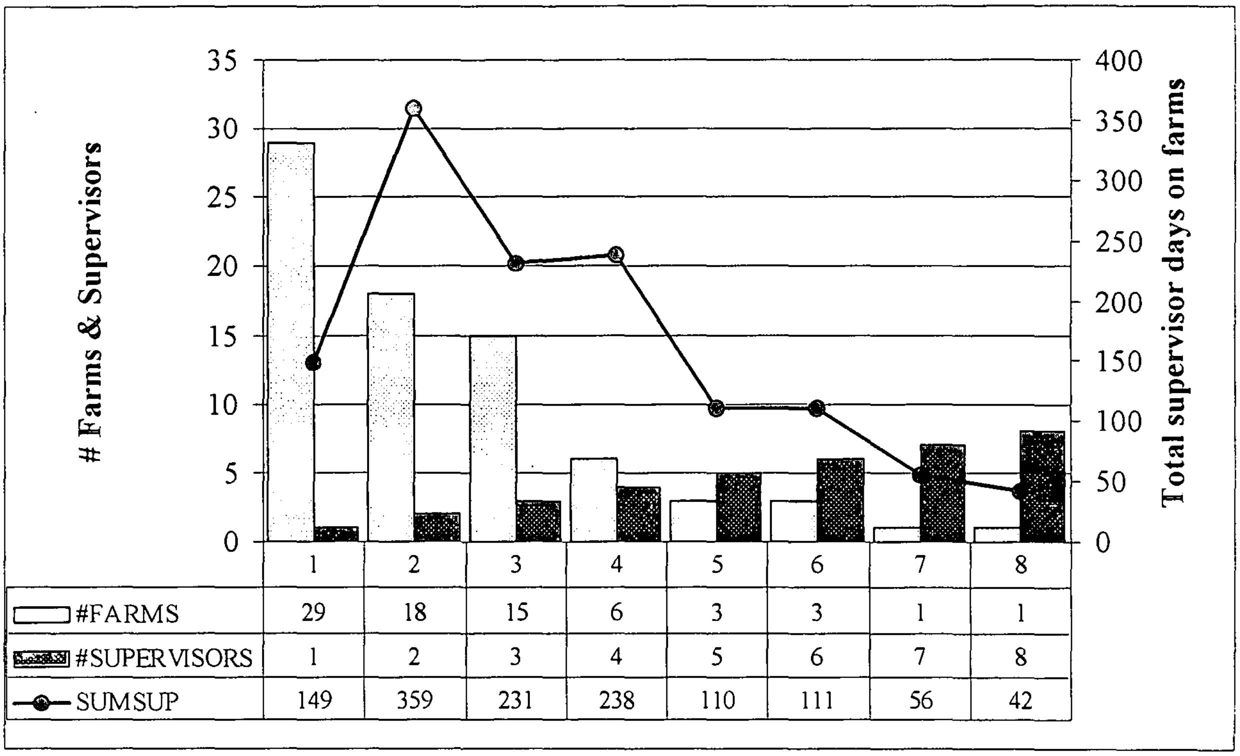


Figure 4.23 Farms in Hanover district treated by supervisor H10. The square and arrow indicates the residential farm of the supervisor.

Each district employed varying numbers of supervisors for different months in the 1996/97 locust control campaign (table 4.2). The extreme scenario's of visits to particular farms in the Hanover district can be summarised as follows: 29 farms were visited by a single supervisor versus one farm been visited by eight supervisors (figure 4.24). The latter scenario applies to the residential farm of the DLO. The supervisors probably attend a meeting at the DLO's resident. Another farm was visited by seven of the supervisors. Since the campaign lasted for more than six months, new locust outbreaks could have occurred on particular farms after the initial spraying actions, which necessitated follow-ups.

In general, as the number of farms decreased, the number of supervisors who visited them increased. There were only six farms visited by four supervisors in comparison with the fifteen farms visited by three supervisors. Higher inverted ratios of farms to supervisors will ensure a lesser amount of overlapping farms sprayed by supervisors.

Eighteen different farms were sprayed by two supervisors. Examples are supervisors H1 and H10 who sprayed the farm HAN148 (codeset) and supervisors H2 and H8 who sprayed farm HAN221. A total number of 359 supervisor days were recorded on these eighteen farms. This was the highest number of collective supervisor days.



	1	2	3	4	5	6	7	8
☐ #FARMS	29	18	15	6	3	3	1	1
▨ #SUPERVISORS	1	2	3	4	5	6	7	8
—●— SUMSUP	149	359	231	238	110	111	56	42

Figure 4.24 Number of farms in Hanover one or more supervisors controlled locusts on and the total number of supervisor days on the respective farms.

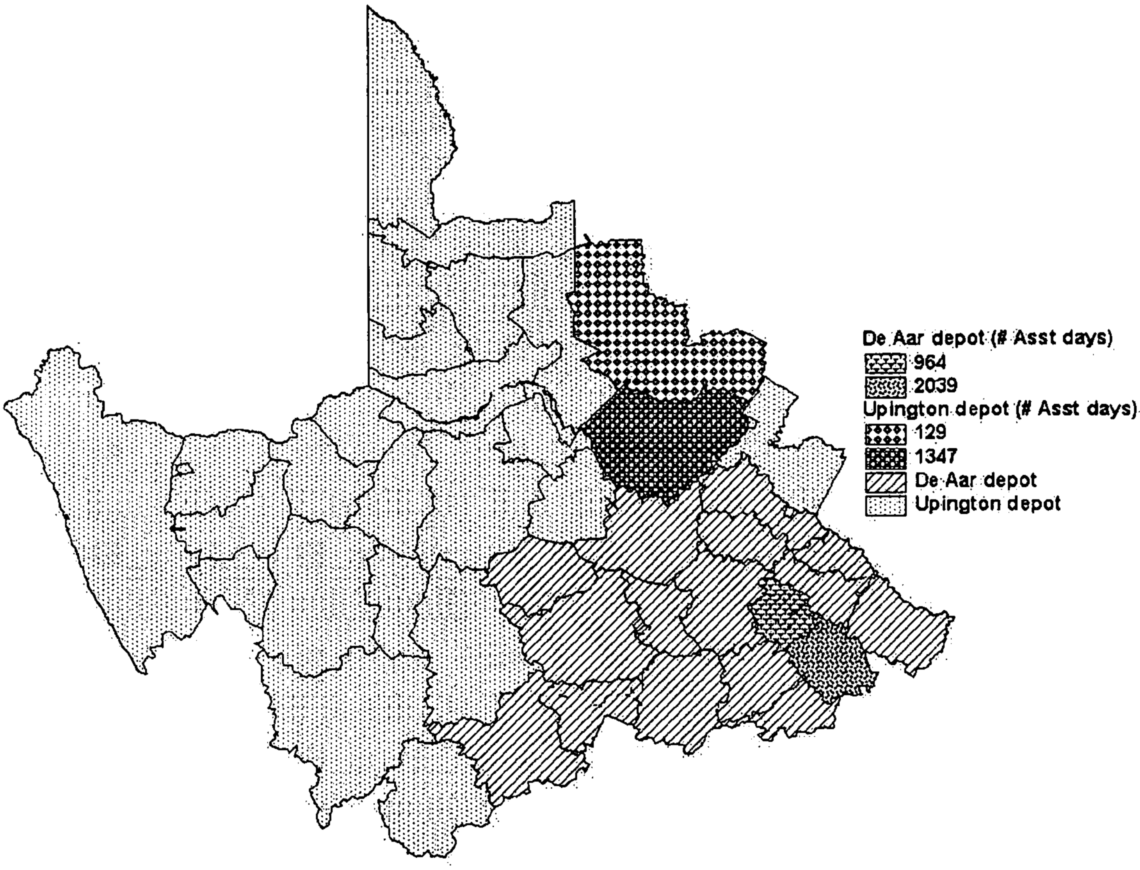


Figure 4.25 Total number of assistant days recorded in the four districts during the 1996/97 locust control campaign.

The highest number of assistant days was recorded in the Hanover district, followed by Hay, De Aar and Postmasburg (figure 4.25). It followed the same pattern (from highest to lowest) as the number of bands and swarms controlled (figure 3.13). However the assistant days did not correlate to the same extend with the area sprayed per district (figure 4.27a), with De Aar to be the highest, followed by Hanover, Hay and Postmasburg.

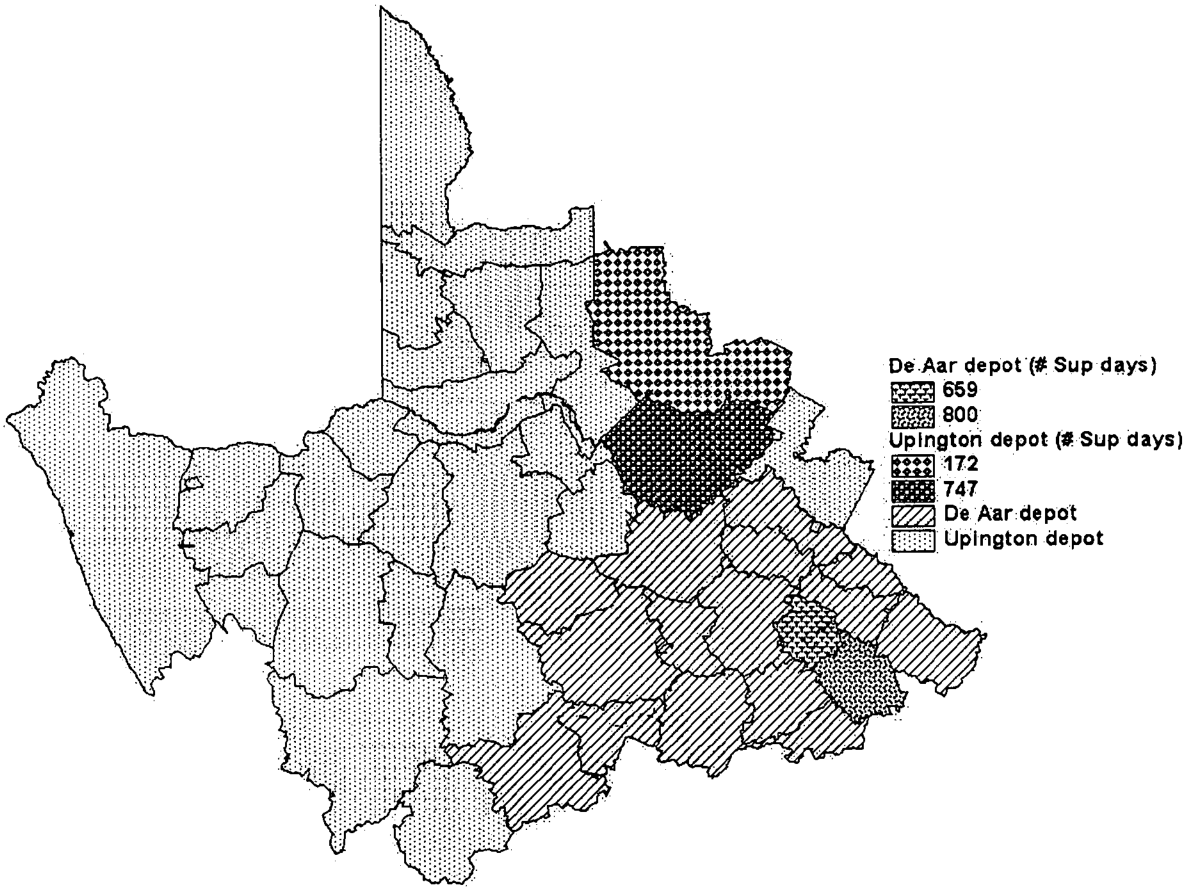


Figure 4.26 Total number of supervisor days in the four districts in the 1996/97 locust control campaign.

The highest number of supervisor days was recorded in Hanover, followed by Hay, De Aar and Postmasburg (figure 4.26). It almost corresponded with the area (ha) sprayed per district. The number of supervisor and assistant days seems to be more dependant of number of bands and swarms controlled than of the area sprayed. However, a total opposite relationship occurred between service area (total district area) and the number of days supervisors and assistants were involved in control activities (figure 4.27b). The latter is totally in conflict with the expected.

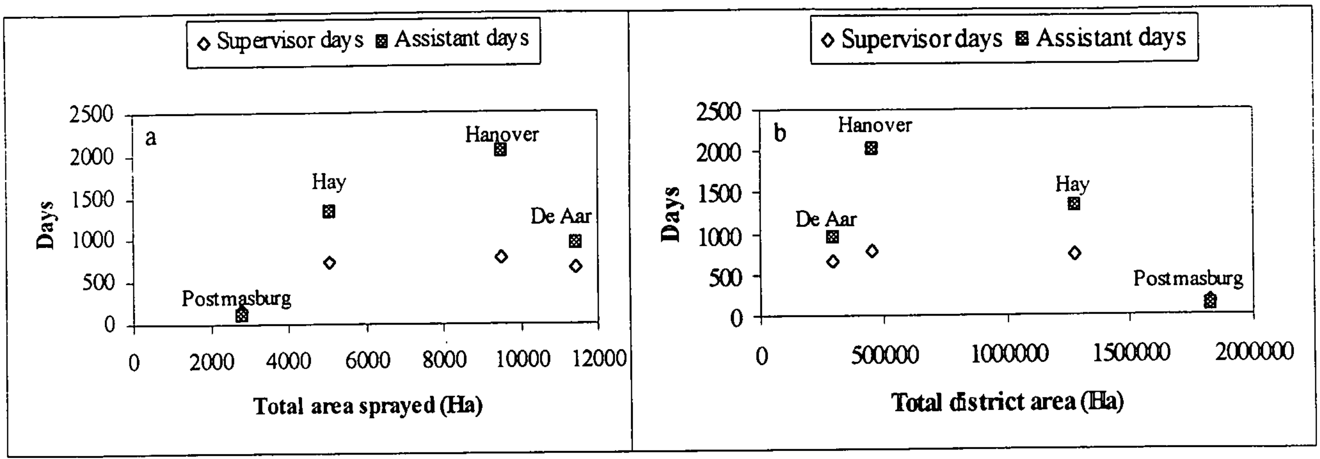


Figure 4.27 The number of supervisor and assistant days involved in locust control in the four districts relative to the treated and total district areas.

Chapter 5

Criterion: Finances

Introduction

The stock farmer currently has to pay the highest price (in terms of inconvenience) for locust control to protect crops from possible damage in the agronomic sectors. As a result of this, communities, with special reference to individuals such as the DLO, supervisors and assistants are involved in the control of a national and international threat and are therefore entitled to financial compensation. The control benefit has to be divided between farmers, interest groups, districts, provinces and countries, which argues favourably for the fact that all of them should make financial inputs (Heyns *et al.*, 1995).

In reviewing the financial criterion the following must be taken into consideration: (a) expenses per supervisor and region, (b) the damage to the natural pastures and damage averted by chemical control of the brown locust. The latter is based on the nutritional requirements of the hopper and adult stages under field conditions.

Chapter 5 analyses and evaluates the distribution of expenses among the various interest groups, financial impact on grazing and determines whether the campaign was justifiable by means of a cost benefit analysis.

Results and discussion

The expenditure of each district consisted of the following components: cost of pesticide, travel cost, supervisor wages and assistant wages (table 2.2). The diverse costs are currently not incorporated and can easily be included in the information system. Apart from receiving wages, the supervisors and DLO's also received a subsidy per kilometre for travelling expenses in combating locusts. Not all the supervisors received remuneration, since some controlled locusts free of cost. The free control activities should benefit the respective district and campaign due to the reduction in expenditure. In these cases only the cost of the pesticide is added to the total district expenditure. On the other hand the fact that free-supervisors existed, proofed to be negative in the sense that all the calculations could not be done.

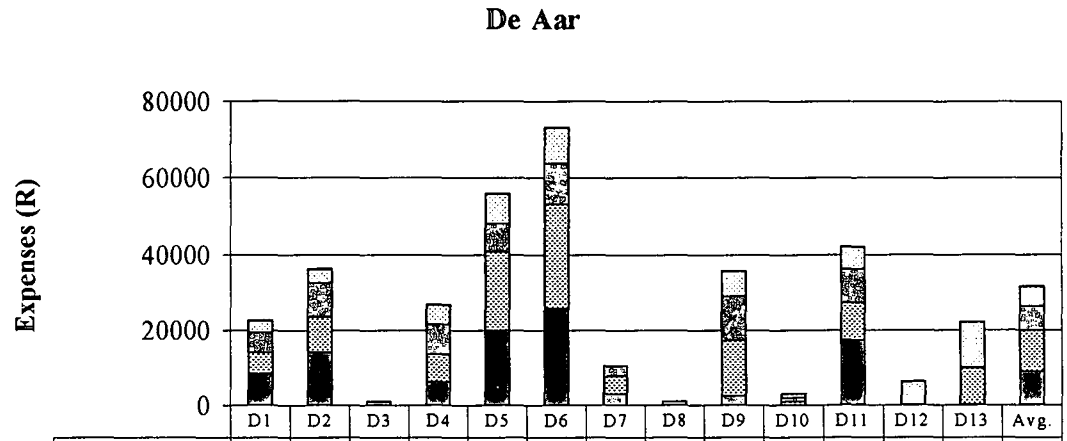
Table 5.1 listed the supervisors in the various districts who worked for free. In the Hanover district no free supervisors or labourers were reported. Some of the free supervisors did not report all the control information required in tables 2.1 and 2.2. Examples of these were supervisors HY11 and P3 who did not report the quantity of pesticide applied. Consequently the expenses for these pesticides could not be calculated. In October 1996 the price of the pesticide was R12,00 per litre and for the remainder of the campaign the cost increased to R12,43 per litre.

Table 5.1 The supervisors who worked for free in the various districts

De Aar	D3		
Hay	HY11		
Postmasburg	P3	P5	P6

Apart from not reporting the travel cost, the free supervisors also did not claim any wages. The fields *Supervisor wages* and *Assistant wages* as well as the fields *Supervisor days* and *Assistant days* and the resulting *Man days* could therefore not be calculated. The direct effect of the unknown data in the records can be seen in figures 4.1 to 4.8. On district level the cumulative effect is also shown in figures 4.9 to 4.12.

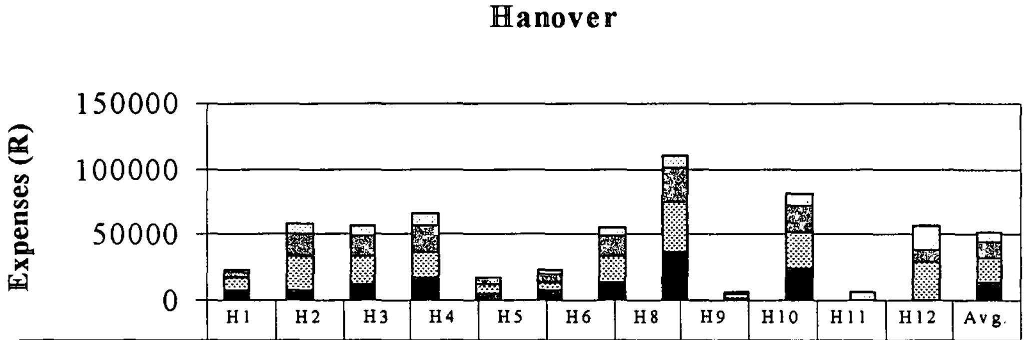
All the variables in figures 5.1 to 5.4 were calculated as the campaign totals for each supervisor in the district. The series *Supervisor wages*, *Assistant wages*, *Travel (R)* and *Pesticide (R)* were calculated as the sum per supervisor of the fields (in table 2.2) *Supervisor wages, Assistant. wages, Travel cost (R)* and *Pesticide (R)* respectively.



	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	Avg.
☐ Supervisor wages	2983	4158		5153	8136	9492	723	181	6870	633	6057	6509	11849	5229
▩ Assistant wages	5157	8888		7586	7396	10517	1854	271	11331	1289	8564			6285
▨ Travel(R)	5966	9178		7378	20813	27325	4719		14480	916	10057		10011	11084
▩ Pesticide (R)	8369	14101	994	6471	19710	25830	3244	406	2869	47	17310			9032

Supervisors

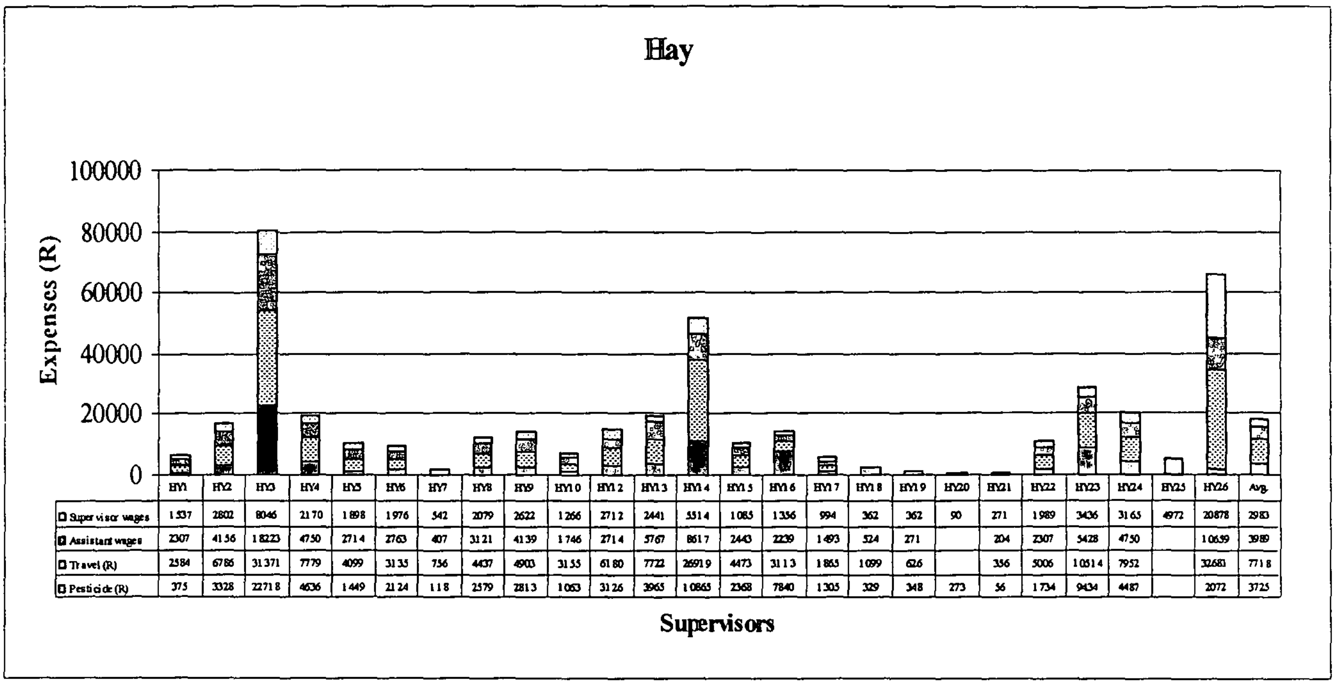
Figure 5.1 The total expenses per supervisor in the De Aar district in the 1996/97 locust control campaign.



	H1	H2	H3	H4	H5	H6	H8	H9	H10	H11	H12	Avg.
☐ Supervisor wages	1989	7322	7232	8136	1718	2802	9854	633	8407	5424	18540	6570
▩ Assistant wages	4342	16488	15470	19609	3867	6174	25919	1425	20355		8820	12577
▨ Travel (R)	9118	26187	21930	21381	7682	5662	38215	2057	28281		29468	19066
■ Pesticide (R)	7277	7697	12204	16092	4176	7557	36675	1990	23763			13078

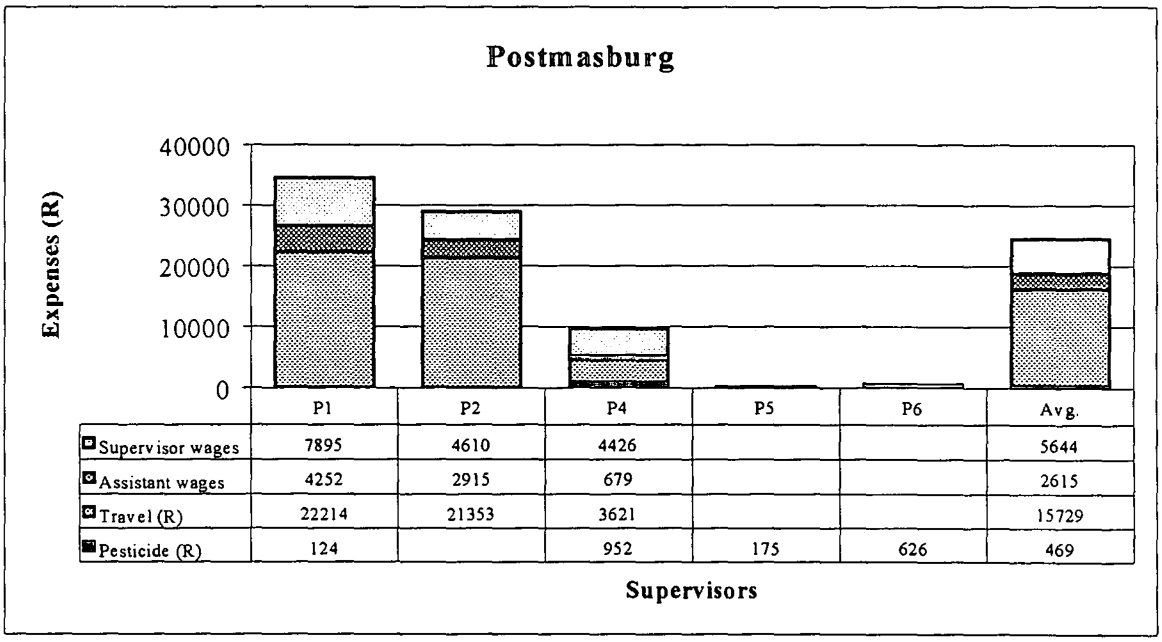
Supervisors

Figure 5.2 The total expenses per supervisor in the Hanover district in the 1996/97 locust control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY25	HY26	Avg.
Supervisor wages	1537	2802	8046	2170	1898	1976	542	2079	2622	1266	2712	2441	5514	1085	1356	994	362	362	90	271	1989	3436	3165	4972	20878	2983
Assistant wages	2307	4136	18223	4750	2714	2763	407	3121	4139	1746	2714	5767	8617	2443	2239	1493	524	271		204	2307	5428	4750		10639	3989
Travel (R)	2584	6786	31371	7779	4099	3135	756	4437	4903	3155	6180	7722	26919	4473	3113	1863	1099	626		356	5006	10514	7952		32681	7718
Pesticide (R)	375	3328	22718	4636	1449	2124	118	2579	2813	1063	3126	3965	10865	2368	7840	1305	329	348	273	56	1734	9434	4487		2072	3725

Figure 5.3 The total expenses per supervisor in the Hay district in the 1996/97 locust control campaign.



	P1	P2	P4	P5	P6	Avg.
Supervisor wages	7895	4610	4426			5644
Assistant wages	4252	2915	679			2615
Travel (R)	22214	21353	3621			15729
Pesticide (R)	124		952	175	626	469

Figure 5.4 The total expenses per supervisor in the Postmasburg district in the 1996/97 locust control campaign.

Figures 5.1 to 5.4 compares the total expenses per supervisor and also compares the average expenses among the districts. From figure 5.1 it is clear that supervisor D3 controlled locusts for free. Supervisor D3 recorded only the pesticide sprayed. The same applied for supervisors P5 and P6 in figure 5.4. Supervisors HY11 and P3 also worked for free, but did not report the amount of pesticide sprayed with the result that the cost of pesticide could not be calculated for them. They were consequently not listed in the figures.

Supervisors D8 and HY20 did not claim any remuneration for their travel expenses and HY20 did not claim for any assistants (figure 4.7). Entities D12, H11 and HY25 (figures 5.1, 5.2 and 5.3) were the secretaries in the respective districts and did not control any locusts. Their wages were added to the district total. In the Postmasburg district all the supervisors controlled locusts and no secretary was appointed.

The highest average expense for any of the four components was recorded in the Hanover district (figures 5.1 to 5.4). This could be explained by the fact that the highest number of bands and swarms was controlled in the Hanover district (figures 3.13 to 3.16). The lowest value for assistant wages was in the Postmasburg district. This correlated with the fact that the lowest number of assistant days was also recorded in the Postmasburg district (figures 4.5 to 4.8). The lowest average value for the cost of pesticides was also recorded in the Postmasburg district. The lowest average value for supervisor wages and travel cost was recorded in the Hay district. According to figures 4.1 to 4.4 the lowest number of kilometres as well as supervisor days were also recorded in the Hay district.

As was the case in equation (4.3) the average values for the series in figures 5.1 to 5.4 were calculated by adding the particular series, for instance *Supervisor wages*, for all the supervisors in that district and dividing it by the number of supervisors with series values greater than zero. Supervisors with zero values for that particular series were not included in the equation.

Figure 5.5 is a breakdown analysis of the expenses in the four districts for the 1996/97 campaign. The district average values in figures 5.1 to 5.4 were used to compare the district expenses in figure 5.5. The travelling expenses were the single largest component. Pesticides, except for the Postmasburg district, constituted a large percentage of the expenditure. The lowest amount of litre sprayed per hectare occurred in the Postmasburg district (figures 3.1 to 3.4) which can be ascribed to the quality of reports returned by the supervisors.

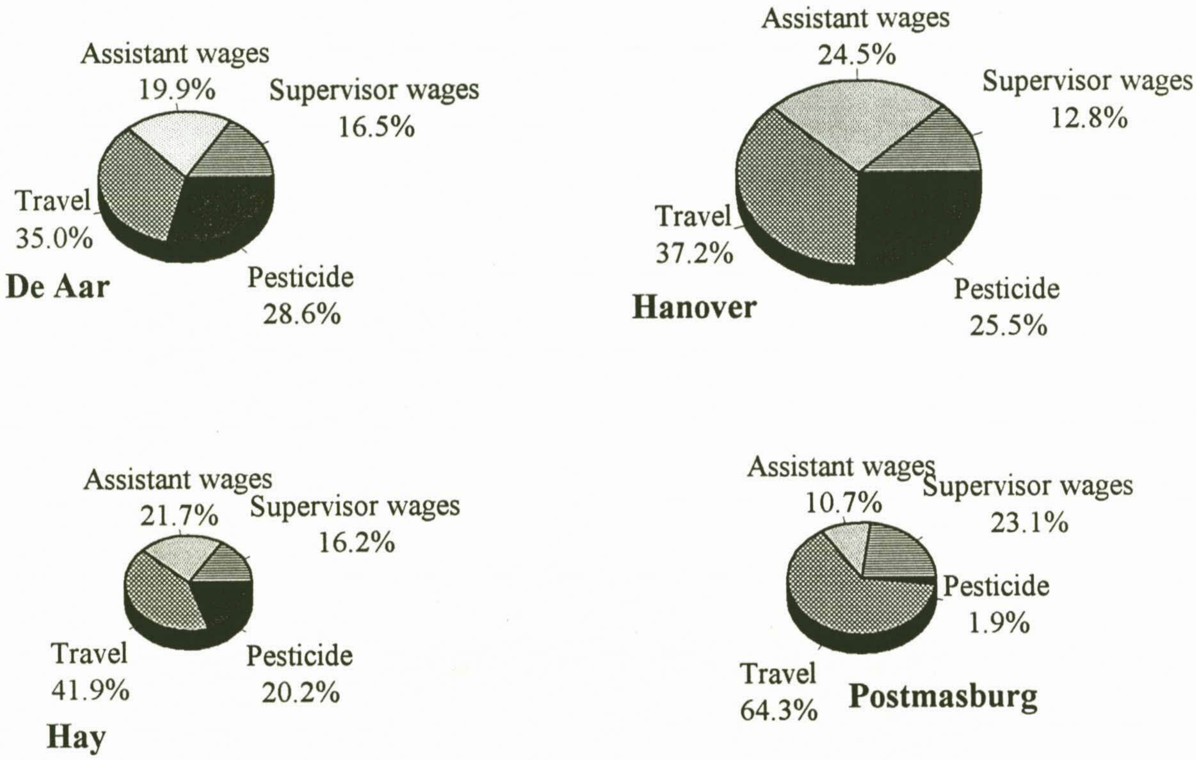


Figure 5.5 Component analysis of the major financial implication of locust control within the various districts (1996/97 campaign.

The pesticide expenses would have contributed a far larger percentage in figure 5.5 if the average application rate in the Postmasburg district was closer to the registered rate. The fact that P2 and P3 (figure 3.8) did not report the amount of pesticides sprayed, also contributed to the low l/ha value (figure 3.4). This further emphasises the fact that data obtained in the campaigns should be accurate and complete.

In figures 5.6 to 5.9 every supervisor's expenses per band and swarm controlled are reflected. The figures reflect the district averages. If a certain value was not entered for a specific supervisor into figures 5.1 to 5.4, the corresponding value per band and swarm also lacks in figures 5.6 to 5.9. For instance supervisor D8 in figure 5.1 had no value recorded for travel expenses and thus no value for travel expenses per band and swarm was recorded in figure 5.6. Although the number of bands and swarms controlled by these supervisors were known (figures 3.5 to 3.8), a zero expense value divided by any number of bands and swarms would have resulted in an answer of zero. This could be misinterpreted as a low (= o) expenses for that particular parameter. For this reason the particular parameter could not be calculated and correspondingly no value was entered into the figures under these circumstances. The parameters do not include the supervisors' total expenses, but eliminate expenses with regards to e.g. scouting for locusts. The expenses therefore reflect actual control actions by the supervisors. The parameters are all fields in table 2.2.

The variables in figures 5.6 to 5.9 were calculated by using the following formulas for each supervisor:

$$Sup/BS\ (R) = \frac{BaSupW + SwSupW}{(\#Bands{+}\#Swarms)} \tag{5.1}$$

$$Asst./BS\ (R) = \frac{BaAsstW + SwAsstW}{(\#Bands{+}\#Swarms)} \tag{5.2}$$

$$Travel/BS\ (R) = \frac{BaTR + SwTR}{(\#Bands{+}\#Swarms)} \tag{5.3}$$

$$Pest/BS\ (R) = \frac{BaPestR + SwPestR}{(\#Bands{+}\#Swarms)} \tag{5.4}$$

All the variables in equations (5.1) to (5.4) are fields in table 2.2. The district average (Avg.) was calculated by using the following formula:

$$Avg.\ of\ Sup/BS\ (R) = \frac{SUM((BaSupW + SwSupW)X{:}(BaSupW + SwSupW)Y)}{SUM((\#Bands{+}\#Swarms)X{:}(\#Bands{:}\#Swarms)Y)} \tag{5.5}$$

The variables *BaSupW* and *SwSupW* are the supervisor wages per band or swarm respectively. *(BaSupW* + *SwSupW)X* and *(BaSupW* + *SwSupW)Y* are the supervisor wages for all the supervisors in any given district. In the same way *(#Bands* + *#Swarms)X* and *(#Bands* + *#Swarms)Y* are the total number of bands and swarms controlled by each supervisor. The average district values of equations (5.2) to (5.4) are calculated in equation (5.5) by substituting *[SUM(BaSupW* + *SwSupW)X : (BaSupW* + *SwSupW)Y]* as the numerator with *[SUM(BaAsstW* + *SwAsstW)X : (BaAsstW* + *AsstW)Y], [SUM(BaTR* + *SwTR)X : (BaTR* + *SwTR)Y] or [SUM(BaPestR* + *SwPestR)X : (BaPestR* + *SwPestR)Y]* respectively in each equation.

The denominator remains *[SUM((#Bands + #Swarms)X : (#Bands + #Swarms)Y)]* in all cases.

The average values in figures 5.6 to 5.9 were calculated taking in account only those supervisors who actually controlled locusts. The values for the secretaries and the DLO's who did not combat locusts were consequently not entered into the respective equations.

From equation (5.5) it is apparent that the supervisors who worked for free were actually a benefit to the district. The same applies to the values obtained from equation (5.10) which are reflected in figures 5.10 to 5.13.

Figures 5.6 to 5.9 reflect the actual control expenses and figures 5.10 to 5.13 the expenses per hectare locust controlled. The district averages are also reflected in the figures. The same principle that applied in figures 5.6 to 5.9 concerning free labourers also applies with figures 5.10 to 5.13.

The variables in figures 5.10 to 5.13 were calculated by using the following formulas for each supervisor:

$$Sup/ha\ (R) = \frac{BaSupW + SwSupW}{Hectare} \qquad (5.6)$$

$$Asst./ha\ (R) = \frac{BaAsstW + SwAsstW}{Hectare} \qquad (5.7)$$

$$Travel/ha\ (R) = \frac{BaTR + SwTR}{Hectare} \qquad (5.8)$$

$$Pest/ha\ (R) = \frac{BaPestR + SwPestR}{Hectare} \qquad (5.9)$$

All the variables in equations (5.6) to (5.9) are listed in table 2.2. The district average (Avg.) was calculated by using the following formula:

$$Avg.\ of\ Sup/ha\ (R) = \frac{SUM((BaSupW + SwSupW)X{:}(BaSupW + SwSupW)Y)}{SUM(HectareX{:}HectareY)} \qquad (5.10)$$

(BaSupW + SwSupW)X and (BaSupW + SwSupW)Y are the supervisor wages for all the supervisors in any given district. In the same way *HectareX* and *HectareY* indicates the total of the number of hectares sprayed per supervisor. The average district values of equations (5.7) to (5.9) are calculated in equation (5.10) by *substituting [SUM(BaSupW + SwSupW)X : (BaSupW + SwSupW)Y]* as the numerator

with *[SUM(BaAsstW + SwAsstW)X : (BaAsstW + AsstW)Y], [SUM(BaTR + SwTR)X : (BaTR + SwTR)Y] or [SUM(BaPestR + SwPestR)X : (BaPestR + SwPestR)Y]* respectively in each equation. The denominator remains *[SUM(HectareX : Hectare)Y)].*

The average values in figures 5.10 to 5.13 were calculated taking in account only those supervisors who actually controlled locusts. The information of the secretaries and the DLO's who did not combat locusts were not used in the respective equations.

Supervisors D10 and H4 had the highest expenses per hectare for the De Aar and Hanover districts respectively (figures 5.10 and 5.11). Both supervisors sprayed locusts on an area smaller than the district average (figures 3.1 and 3.2), especially D10 who controlled locusts on an area of 0,664 ha. The highest contributing factors to these supervisors' expenses were the variables *Asst/ha (R)* and *Travel/ha (R)* (figures 5.10 and 5.11). These values were much higher than the district averages. It was sometimes necessary for the supervisors to scout for the locusts, equipped with assistants and spraying apparatus, resulting in a number of kilometres travelled without actually spraying locusts. The actual number of bands and swarms controlled by these supervisors were in each case lower than the district average (figures 3.5 and 3.6). This could have resulted in higher travelling and wage expenses.

The recommended application rate of Decis® is 2,5 l/ha (Heyns *et al.*, 1995; Krause *et al.*, 1996). Supervisors D10 and H4 had an average application rate of 5,67 and 7,024 l/ha (figures 3.1 and 3. 2). This accounts for the high expenses in pesticide sprayed per hectare (figures 5.10 and 5.11). These values were also higher than the district average.

Figures 5.12 and 5.13 shows supervisors HY7 and P4 having had far greater expenses per hectare than the average value. According to figures 3.3 and 4.3, supervisor HY7 controlled locusts on an area of one hectare and drove 275 kilometres in doing so. He furthermore applied an average of 7,446 l/ha, which all accounts for his expenses per hectare that exceeded the district average by far.

Supervisors P3, P5 and P6 worked for free (table 5.1). This left only supervisors P1, P2 and P4 (half the number of supervisors in Postmasburg) to receive remuneration for their control actions. Supervisor P2 did not report any pesticides (figure 3.8) and P1 sprayed at a very low application rate of 0,007 l/ha (figure 3.4), which is in sharp contrast to the 2,5 l/ha recommended application rate. Supervisor P4 was therefore the only supervisor in the Postmasburg district who received full remuneration and sprayed close to the correct application rate (figures 3.4, 5.4 and 5.13), resulting in a relative low average expense per hectare in the Postmasburg district. This average low expense per hectare usually reflects positively on a district, in contrast to a district that has high expenses per hectare or per band and swarm.

In contrast to supervisor P4, HY7's expenses were high due to over-spraying, far travelling and employing assistants without spraying much. P4's *Sup/ha (R)* and *Travel/ha (R)* were the highest single components adding to his total expenses per hectare and was due to the time spent for travelling and scouting. The rest of his expenses per hectare compared well with the averages obtained in the other districts (figures 5.10 to 5.13).

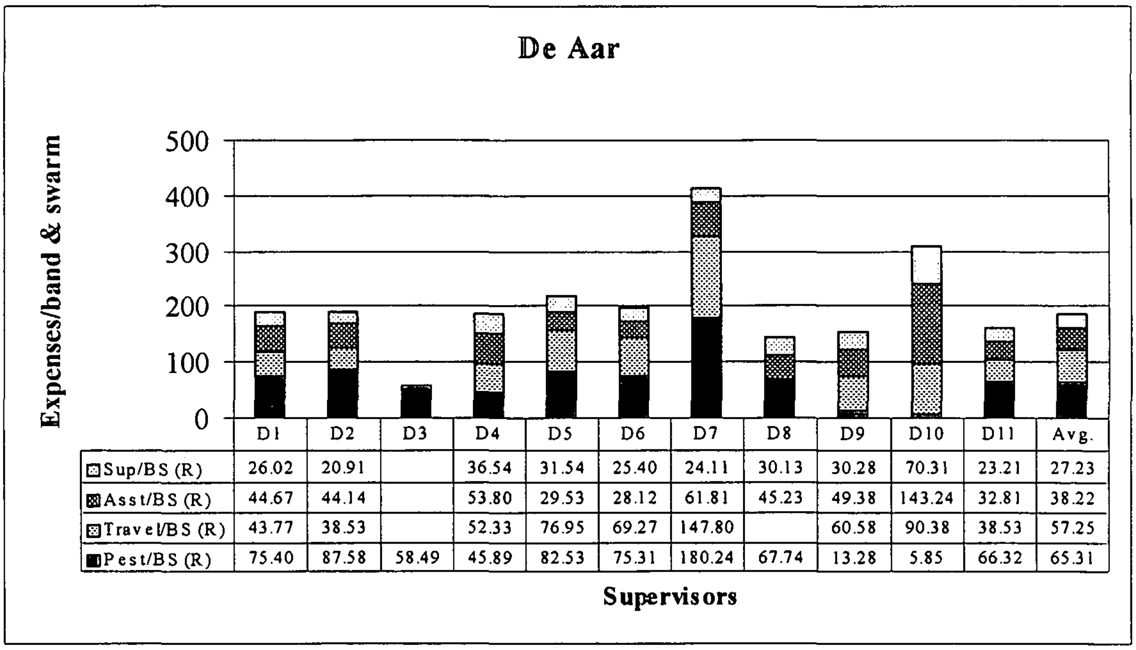
Table 5.2 Expenses (R) per band or swarm and the average expense per hectare sprayed.

District	Expenses/band or swarm	Expenses/ha
De Aar	188,01	25,03
Hanover	76,64	43,52
Hay	180,58	70,07
Postmasburg	75,94	23,17

Table 5.2 summarises the average expense per district as reflected in figures 5.6 to 5.13. The expenses per band or swarm controlled are the total expenses per district (excluding expenses related to scouting) divided by the total number of bands and swarms controlled in that district. This equation did not provide for the difference in sizes between bands and swarms, but simply give a rough estimate of the cost involved in controlling either a band or a swarm. In the De Aar district the high cost were due to the high expenses for travelling, pesticides and assistant wages. The high expenses in the Hay district was due to high travelling costs, but if the relative size of

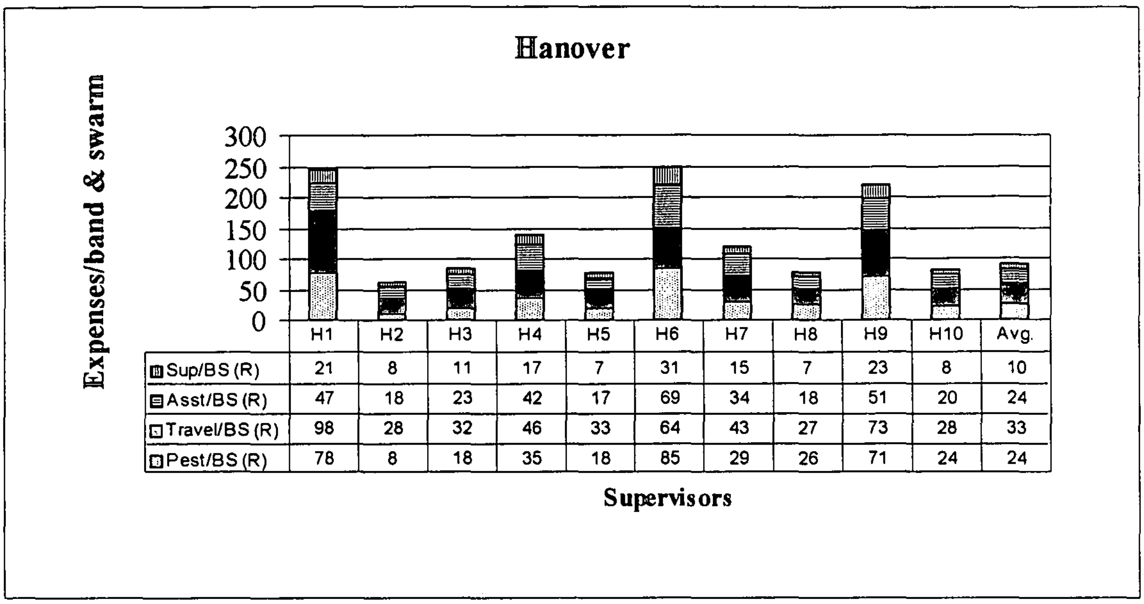
this district is taken into account, this might be justified (table 4.1). The high supervisor wages in the Postmasburg district was the result of more supervisor days than assistant days (figure 4.9). This was the only district were fewer assistant days than supervisor days were recorded.

The expenses per ha were determined by dividing the total expenses per district (excluding expenses related to scouting) by the total number of hectares sprayed in a district. The highest expense in the Hay district was for travelling, which is justified by the relative size of this district. Since all the supervisors in the Hanover district received full remuneration, Hanover is the only district reflecting a true scenario for locust control.



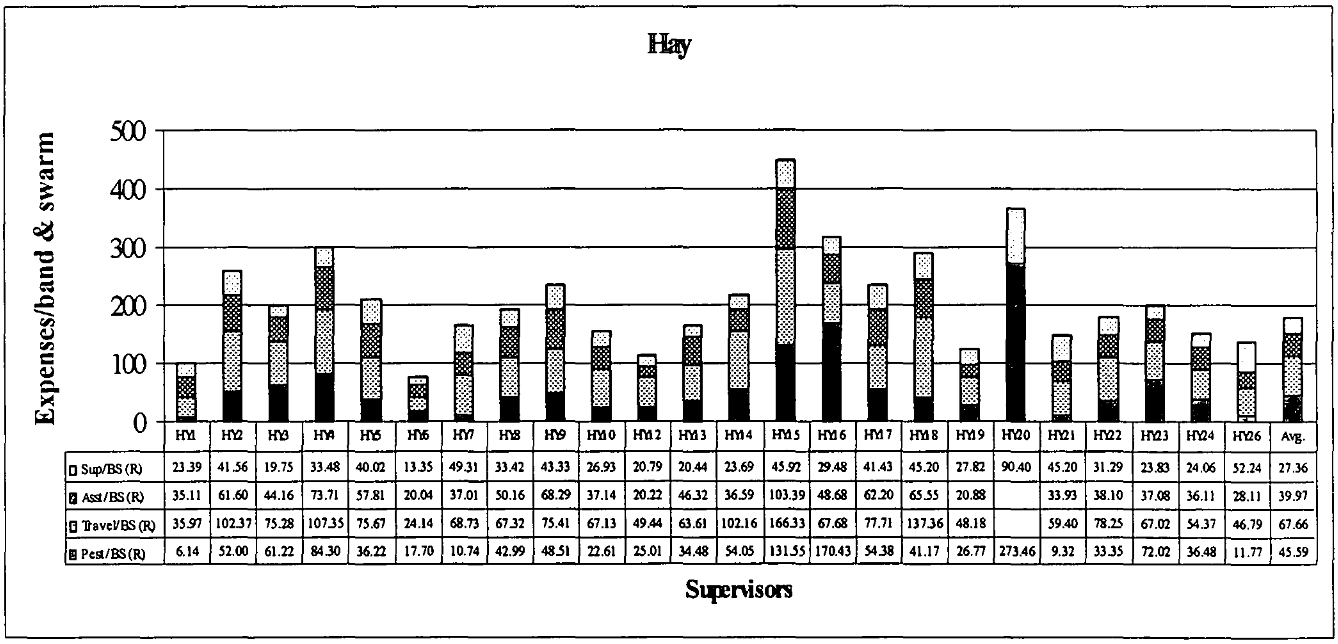
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
▨ Sup/BS (R)	26.02	20.91		36.54	31.54	25.40	24.11	30.13	30.28	70.31	23.21	27.23
▩ Asst/BS (R)	44.67	44.14		53.80	29.53	28.12	61.81	45.23	49.38	143.24	32.81	38.22
▨ Travel/BS (R)	43.77	38.53		52.33	76.95	69.27	147.80		60.58	90.38	38.53	57.25
■ Pest/BS (R)	75.40	87.58	58.49	45.89	82.53	75.31	180.24	67.74	13.28	5.85	66.32	65.31

Figure 5.6 Supervisor -, assistant wages, travel cost and the cost of pesticides per band or swarm controlled in the De Aar district in the 1996/97 control campaign.



	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Avg.
▥ Sup/BS (R)	21	8	11	17	7	31	15	7	23	8	10
▤ Asst/BS (R)	47	18	23	42	17	69	34	18	51	20	24
■ Travel/BS (R)	98	28	32	46	33	64	43	27	73	28	33
▨ Pest/BS (R)	78	8	18	35	18	85	29	26	71	24	24

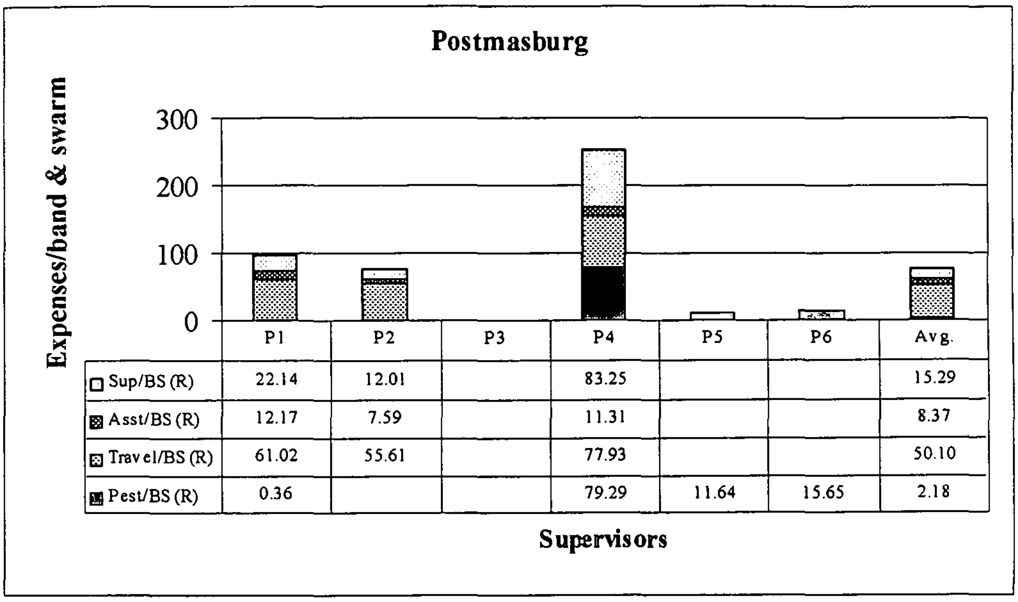
Figure 5.7 Supervisor -, assistant wages, travel cost and the cost of pesticides per band or swarm controlled in the Hanover district in the 1996/97 control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY12	HY13
□ Sup/BS (R)	23.39	41.56	19.75	33.48	40.02	13.35	49.31	33.42	43.33	26.93	20.79	20.44
▩ Asst/BS (R)	35.11	61.60	44.16	73.71	57.81	20.04	37.01	50.16	68.29	37.14	20.22	46.32
▨ Travel/BS (R)	35.97	102.37	75.28	107.35	75.67	24.14	68.73	67.32	75.41	67.13	49.44	63.61
■ Pest/BS (R)	6.14	52.00	61.22	84.30	36.22	17.70	10.74	42.99	48.51	22.61	25.01	34.48

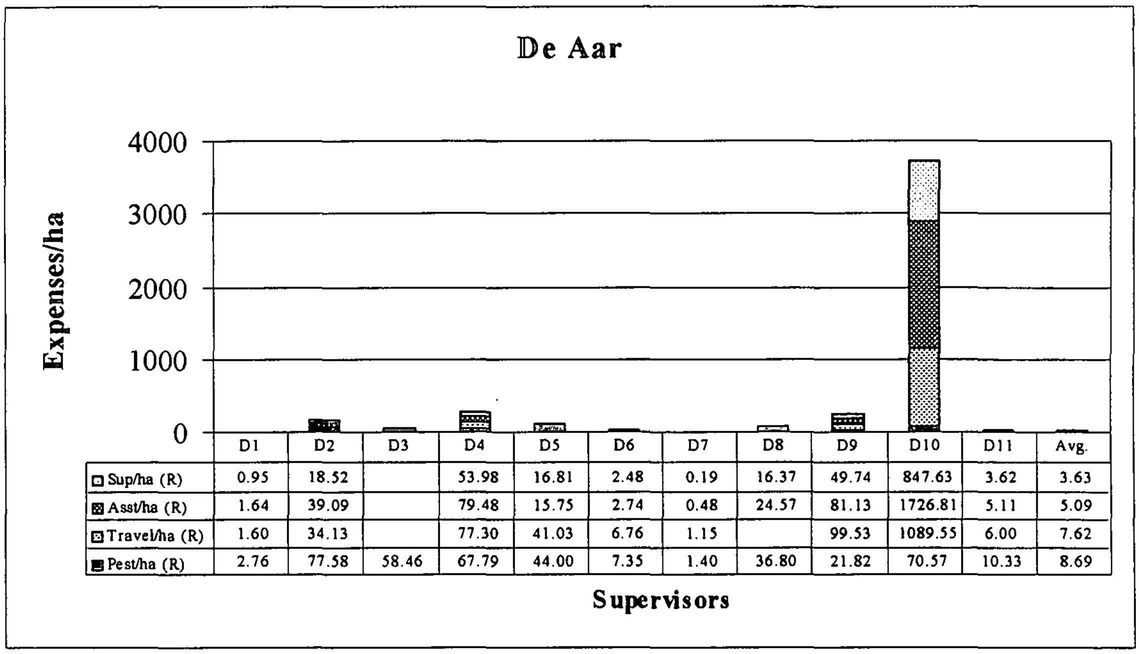
	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY26	Avg.
□ Sup/BS (R)	23.69	45.92	29.48	41.43	45.20	27.82	90.40	45.20	31.29	23.83	24.06	52.24	27.36
▩ Asst/BS (R)	36.59	103.39	48.68	62.20	65.55	20.88		33.93	38.10	37.08	36.11	28.11	39.97
▨ Travel/BS (R)	102.16	166.33	67.68	77.71	137.36	48.18		59.40	78.25	67.02	54.37	46.79	67.66
■ Pest/BS (R)	54.05	131.55	170.43	54.38	41.17	26.77	273.46	9.32	33.35	72.02	36.48	11.77	45.59

Figure 5.8 Supervisor -, assistant wages, travel cost and the cost of pesticides per band or swarm controlled in the Hay district in the 1996/97 control campaign.



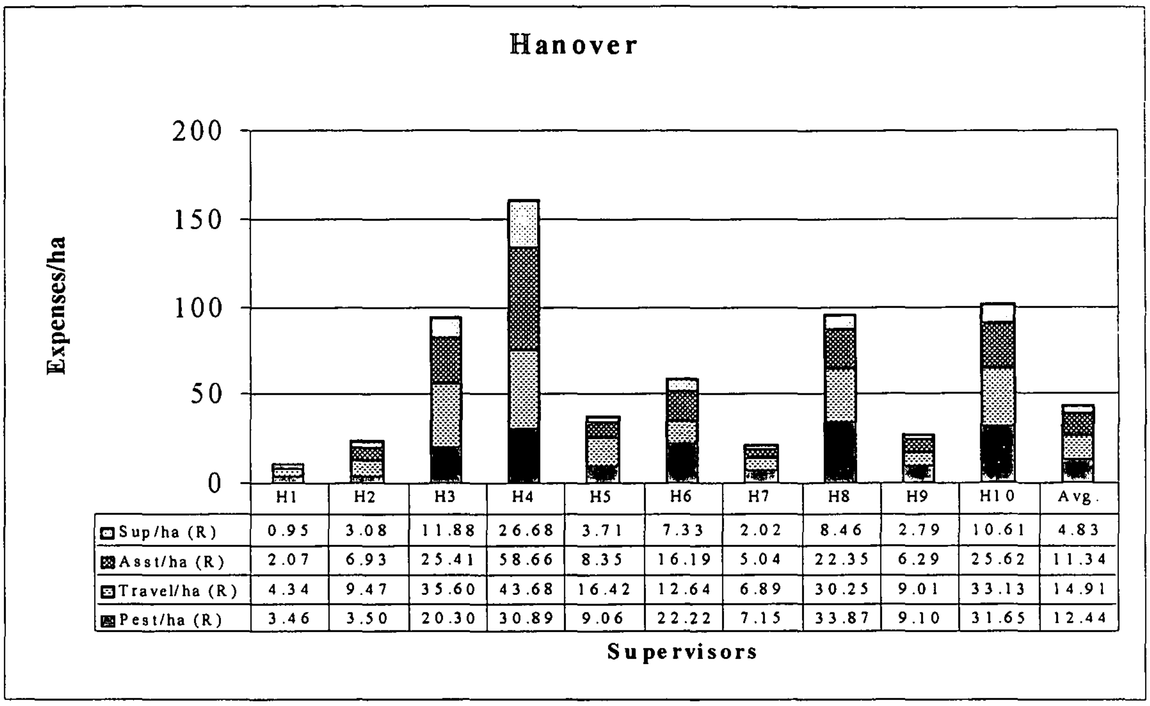
	P1	P2	P3	P4	P5	P6	Avg.
□ Sup/BS (R)	22.14	12.01		83.25			15.29
▩ Asst/BS (R)	12.17	7.59		11.31			8.37
▨ Travel/BS (R)	61.02	55.61		77.93			50.10
■ Pest/BS (R)	0.36			79.29	11.64	15.65	2.18

Figure 5.9 Supervisor -, assistant wages, travel cost and the cost of pesticides per band or swarm controlled in the Postmasburg district in the 1996/97 control campaign.



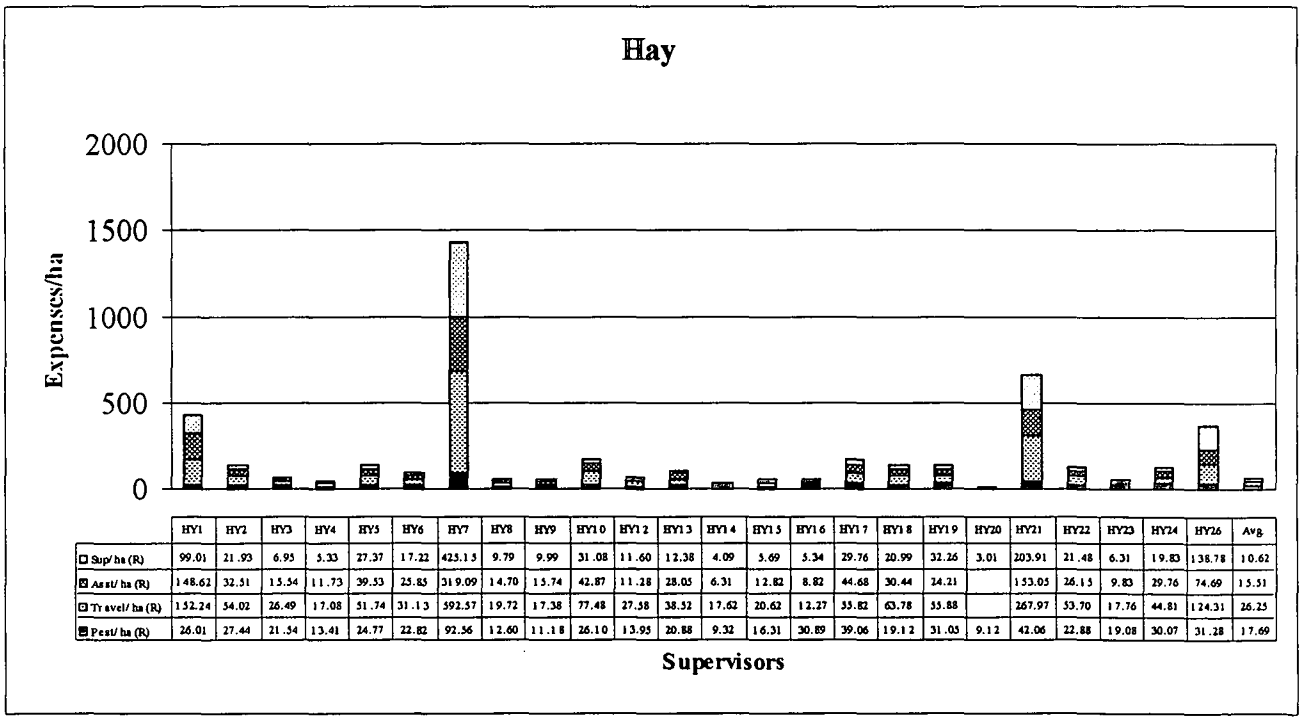
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
□ Sup/ha (R)	0.95	18.52		53.98	16.81	2.48	0.19	16.37	49.74	847.63	3.62	3.63
▩ Asst/ha (R)	1.64	39.09		79.48	15.75	2.74	0.48	24.57	81.13	1726.81	5.11	5.09
▨ Travel/ha (R)	1.60	34.13		77.30	41.03	6.76	1.15		99.53	1089.55	6.00	7.62
■ Pest/ha (R)	2.76	77.58	58.46	67.79	44.00	7.35	1.40	36.80	21.82	70.57	10.33	8.69

Figure 5.10 Supervisor -, assistant wages, travel cost and the cost of pesticides per hectare sprayed in the De Aar district in the 1996/97 control campaign.



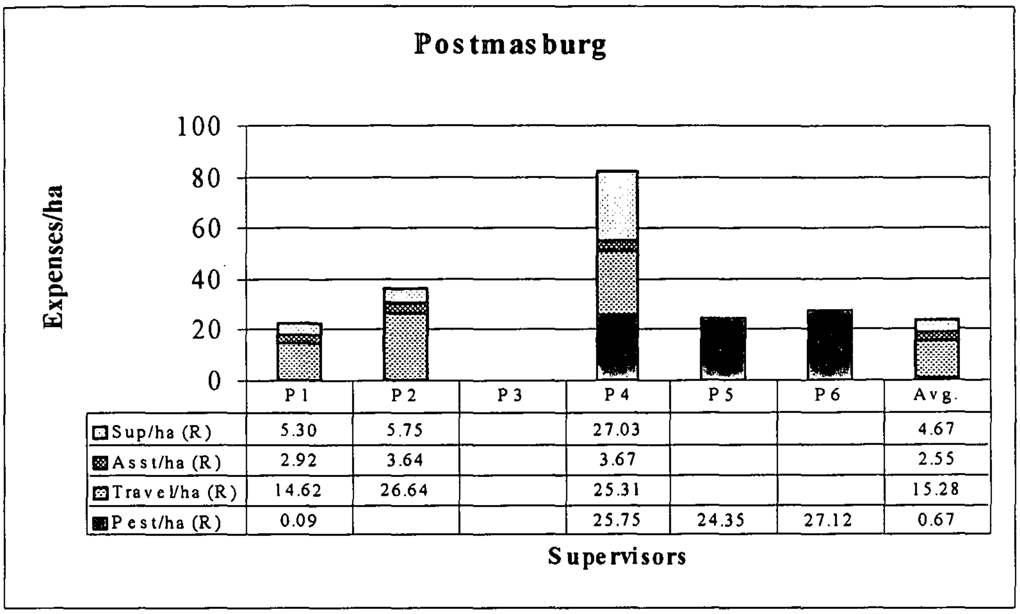
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Avg.
☐ Sup/ha (R)	0.95	3.08	11.88	26.68	3.71	7.33	2.02	8.46	2.79	10.61	4.83
▩ Asst/ha (R)	2.07	6.93	25.41	58.66	8.35	16.19	5.04	22.35	6.29	25.62	11.34
▤ Travel/ha (R)	4.34	9.47	35.60	43.68	16.42	12.64	6.89	30.25	9.01	33.13	14.91
■ Pest/ha (R)	3.46	3.50	20.30	30.89	9.06	22.22	7.15	33.87	9.10	31.65	12.44

Figure 5.11 Supervisor -, assistant wages, travel cost and the cost of pesticides per hectare sprayed in the Hanover district in the 1996/97 control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY26	Avg
☐ Sup/ha (R)	99.01	21.93	6.95	5.33	27.37	17.22	425.15	9.79	9.99	31.08	11.60	12.38	4.09	5.69	5.34	29.76	20.99	32.26	3.01	203.91	21.48	6.31	19.83	138.78	10.62
▩ Asst/ha (R)	148.62	32.51	15.54	11.73	39.53	25.85	319.09	14.70	15.74	42.87	11.28	28.05	6.31	12.82	8.82	44.68	30.44	24.21		153.05	26.15	9.83	29.76	74.69	15.51
▤ Travel/ha (R)	152.24	54.02	26.49	17.08	51.74	31.13	592.57	19.72	17.38	77.48	27.58	38.52	17.62	20.62	12.27	55.82	63.78	55.88		267.97	53.70	17.76	44.81	124.31	26.25
■ Pest/ha (R)	26.01	27.44	21.54	13.41	24.77	22.82	92.56	12.60	11.18	26.10	13.95	20.88	9.32	16.31	30.89	39.06	19.12	31.05	9.12	42.06	22.88	19.08	30.07	31.28	17.69

Figure 5.12 Supervisor -, assistant wages, travel cost and the cost of pesticides per hectare sprayed in the Hay district in the 1996/97 control campaign.



	P 1	P 2	P 3	P 4	P 5	P 6	Avg.
☐ Sup/ha (R)	5.30	5.75		27.03			4.67
▩ Asst/ha (R)	2.92	3.64		3.67			2.55
▨ Travel/ha (R)	14.62	26.64		25.31			15.28
■ Pest/ha (R)	0.09			25.75	24.35	27.12	0.67

Figure 5.13 Supervisor -, assistant wages, travel cost and the cost of pesticides per hectare sprayed in the Postmasburg district in the 1996/97 control campaign.

In figures 5.15 to 5.18 the investment return factor (IRF) for the hopper bands and adult swarms controlled by each supervisor in the various districts is displayed. From the figures the district averages (Avg.) can also be compared. These values were calculated using the formulas in table 5.3.

Table 5.3 List of the column references, series and formulas used to calculate the variables concerning the investment return factor.

Column reference	Series		Formula
A	Supervisor		Supervisor name
B	*# Bands*		Sum of *# Bands* for A
C	*# Swarms*		Sum of *# Swarms* for A
D	Hopper area (ha)		Sum of *Bands Ha* for A
E	Swarm area (ha)		Sum of *Swarms Ha* for A
F	Pesticide (R)	Hoppers	Sum of *BaPest(R)* for A
G		Adults	Sum of *SwPest(R)* for A
H	Travel (R)	Hoppers	Sum of *BaT(R)* for A
I		Adults	Sum of *SwT(R)* for A

Table 5.3 (Continued)

J	Assistant wages	Hoppers	Sum of *BaAsstW* for A
K		Adults	Sum of *SwAsstW* for A
L	Supervisor wages	Hoppers	Sum of *BaSupW* for A
M		Adults	Sum of *SwSupW* for A
N	Total hoppers		=D3*10000*295
O	Total adults		=E3*10000*302
P	Hoppers vs. adults %	Hoppers	=N3/SUM(N3:O3)*100
Q		Adults	=O3/SUM(N3:O3)*100
R	Actual damage tons	Hopper	=(N3*0.0066)/1 000
S		Adult	=O3*(6.6+(14*0.45))/1 000 000
T		Total	=SUM(R3:S3)
U	Potential damage tons	Hopper	=(N3*0.0351)/1 000
V		Adult	=O3*(35.1-(14*0.45))/1 000 000
W		Total	=SUM(U3:V3)
X	Actual damage (R)	Hopper	=R3/0.56*75
Y		dult	=S3/0.56*75
Z	Potential damage (R)	Hopper	=U3/0.56*75
AA		Adult	=V3/0.56*75
AB	Hopper control cost		=F3+H3+J3+L3
AC	Adult control cost		=G3+I3+K3+M3
AD	Expenses		=SUM(AB3:AC3)
AE	IRF	Hoppers	=(Z3/AB3)
AF		Adults	=(AA3/AC3)
AG	Average IRF		=(SUM(Z3:AA3)/SUM(AB3:AC3))

Column reference A in table 5.3 represents the names or codes of the different supervisors. Table 5.3 is an example of the calculations for the supervisor entered into row 3 in a Microsoft ® Excel spreadsheet. By entering the district totals in the same way, the IRF for a district can be obtained. The series in column references B to M are the totals per supervisor (table 2.2).

Column references N and O calculate the total number of either hoppers or adults controlled by the supervisor. According to Van der Westhuizen & Botha (1997) an average of 295 hoppers and 302 adults per square metre were used in the calculations of the numbers of locusts controlled. Since area in hectare was entered into column references D and E, multiplication by 10 000 was necessary to convert hectare to square metres.

The percentage hoppers vs. adults controlled is calculated in column references P and Q, based on the relative numbers obtained in column references N and O.

Column references R and S compute the damage (ton) by the hoppers (bands) and adults (swarms) to natural pasture. The pasture impact and averted impact were based on the nutritional requirements of the hopper and adult stages under field conditions. To estimate the grazing impact of these swarms, the hopper bands were assumed to be in the late immature stages and the adult swarms as being two weeks after maturity. This assumption worked favourably in respect of the damage caused and conservatively in respect to the damage averted by control. In figure 5.14 the food requirements and cumulative food requirements of the different developmental stages of the brown locust is illustrated (Coetzee, 1994). The total food requirements of the five immature stages and the adult are respectively 6.6 g and 35.1 g per locust. This implied a saving of more than 80% in total impact per locust if the swarm is controlled during the hopper stages (Steenkamp, Botha & Van der Westhuizen, 1997).

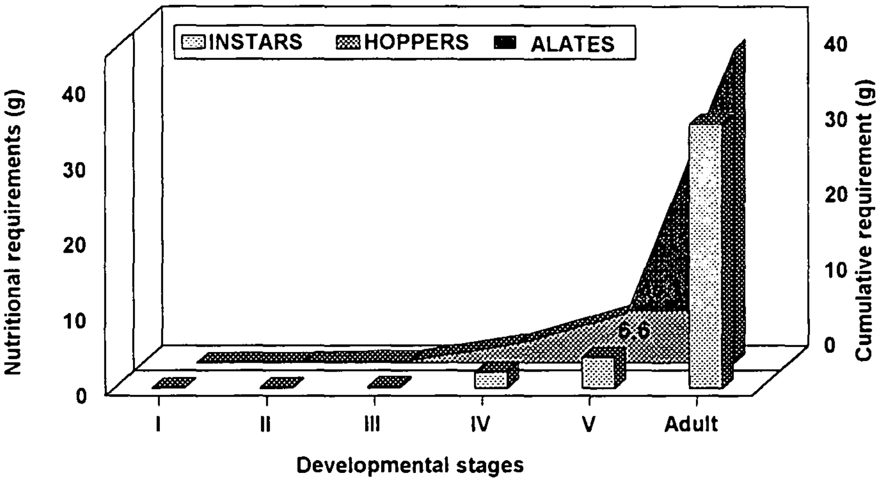


Figure 5.14 Developmental stages and corresponding food requirements of the brown locust (Coetzee, 1994).

The daily food requirement of an adult brown locust under field conditions is 450 mg of dry matter, which is about half the wet mass of the locust (Coetzee, 1994). The pasture requirement of a 50 kg reproductive Dorper ewe is 560 kg dry matter annually (Meissner, 1982) The economic considerations of locust impact were based on the nutritional needs of a 50 kg productive Dorper ewe at an annual gross margin of R75,00 (Van Rensburg[5], pers. comm.) in the Karoo versus that of brown locusts. It was calculated that about 3 400 adult locusts consume the same amount of grazing per day (1,535 kg dry matter) than a 50 kg Dorper ewe. A swarm of 1,2 million adult locusts consume the annual nutritional need of a 50 kg Dorper ewe per day. It is therefore stated that 1,2 million adult locusts cause damage to grazing amounting to R75,00 per day (Coetzee, 1994; Heyns *et al.*, 1995; Van der Westhuizen & Botha, 1997).

Column reference R calculates the actual damage in tons caused by the hoppers, by multiplying the number of hoppers in (N) by the nutritional requirements of the five hopper instars (kg → tons, $\therefore$ /1 000). It was already stated that the adults were assumed to be two weeks into maturity. This explains the 0,45 g (adult daily requirement) that was multiplied by 14 days (two weeks) and added to the hopper food requirements. This was then multiplied by the total number of adults (O) in the equation used in column reference S. By dividing the equation by 1 000 000, gram was converted to tons to show the actual damage caused by the adults.

The potential damage (tons) caused by the hoppers is calculated in column reference U. This value is the damage that could have been caused by the hoppers, had they not been controlled. It takes into account the total number of hoppers and multiplies that by the nutritional requirements of the adult stage. Column reference V determines the potential damage that could have been caused by not controlling the adults. Since it was assumed that the adults were two weeks into maturity, the amount of food eaten in 14 days were subtracted from their total adult requirement to estimate how much they would have eaten if not controlled. This was then multiplied by the number of adults controlled to present the potential damage value.

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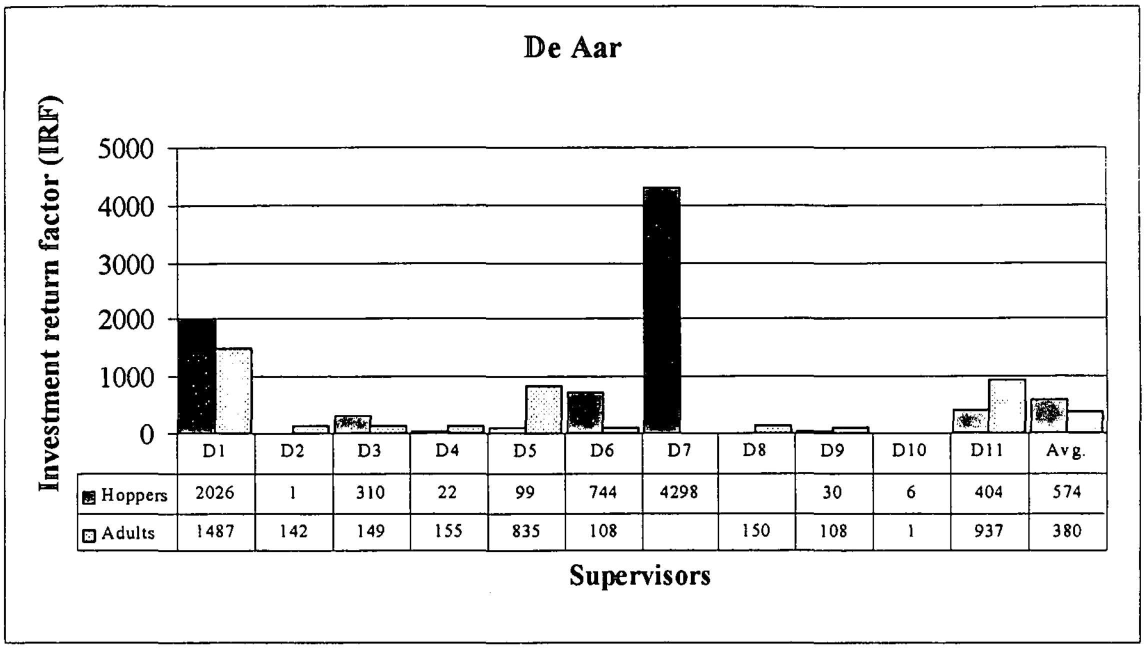
In columns references X and Y, the actual damage in Rand is calculated by dividing the actual damage in tons caused by either the hoppers or adults by the amount of dry matter consumed annually by a 50 kg Dorper ewe. This value is then multiplied by the annual gross margin (R 75,00) of a Dorper ewe in the Karoo.

Column references Z and AA compute the potential damage in Rand or the potential financial loss that could have been caused by the hoppers and adults respectively. This value is the same as the control benefit value (Headley, 1975) used in calculating the IRF. The only difference between the actual and potential damage (R) is the use of the fields "potential damage tons" in stead of "actual damage tons". Apart from that, the equations in column references Z and AA use the same parameters as those in column references X and Y.

The cost of controlling the hoppers and adults is calculated in column references AB and AC. It adds up the totals of the relative expenses fields per supervisor in table 2.2.

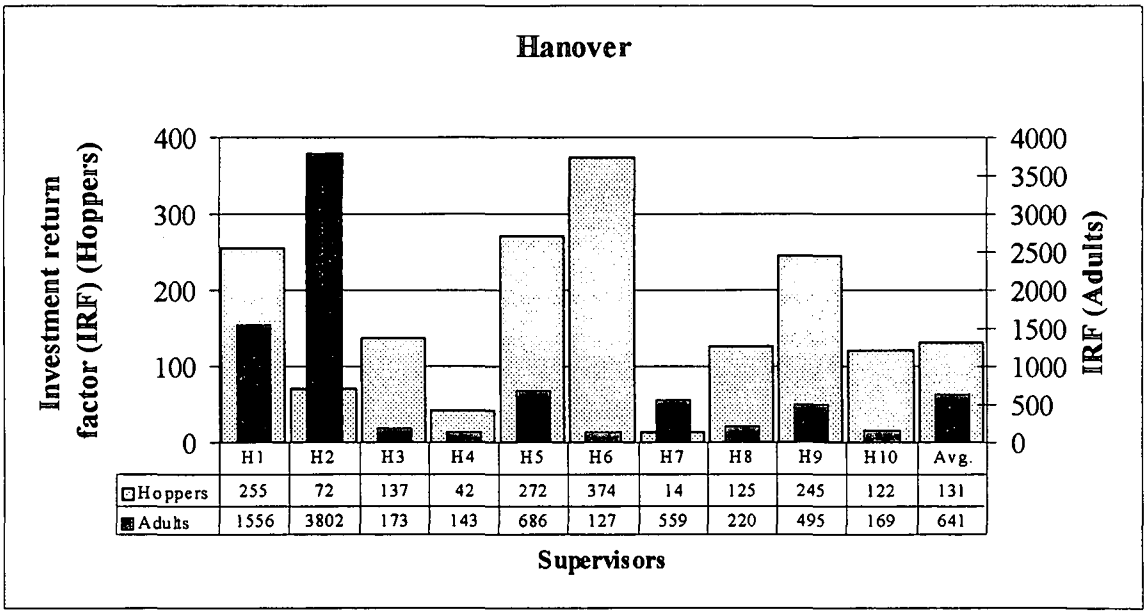
The investment return factors (IRF) for the hoppers and adults are calculated in column references AE and AF. In each case this is obtained by dividing the potential damage (R) or control benefit by the control cost. An IRF of 2 is regarded as successful and any value greater than 2 as highly effective (Van der Westhuizen, De Jager, Mason & Deall, 1994). In column reference AG the IRF value for a supervisor is calculated. The IRF value is obtained by dividing the sum of the potential damage (R) for hoppers and adults by the total of the hopper and adult control costs. By entering the district totals into the equations, the total average IRF for a district can also be calculated.

The investment return factors (IRF) displayed in figures 5.15 to 5.18 reflect those of the supervisors and DLOs who controlled locusts. None of the secretaries controlled locusts and therefore no IRF could be calculated for them. Any additional expenses not related to the actual control of locusts (e.g. scouting) were neglected in the calculations of IRF values. The totals per supervisor of the fields (in table 2.2) *BaPestR*, *SwPestR*, *BaTR*, *SwTR*, *BaAsstW*, *SwAsstw*, *BaSupW* and *SwSupW* were therefore entered into column references F to M.



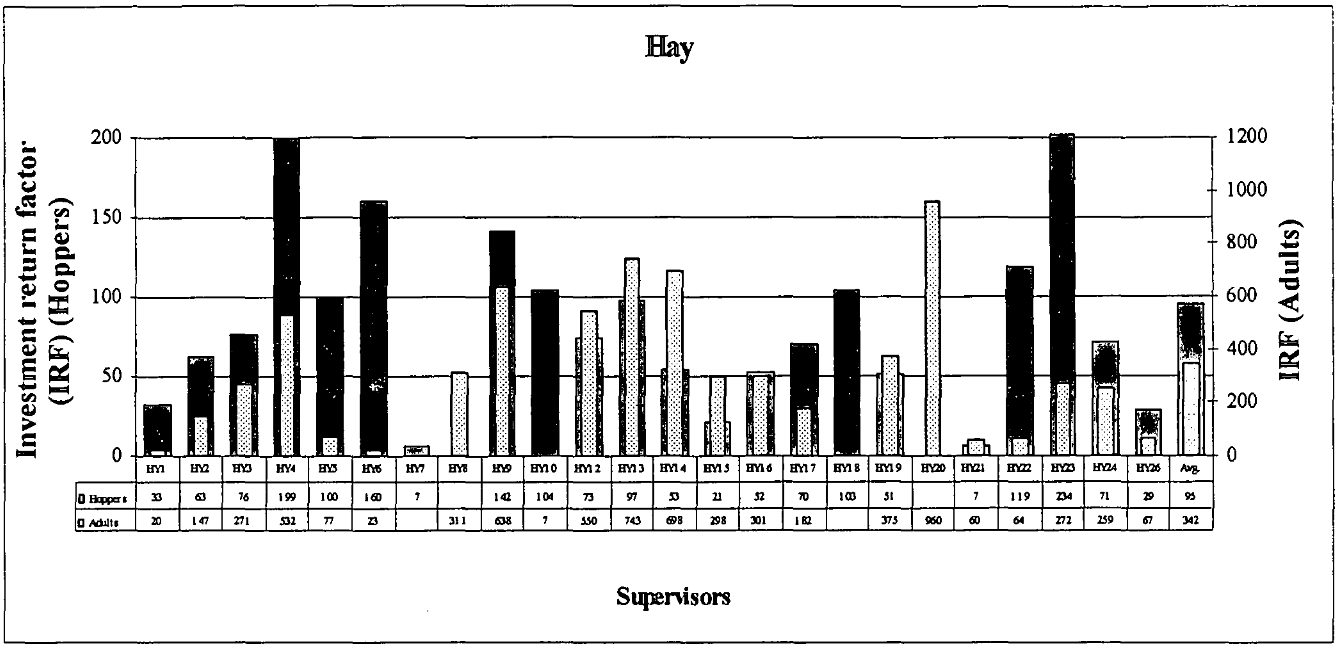
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
■ Hoppers	2026	1	310	22	99	744	4298		30	6	404	574
□ Adults	1487	142	149	155	835	108		150	108	1	937	380

Figure 5.15 Financial effectiveness of locust control by the supervisors in the De Aar district during the 1996/97 campaign.



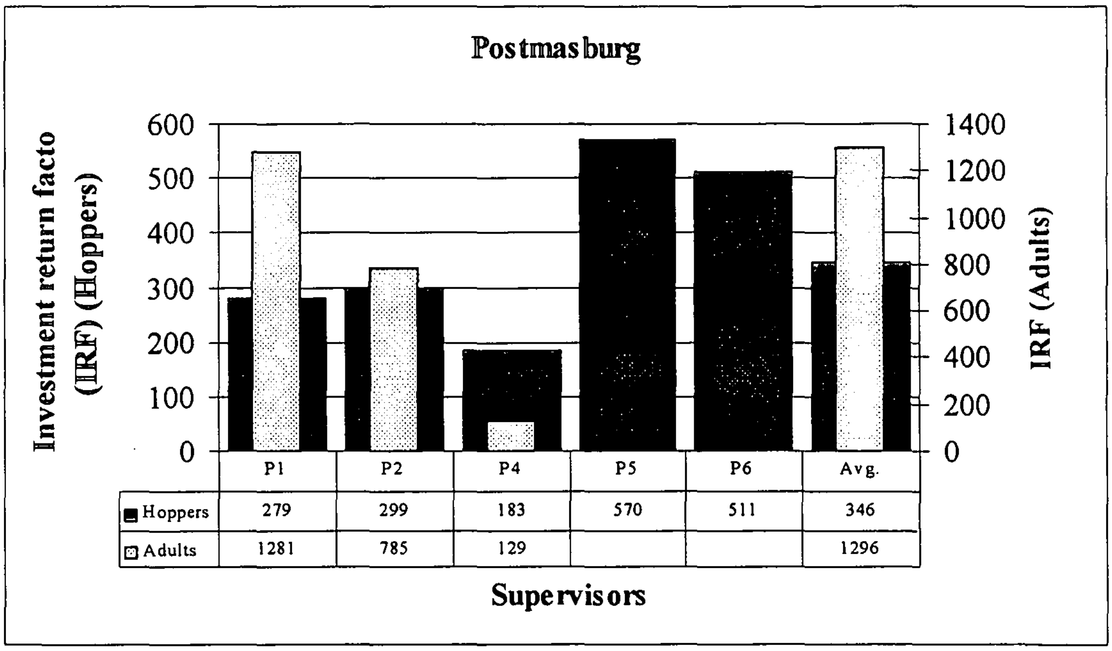
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Avg.
□ Hoppers	255	72	137	42	272	374	14	125	245	122	131
■ Adults	1556	3802	173	143	686	127	559	220	495	169	641

Figure 5.16 Financial effectiveness of locust control by the supervisors in the Hanover district during the 1996/97 campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY12	HY13	HY14	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY26	Avg.
■ Hoppers	33	63	76	199	100	160	7		142	104	73	97	53	21	52	70	103	51		7	119	234	71	29	95
▨ Adults	20	147	271	532	77	23		311	638	7	550	743	698	298	301	182		375	960	60	64	272	259	67	342

Figure 5.17 Financial effectiveness of locust control by the supervisors in the Hay district during the 1996/97 campaign.



	P1	P2	P4	P5	P6	Avg.
■ Hoppers	279	299	183	570	511	346
▨ Adults	1281	785	129			1296

Figure 5.18 Financial effectiveness of locust control by the supervisors in the Postmasburg district during the 1996/97 campaign.

As stated previously it is more advantageous to the environment and the economy to control the locusts in the hopper stage. More matured locusts destroy valuable food resources. Since the control cost for both was a constant value, the higher control benefit of the bands would therefore result in the IRF for the bands been higher than the IRF for the swarms. This is furthermore supported by the equations in table 5.3.

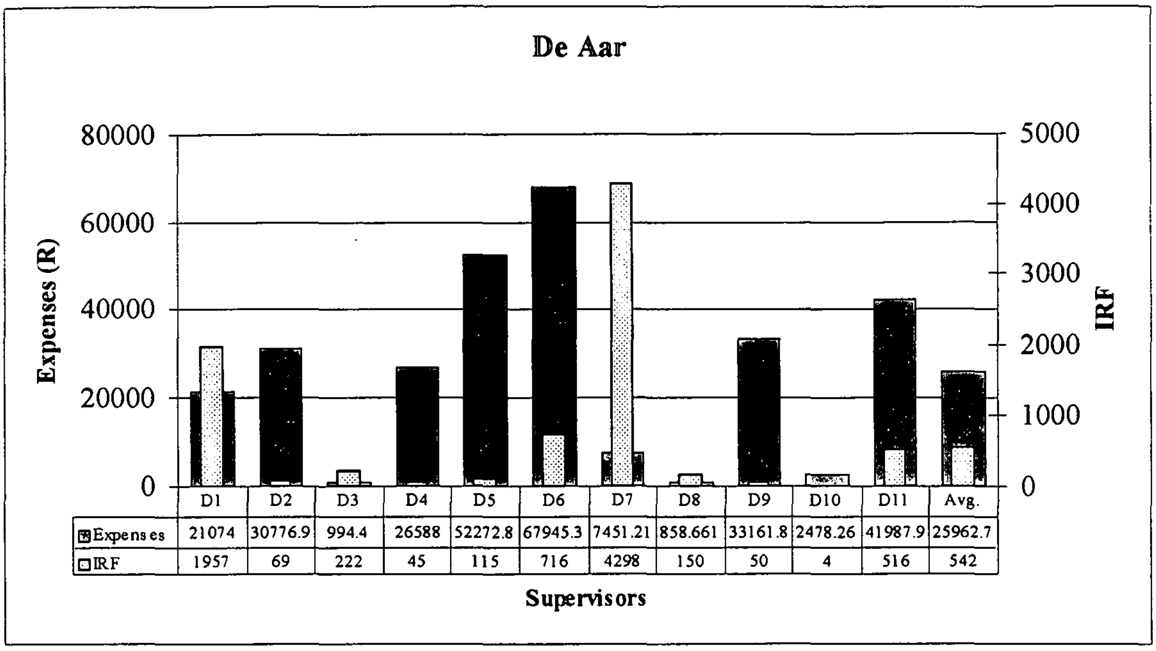
Supervisors D7, D8, HY7, HY8, HY18, HY20, P5 and P6 controlled only bands or swarms and not both. For this reason only one IRF could be calculated for them. H11 and P3 worked for free and did not report the quantity of pesticide used. No control cost and IRF could thus be calculated. D3, P5 and P6 also worked for free, but reported the quantity of pesticide used; consequently *BaPestR* and *SwPestR* were the only expenses entered to calculate their investment return factors.

According to table 5.3 the totals of the following fields are required to calculate the investment return factor in general: *# Bands, # Swarms, Bands Ha, Swarms Ha* and the expenses *[Pesticide (R), Travel cost (R), Asst. wages* and *Sup wages].* This can be calculated per supervisor, district, depot or on national level. If the number of hectares sprayed (figures 3.1 to 3.4), the number of bands and swarms controlled (figures 3.5 to 3.8) and the expenses (figures 5.1 to 5.4) in the districts are compared, it is clear that there are considerable differences between the supervisors and the districts regarding these variables. Vast differences in parameters are thus expected in figures 5.15 to 5.18.

The expenses referred to in figures 5.15 to 5.18 differ from those in figures 5.19 to 5.22 with respect to the following: In the latter the total expenses comprised of the travelling cost and wages allocated to control and non-control activities (scouting) by supervisors. The average IRF (bands + swarms) was calculated using column reference AG in table 5.3. Consequently the totals per supervisor of the fields (in table 2.2*) Pesticide (R), Travel cost (R), Assistant wages* and *Supervisor wages* were entered into column references F, H, J, L or G, I, K, M in table 5.3. For these calculations the headings "hoppers" and "adults" can be ignored and values entered as explained will render the required total expenses and total average IRF. The highest average expenses were in the Hanover district and the highest average IRF was in the

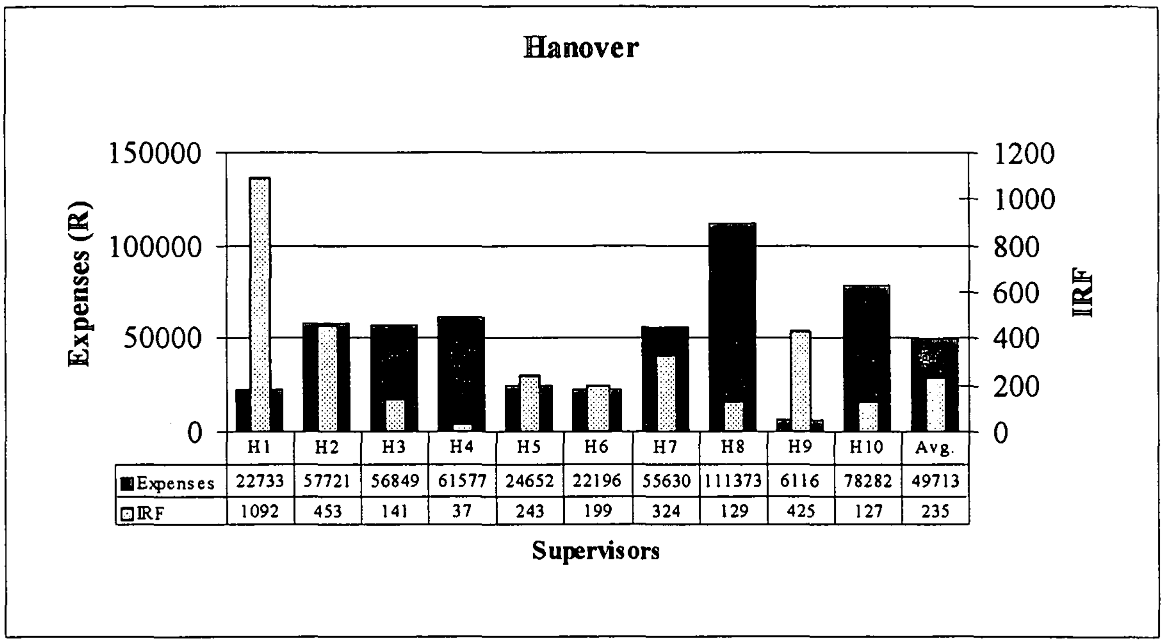
De Aar district. Pest control within the crop production sector resulted in an IRF of 6,4 in South Africa (Oerke, Dehne, Schönbeck & Weber, 1994). The efficiency of locust control in South Africa is extremely high relative to the crop sector and the very low continental norm (Herok & Krall, 1995). The average IRF of all districts were higher than one hundred, which proofed to be very successful. Chemical control in terms of ecological and financial norms is only justified if the control benefit is more than the control cost (Chiang, 1973; Dent, 1991). The locust swarms are migratory pests and not localised ones, which implies a benefit to the region rather that the particular farm involved. The benefits of the control actions extend to neighbouring farms, districts and even countries (Heyns *et al.*, 1995).

The supervisors who worked for free (table 5.1) resulted in a reduction in expenses and thus increased IRF. This was the reason why the Postmasburg district in particular had such a high IRF. The district average expenses and the IRF per district in figures 5.19 to 5.22 were compared in table 5.4 relative to a 10% deviation. The expenses or IRF values of the supervisors deviate more than 10% from the district averages. The highest IRF in the De Aar district was achieved by D7. This supervisor only controlled hoppers (figures 3.9 and 5.15) and it is more cost effective in controlling hoppers than adult locust. Supervisor D7 achieved the highest IRF in all districts. It is apparent that the supervisors who achieved high investment return factors also had some of the lowest expenses in that particular district (figures 5.19 to 5.22). The opposite is also true. The supervisors in figures 5.19 to 5.22 who had some of the highest expenses in the respective districts, could only achieve moderate to low investment return factors compared to those with low expenses.



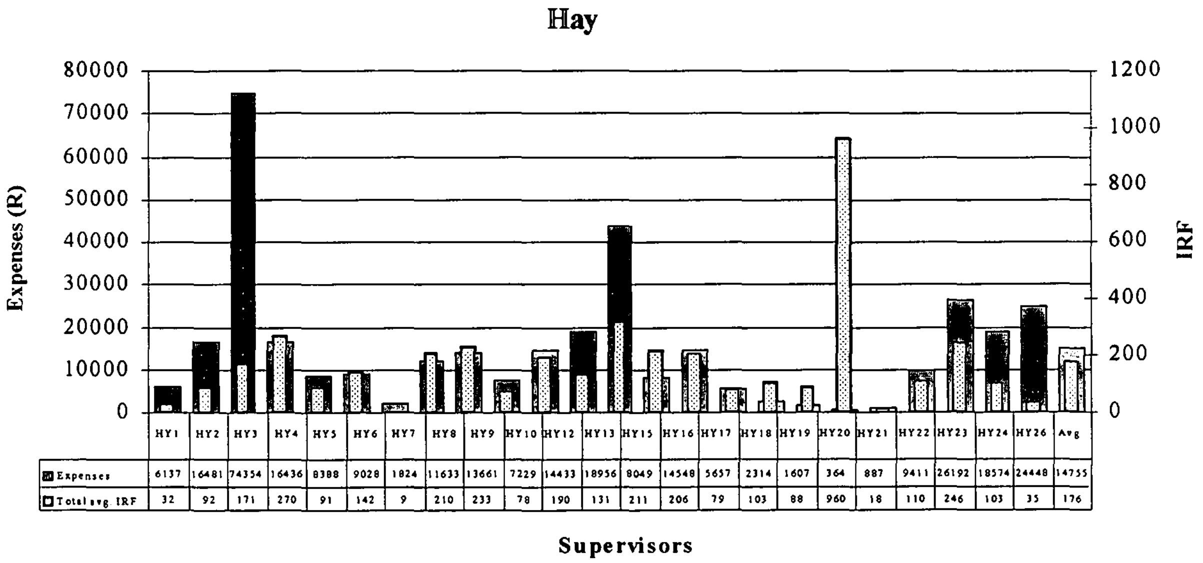
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Avg.
▨Expenses	21074	30776.9	994.4	26588	52272.8	67945.3	7451.21	858.661	33161.8	2478.26	41987.9	25962.7
▢IRF	1957	69	222	45	115	716	4298	150	50	4	516	542

Figure 5.19 Total expenses and IRF of the supervisors in the De Aar district in the 1996/97 locust control campaign.



	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Avg.
■Expenses	22733	57721	56849	61577	24652	22196	55630	111373	6116	78282	49713
▢IRF	1092	453	141	37	243	199	324	129	425	127	235

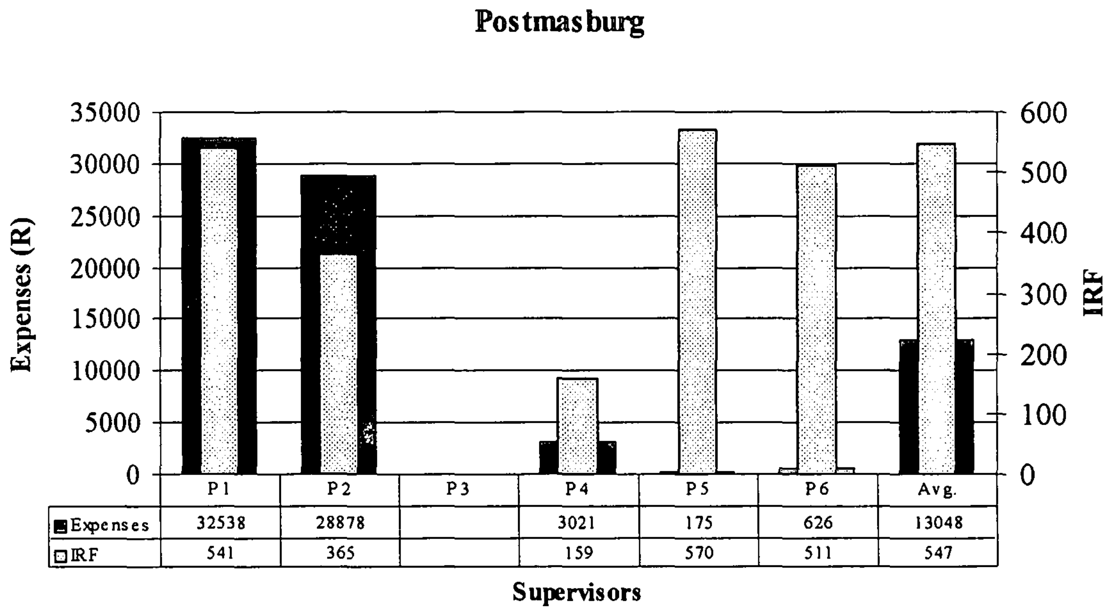
Figure 5.20 Total expenses and IRF of the supervisors in the Hanover district in the 1996/97 locust control campaign.



	HY1	HY2	HY3	HY4	HY5	HY6	HY7	HY8	HY9	HY10	HY12	HY13
■ Expenses	6137	16481	74354	16436	8388	9028	1824	11633	13661	7229	14433	18956
☐ Total avg. IRF	32	92	171	270	91	142	9	210	233	78	190	131

	HY15	HY16	HY17	HY18	HY19	HY20	HY21	HY22	HY23	HY24	HY26	Avg
■ Expenses	8049	14548	5657	2314	1607	364	887	9411	26192	18574	24448	14755
☐ Total avg. IRF	211	206	79	103	88	960	18	110	246	103	35	176

Figure 5.21 Total expenses and IRF of the supervisors in the Hay district in the 1996/97 locust control campaign.



	P1	P2	P3	P4	P5	P6	Avg.
■ Expenses	32538	28878		3021	175	626	13048
☐ IRF	541	365		159	570	511	547

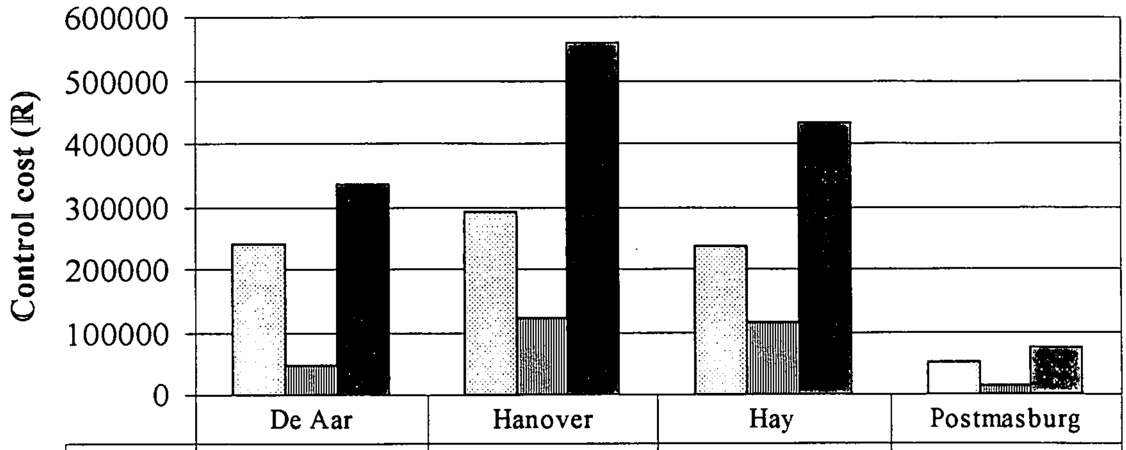
Figure 5.22 Total expenses and IRF of the supervisors in the Postmasburg district in the 1996/97 locust control campaign.

Table 5.4 Deviation (10%) within and among the expenses and IRF of De Aar, Hanover, Hay and Postmasburg districts.

District	**Expenses (R)**		**Total average IRF**	
	- 10%	+ 10%	- 10%	+ 10%
De Aar	25 152,3	30 741,7	453,6	554,4
Hanover	44 741,7	54 684,3	211,5	258,5
Hay	16 059,6	19 628,4	131,4	160,6
Postmasburg	13 291,2	16 244,8	434,7	531,3

In figure 5.23 the relative control costs of the four districts were compared. The hopper and adult control costs were calculated using column references AB and AC in table 5.3. The "Total" values in figure 5.23 are the sum of the expenses involved in controlling the hoppers and adults and are not merely the sum of the hopper and adult control costs. The Hanover district had the highest total control cost, followed by Hay, De Aar and Postmasburg. This same order can be seen in figure 3.13 with respect to the total number of bands and swarms controlled. The pattern however is not repeated in figure 3.14 where the total number of hectares sprayed is compared. The highest number of hectares was sprayed in the De Aar district and the lowest number in the Postmasburg district. The number of bands and swarms and the respective hectares controlled are important parameters in calculating the control cost.

In general, the adult control cost was dramatic less than the hopper control cost. From figure 3.13 it is clear that more hopper bands than adult swarms were controlled in each district. However, except in the De Aar district, larger areas of adults were controlled (figure 3.14).



	De Aar	Hanover	Hay	Postmasburg
☐ Hopper	239492	290549	237611	51497
▥ Adult	46098	122709	116520	13741
▣ Total	335791	557693	433222	73840

Figure 5.23 Control cost of locusts during the 1996/97 locust control campaign.

Figure 5.24 is a breakdown analysis of the expenses regarding the control of bands and swarms in the four districts during the 1996/97 campaign. The control cost of hoppers was dramatic higher than that of adult locusts. Apart from the pesticides, the travelling expenses and assistant wages contributed to a large extent to the total expenses. The travelling expenses made up a particular high percentage in especially the Hay and Postmasburg districts. This may be due to the vastness of those districts. See table 4.1.

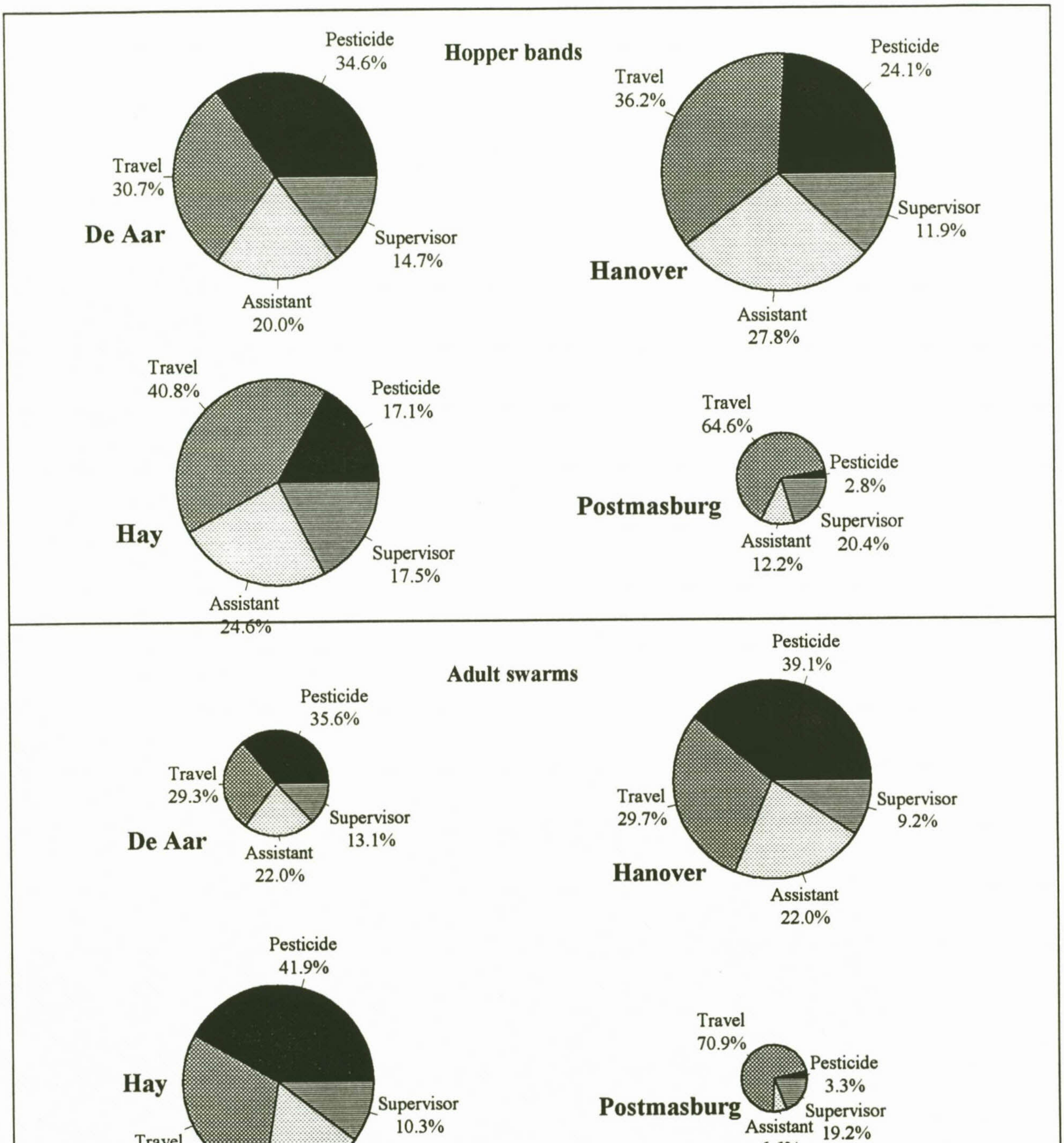
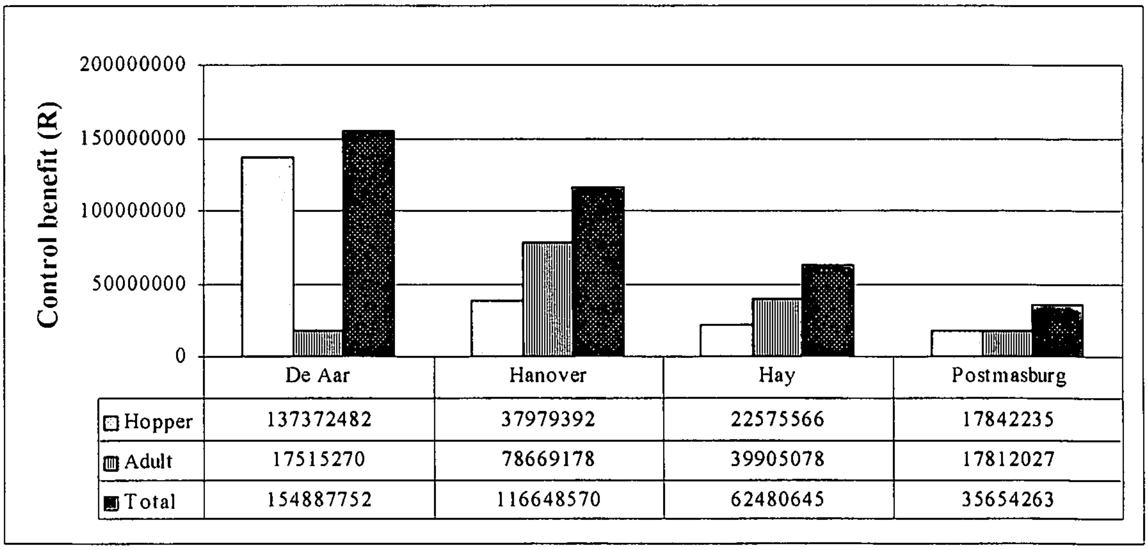


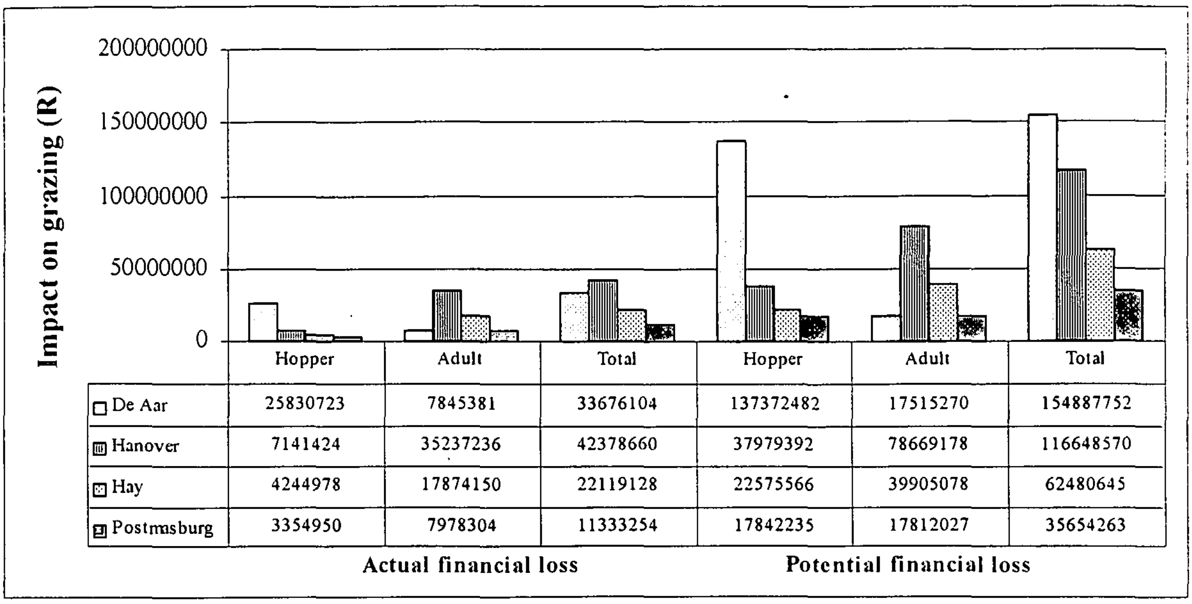
Figure 5.24 Breakdown of pesticides, travelling and wages with regard to the control of bands and swarms in the four districts. Expenses of scouting activities are excluded.

The values in figure 5.25 were obtained from column references Z and AA in table 5.3. The potential damage averted by chemical control of the locusts is also referred to as the control benefit. The total values in figure 5.25 are the sum of column references Z and AA. In comparison with figure 5.23 it is evident that the control benefit was much higher than the control cost in each district. From figure 5.25 the hopper control benefit is higher than the adult control benefit for De Aar and Postmasburg. In Hanover and Hay the adult control benefit was higher than the hopper control benefit. According to table 5.3 the first variable to affect the control benefit (Potential damage (R)) is the respective areas of locust control (column references D and E). Adult locusts were controlled on larger areas than hopper bands in Hanover and Hay (figure 3.14). In De Aar district hopper bands were controlled on a far greater area than adult swarms. This explains the higher control benefits in the relevant districts (figure 5.25). Figure 3.14 further points out that the difference between the hopper and adult areas in the Postmasburg district was not significant. If this small difference is accommodated into further calculations, it results in the hopper control benefit being slightly greater than the adult control benefit in the Postmasburg district.



	De Aar	Hanover	Hay	Postmasburg
□ Hopper	137372482	37979392	22575566	17842235
▥ Adult	17515270	78669178	39905078	17812027
■ Total	154887752	116648570	62480645	35654263

Figure 5.25 Control benefits of locust control in the four districts during the 1996/97 locust control campaign.



	Hopper	Adult	Total	Hopper	Adult	Total
□ De Aar	25830723	7845381	33676104	137372482	17515270	154887752
▥ Hanover	7141424	35237236	42378660	37979392	78669178	116648570
▒ Hay	4244978	17874150	22119128	22575566	39905078	62480645
▦ Postmasburg	3354950	7978304	11333254	17842235	17812027	35654263
	Actual financial loss			**Potential financial loss**		

Figure 5.26 Impact on grazing (R) by hoppers and adults in the four districts with special reference to the actual and potential financial losses.

The actual financial losses in figure 5.26 were calculated by using column references X and Y (table 5.3). The potential financial losses were calculated in a similar manner by using column references Z and AA (table 5.3). The hopper bands had the greatest impact on grazing in the De Aar district (figure 5.26). The adult swarms had the greatest impact on grazing in the Hanover district. The total impact was the greatest in the Hanover district. The same pattern can be seen in figure 3.15 where the impact on grazing with respect to tons is shown.

In table 5.3 the first variable to influence the actual and potential control costs, is the respective areas the locusts were controlled on (column references D and E). This is further reflected in figure 3.14 where the largest area of hoppers was controlled in De Aar district and the largest area of adults was controlled in Hanover.

Figure 5.26 further visualises a dramatic advantage in damage averted by chemical control of the locusts. The control was thus justified in all districts. Locusts as a migrating pest not only pose a threat to the local communities, but also to neighbouring districts and crops. As these potential financial losses were calculated with pasture in mind, these values can easily escalate when locusts threaten cash crops in the irrigation scheme.

Reliable statistical information on the damage effect of locust outbreak and expenditure are limited due to the peculiar difficulties with data capturing during control campaigns (Musuna, 1988). Environmental or social risks may involve damage to non-target species, threats to human health and imposition of an undesired imbalance in the ecosystem. Some external "costs" are known and treatment effects on physical and biological systems are largely unknown (Davis, Skold, Berry & Kemp, 1992).

The 1985/86 locust control campaign cost the tax payer of South Africa R8,8 million. The value of the maize crops alone that might be at risk accounted to over R2 000 million in a year of good harvest (Anon, 1993). The possible threat to the maize and wheat crops in adjacent areas to the Karoo justifies the control of pest proportions of locusts (Lindeman, Nduli & Van der Westhuizen, 1997).

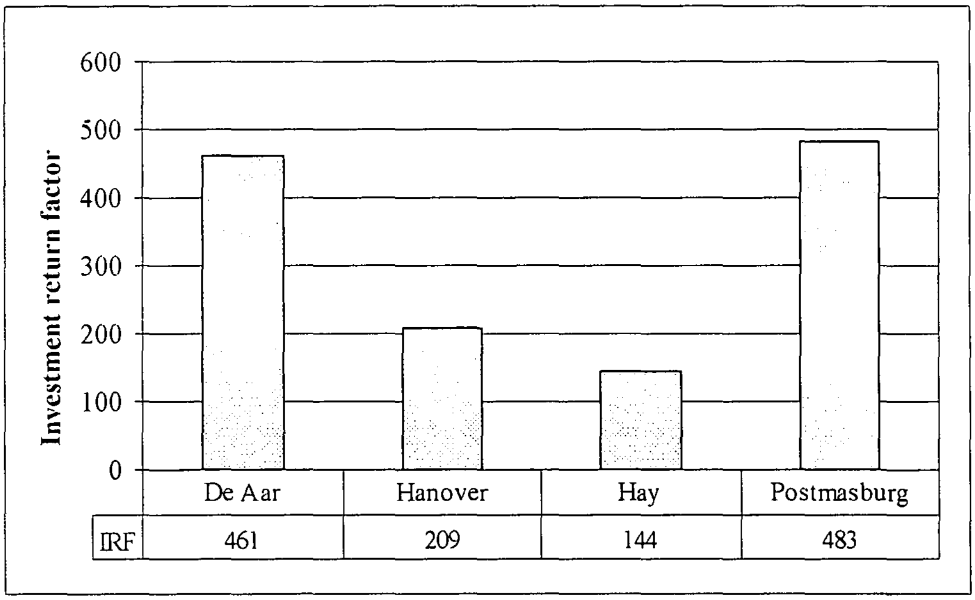


Figure 5.27 Financial efficiency of locust control in the 1996/97 campaign.

The IRF (figure 5.27) was calculated by using column reference AG in table 5.3. All the expenses relating to locust control were entered into the formula, including travelling expenses and wages paid for scouting for locusts and the wages of the

DLO's and secretaries. On district level no distinction is made between hopper and adult IRF, because most DLO's and secretaries did not control locusts and the allocation of expenses to hoppers and adults would therefore have been unrealistic. In calculating the IRF, all district expenses can be entered into either "hoppers" or "adults" in column references F to M (F, H, J, L or G, I, K, M). It should be emphasised that in such a case all the other column references in table 5.3, except column reference AG are disregarded.

From figure 5.27 the highest average IRF was in the Postmasburg district, followed by De Aar, Hanover and Hay. It was already established that the total number of hectares of bands or swarms controlled greatly influence the potential damage or control benefit. If bands and swarms were controlled on the same number of hectares, the potential damage of the bands would actually be higher than those of the swarms. It is therefore more advantageous to control the locusts during the hopper stage (Quinn, Kepner, Walgenbach, Foster, Bohls, Pooler, Reuter & Swain, 1993; Coetzee, 1994; Heyns *et al.* 1995; Van der Westhuizen & Botha, 1997; Anon, 1998d; Roux, 1998).

Figure 3.14 points out that a larger area of hopper bands than adult swarms were controlled in De Aar. The opposite was true for the other districts, with the smallest difference in Postmasburg. It is further evident that the highest percentage hoppers relative to adults were controlled in De Aar (figures 3.9 to 3.12). In all the other districts the proportions were inverted. This could explain why De Aar had the second highest IRF next to Postmasburg where half the supervisors worked for free.

In the remaining two districts swarms were controlled on larger areas than hoppers, thus resulting in lower IR-factors. The values in the four districts were still relative high in comparison with the overall campaign IRF of 87, according to the cost benefit analysis done by Van der Westhuizen and Botha (1997). The IRF values of the De Aar, Hanover, Hay and Postmasburg districts are even higher than the 1996/97-value. The 1996/97 campaign norm included diverse costs (departmental transport, fuel, repairs, etc.) which apparently lowered the national IRF value. However, any IRF more than two, justify control (Van der Westhuizen, 1995).

The first component of a cost benefit analysis comprises a discussion of how costs and benefits may be evaluated. The second is concerned with the decision related features of cost benefit analysis (Abelson, 1979). Cost benefit analysis is used in circumstances where important components of either the real costs or real benefits of a project would not be adequately represented by market prices, or would not be traded through markets at all. Non-market evaluation procedure is required to assess the net worth of a project (Perman, Ma & McGilvray, 1996). Many environmental resources do not have prices attached to them. It is therefore important that we should develop an idea of what the environment is worth (Dransfield, 1998).

Vermaak (1995) stated that more sensible decisions could be made with a cost benefit analysis where marginal benefits are brought into perspective with marginal cost. It is therefore not only the economic well being that is important, but more so the social and environmental benefit created in any given program. What counts as a benefit or loss to one part of the economy or persons may not count as a benefit or loss to the economy as a whole (Mishan, 1982). This further emphasises the need for a cost benefit analysis in the locust control campaigns.

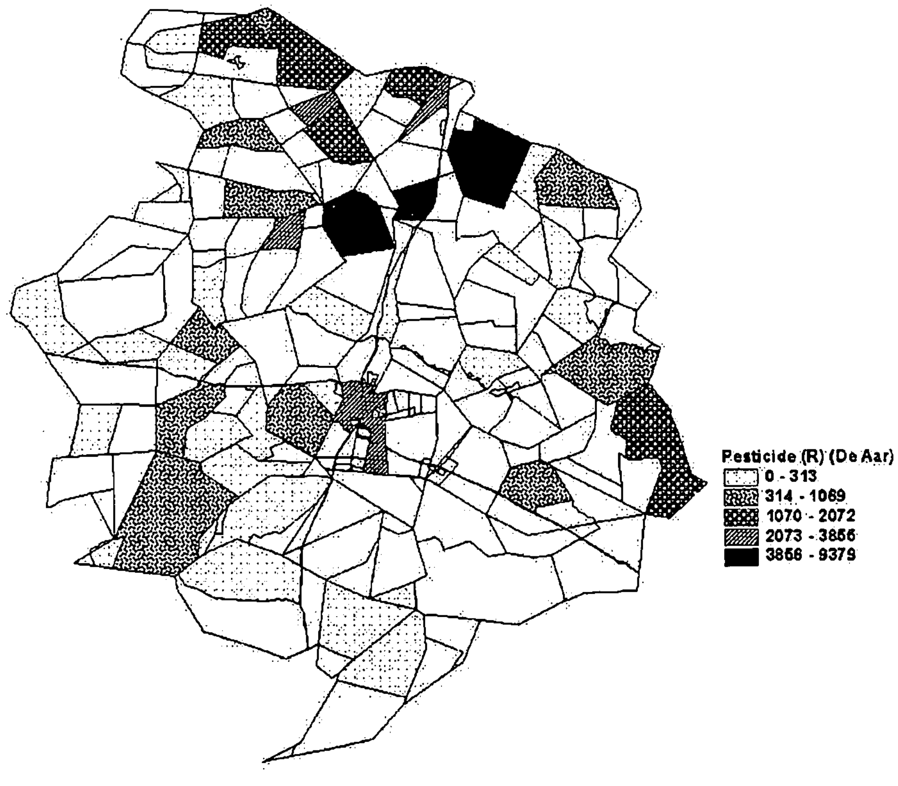


Figure 5.28 Accumulative cost of pesticides per farm in the De Aar district.

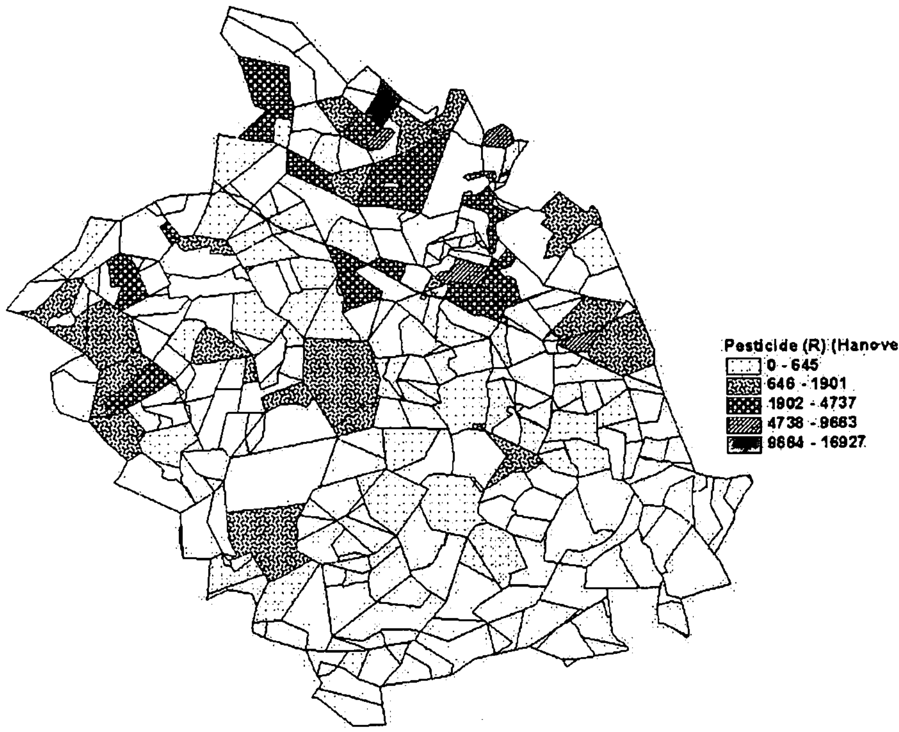


Figure 5.29 Accumulative cost of pesticides per farm in the Hanover district.

Figure 5.30 Accumulative cost of pesticides per farm in the Hay district.

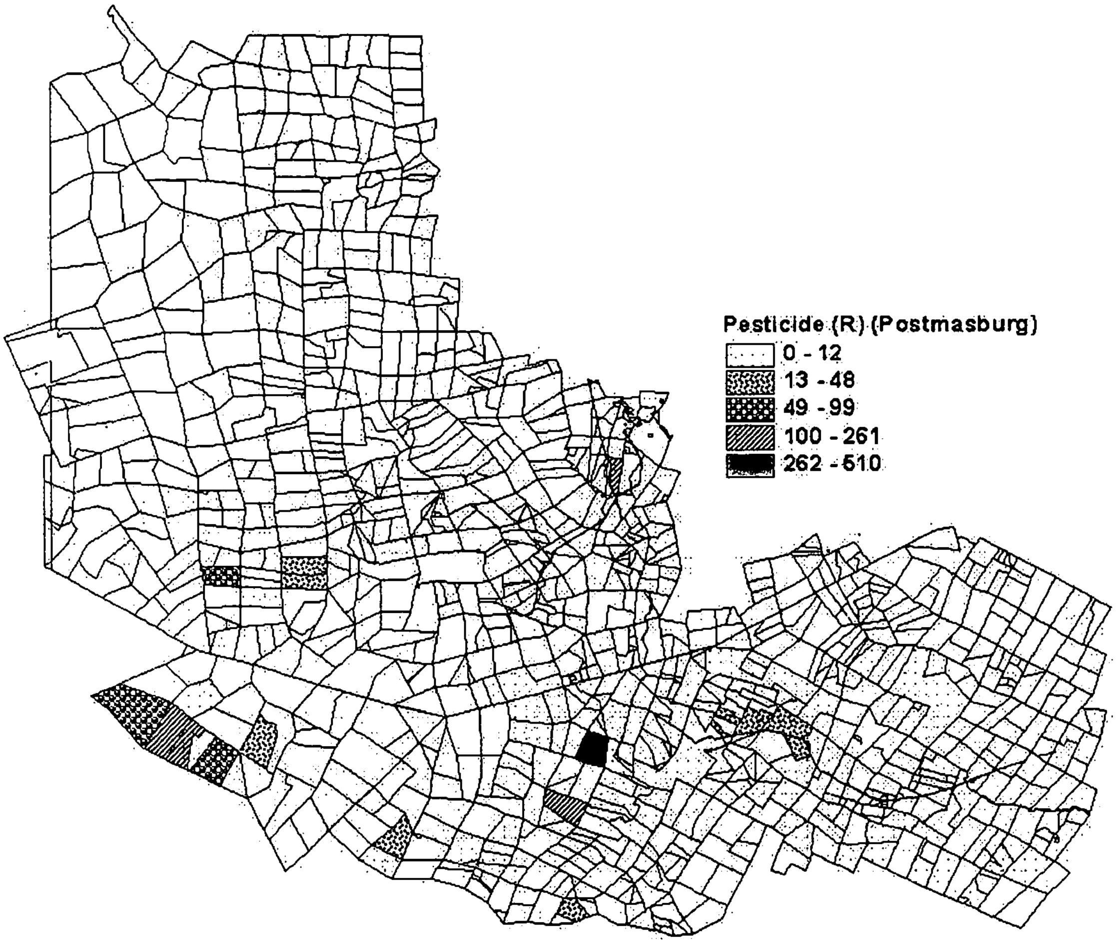


Figure 5.31 Accumulative cost of pesticides per farm in the Postmasburg district.

Spatial analysis of pesticides applied per farm are shown in figures 5.28 to 5.31. On farm level only the cost of the pesticides were displayed. On district level the cost of the pesticides, travel and wages were analysed. The costs of the pesticides were grouped into five classes.

In the De Aar district the highest values were recorded on the following farms: PHI529, PHI503 and PHI484. In Hanover the highest value was on farm HAN49. The codesets of the farms are displayed in appendix 1 to 4.

In the Hay district the highest values were on farms: HAY756, HAY762, HAY830, HAY956 AND HAY1063. In Postmasburg the highest value was recorded on farm HAY165. Very low or no pesticide expenses were reported on farms adjacent to those in the highest class in the De Aar and Hanover districts. In Postmasburg the farms adjacent to farm HAY165 reported pesticide expenses belonging only to the lowest class or no expenses at all. In the Hay district the farms adjacent to those the highest pesticide expenses were recorded also had relative high expenses. It seems like those farms were situated in high outbreak areas.

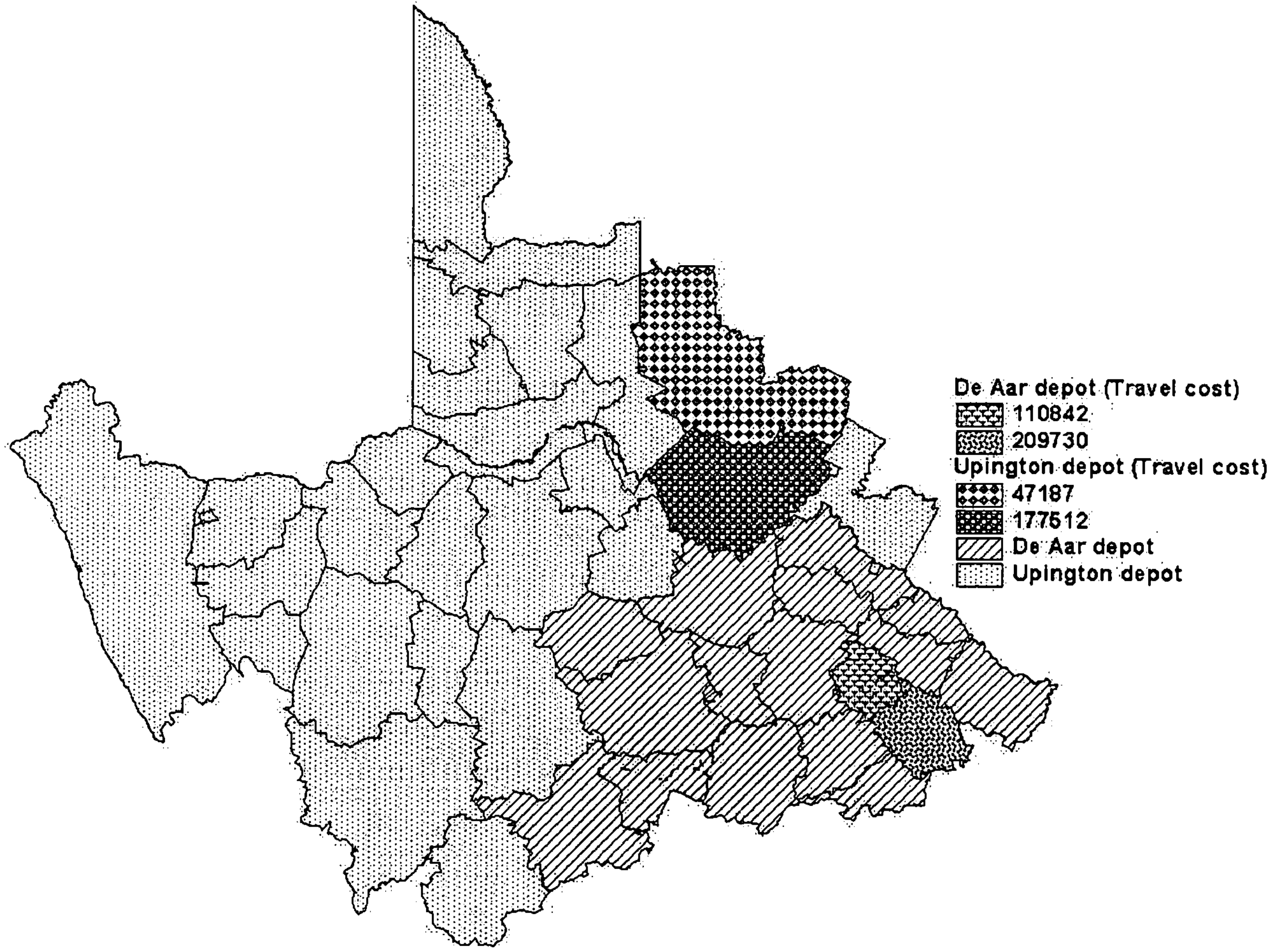


Figure 5.32 Total travelling expenses per district for Postmasburg, Hay (Upington depot), De Aar and Hanover (De Aar depot) in the 1996/97 campaign.

The highest total expenses for travelling was in Hanover followed by Hay, De Aar and Postmasburg districts (figure 5.32). The largest total areas (ha) were sprayed in De Aar and Hanover (figure.3.14). The smallest area was sprayed in Postmasburg. The highest number of bands and swarms was controlled in Hanover followed by Hay, De Aar and Postmasburg (figures 3.13 and 3.24 to 3.27). The travelling expenses seem to be directly related to the number of bands and swarms controlled.

In campaigns it is sometimes necessary to travel significant distances to control small swarms and also to scout for the locusts. These could have attributed to the high expenses due to travelling.

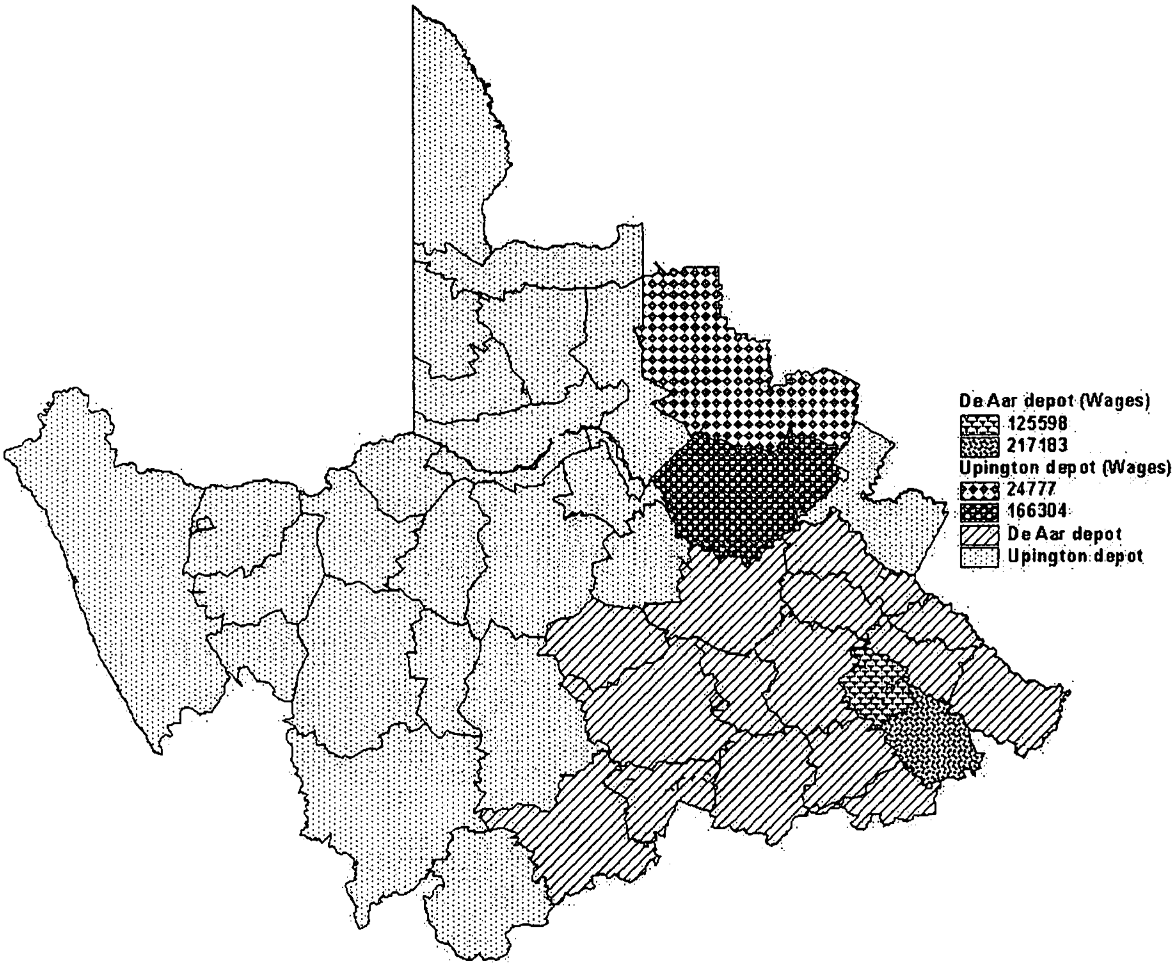


Figure 5.33 Total wages per district for Postmasburg, Hay (Upington depot), De Aar and Hanover (De Aar depot) in the 1996/97 campaign.

The highest amount of money paid for wages was in Hanover followed by Hay, De Aar and Postmasburg (figure 5.33). This is in comparison with the total number of man days in figure 4.9. All districts except Postmasburg had a secretary. The wages paid to the secretaries and district locust officers (DLO's) were also added to the district total.

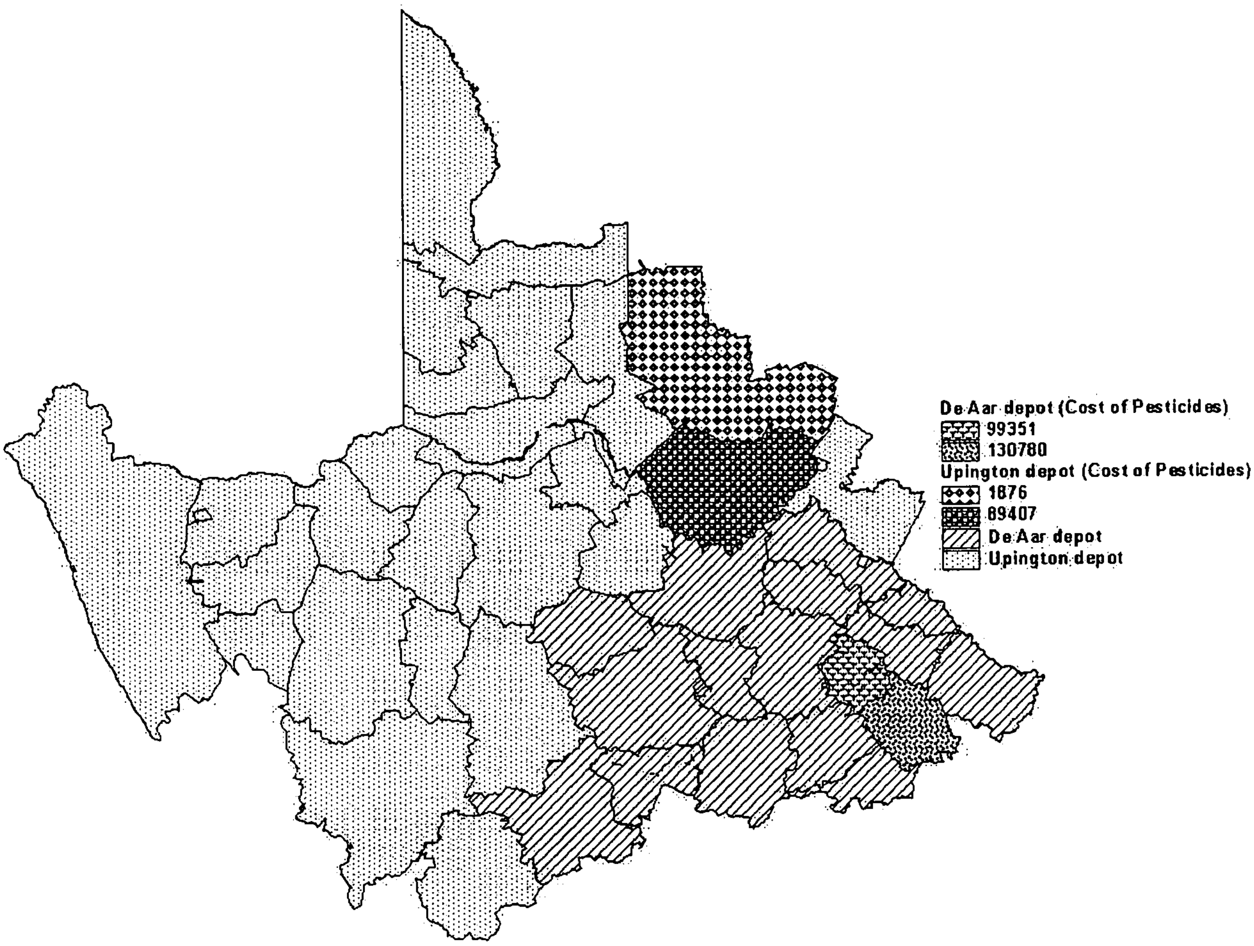


Figure 5.34 Total cost of pesticides per district for Postmasburg, Hay (Upington depot), De Aar and Hanover (De Aar depot) in the 1996/97 campaign.

The highest total costs of pesticides were recorded in Hanover followed by De Aar, Hay and Postmasburg (figure 5.34). This correlate with the average amount of pesticide (litre) sprayed per supervisor in figures 3.5 to 3.8. These total values however do not follow the same pattern (from highest to lowest value) as the total number of hectares sprayed in figure 3.14. Hence, the highest area sprayed was in De Aar followed by Hanover. This means that on average the supervisors in De Aar sprayed far less than the required rate of 2,5 l/ha (Heyns *et al*, 1995; Krause *et al.*, 1996). The supervisors in Hanover under-applied pesticides, but still at a higher rate than those in the De Aar district (figures 3.1 and 3.2).

General conclusion

The endemic region of the brown locust (*Locustana pardalina,* Walker) comprises an area of approximately 40 million hectares in the Karoo region of South Africa. Stock production, with the emphasis on sheep farming, is the main agricultural activity of this region. The brown locust in the *gregaria* phase causes considerable damage to natural pastures and is in direct competition with stock farming.

The National Department of Agriculture administers locust control campaigns aimed at preventing the locusts from reaching the crop production areas of South Africa. The outbreak region is divided into two depots, which are subdivided into various locust districts. Trained volunteers (supervisors and assistants) in the respective locust districts conduct the locust control campaigns and are remunerate for their efforts.

Any sustainable agricultural setup and pest control should adhere to the following three criteria: environment, manpower and financial resources. This study was aimed at analyzing the 1996/97 locust control campaign based on these three criteria. The De Aar, Hanover, Hay and Postmasburg locust districts were used in the analysis. The project was divided into two main parts, namely a component analysis for managerial purposes and a spatial analysis (in ArcView-GIS) for operational purposes. The component analysis was only done on supervisor level within the districts. All the districts can be incorporated into the system to extend the analysis to depot- and national level. The spatial analysis was done on both farm and district levels.

Within the environmental criterion great variation existed between the supervisors regarding the number of hectares sprayed as well as the application rate. The supervisors controlled different numbers of hopper bands and adult swarms. The highest number of bands and swarms was controlled in the Hanover district (5 392), followed by Hay (1 961) De Aar (1 519) and Postmasburg (859). This resulted in varied quantities of pesticides applied in the control actions.

On average the supervisors in the De Aar district controlled a higher percentage of hopper versus. adult locusts (87 vs. 13 %). The opposite was encountered in Hanover (28 vs. 72 %), Hay (32 vs. 68 %) and Postmasburg (45 vs. 55 %). The highest total area (Ha) bands and swarms was sprayed in the De Aar district (1 1410), followed by Hanover (9 493), Hay (5 054) and Postmasburg (2 816). Locusts had the highest impact on grazing in the Hanover district. However, the averted damage in all the districts was much higher than the damage caused.

Damage caused by the locusts was also viewed in terms of the grazing capacity of the farms. Locusts feeding resulted in a dramatic reduction in the number of hectares per large stock unit (Ha/LSU). Effective control operations resulted in small areas of each district being sprayed. Spatial analysis revealed the following percentages: De Aar (2,13 %), Hanover (2,63 %), Hay (0,40 %) and Postmasburg (0,16 %). Areas of intensive control activities could be identified for future reference. An early warning system to facilitate locust control is possible with the incorporation of reliable biotic and abiotic data. This will however not exclude the current successful scouting operations for locusts.

The number of supervisors employed in the districts varied from six in the Postmasburg district to 24 in Hay. Analysis of the manpower criterion further revealed that considerable differences occurred between the supervisor regarding the distances travelled and number of days employed in locust control. Dissimilarities in manpower utilisation were evident through the area (Ha) and amount of pesticide sprayed per assistant per day in the various districts. The average area controlled per day ranged from 3,75 to 21,827 hectares per assistant- day and the amount of pesticide sprayed per assistant ranged from 1,17 to 8,301 litre per day.

The highest numbers of supervisor (800) and assistant (2039) days were recorded in the Hanover district. The lowest numbers (172 vs. 129) were recorded in the Postmasburg district. The implementation of a geographic information system enables the visual monitoring of job creation and the consequential socio-economic implications of locust control at farm, district, depot and national level.

Analysis of the financial criterion revealed the pesticide and travelling expenditure to be the highest factors contributing to total expenses. Wages accounted for approximately 30 % of the expenses. The expenses per hectare (R/Ha) were the highest in the Hay district (70,07) and the lowest in Postmasburg (23,17).

Hopper and adult control cost was the highest in the Hanover district and the lowest in Postmasburg. Control benefit or pasture damage (R) averted by locust control was the greatest in the Hanover district. The actual financial damage caused by the locusts was much lower than the potential financial loss. An analysis of the financial effectiveness of locust control presented investment return factors (IRF's) of more than one hundred for all the districts. An IRF of two is regarded as successful. Locust control in South Africa by far exceeds the effectiveness obtained for pest control in crop production areas.

The integrated operational and management information system enables visual access to extensive control data. Expansion of the database to include previous and future campaigns can easily be accommodated. This information system eases management by facilitating proper planning within and among campaigns.

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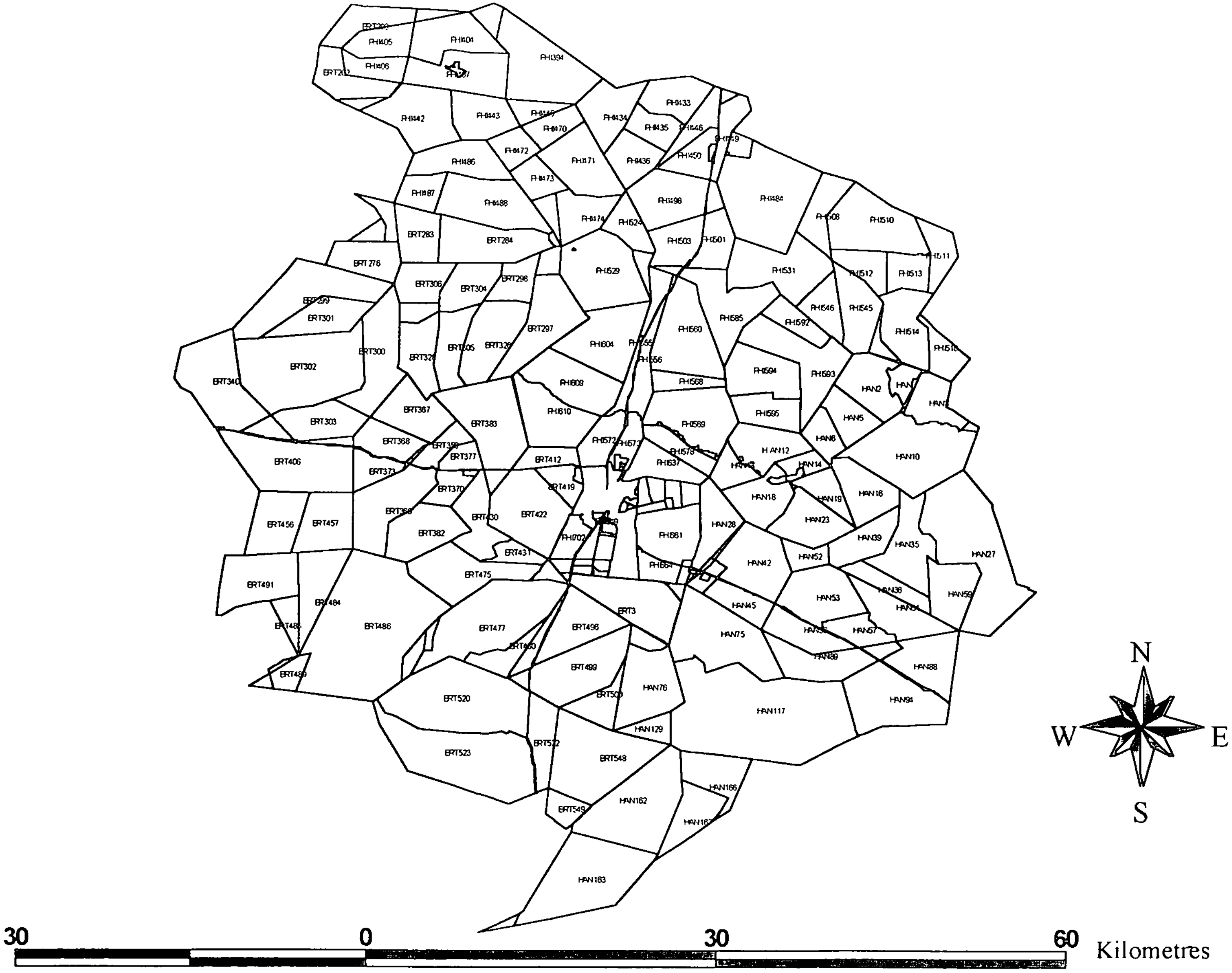
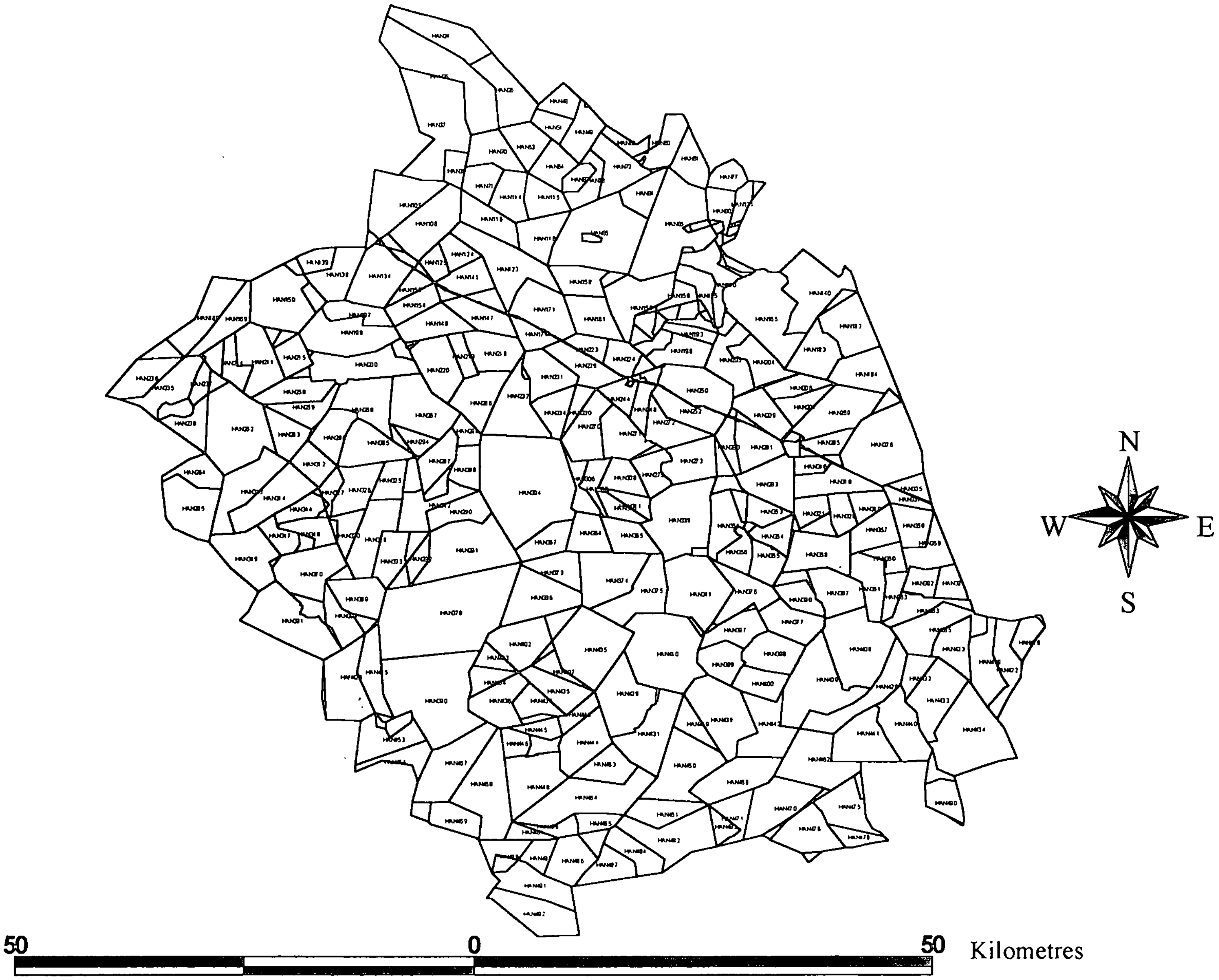
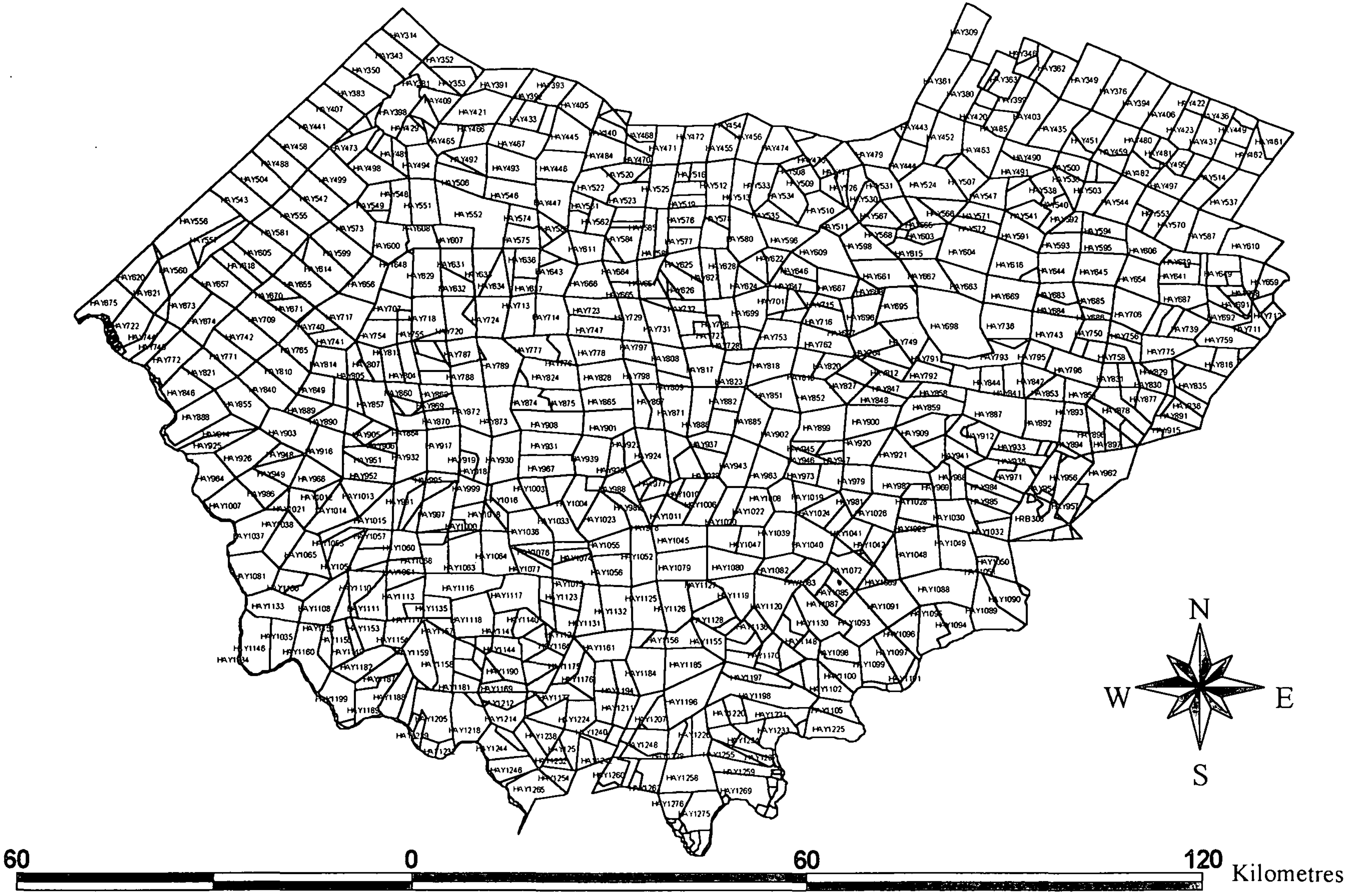
Appendix 1: De Aar locust district. Codesets displayed are of farms with as area > 500 ha only.



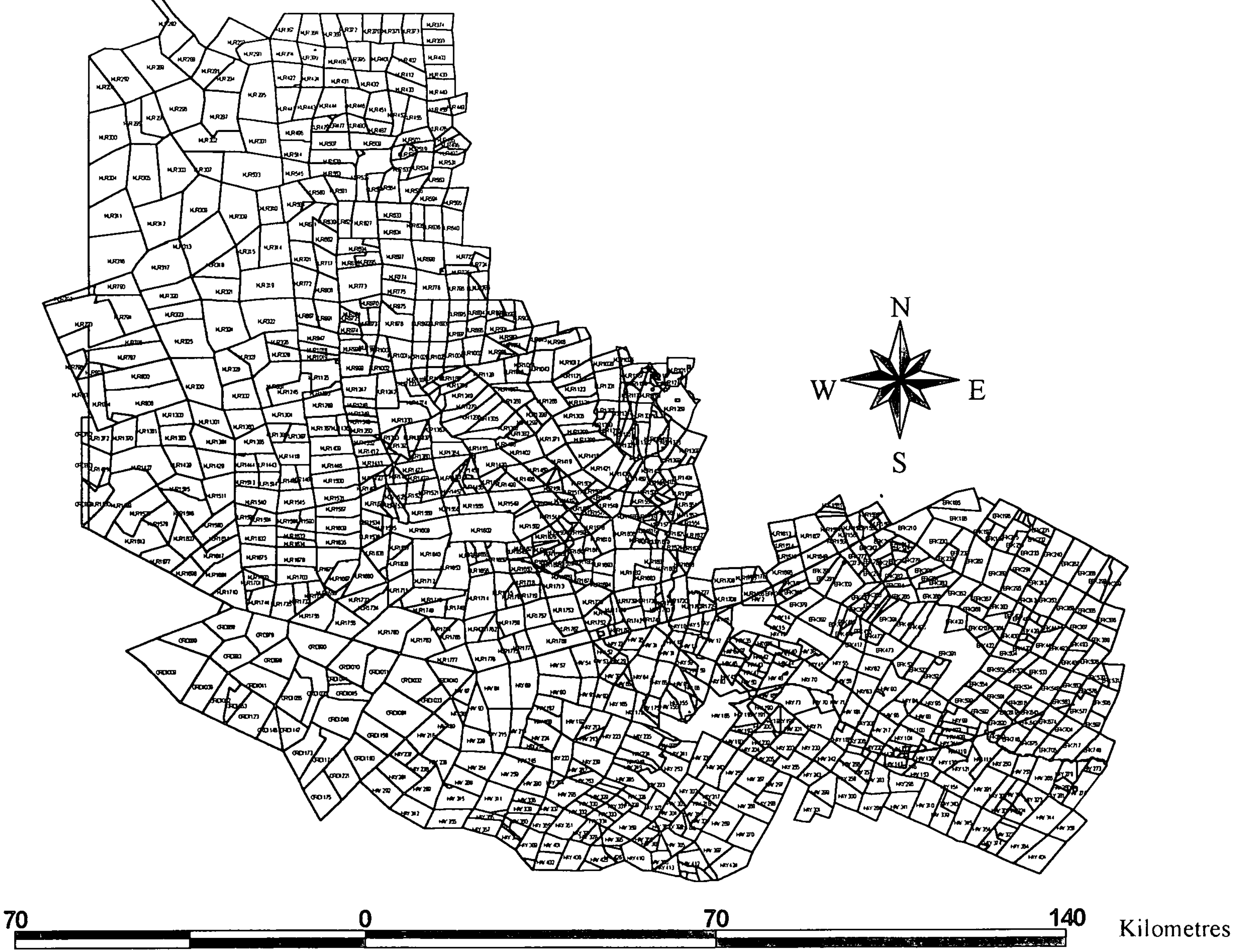
Appendix 2: Hanover locust district. Codesets displayed are of farms with an area > 500 ha only.



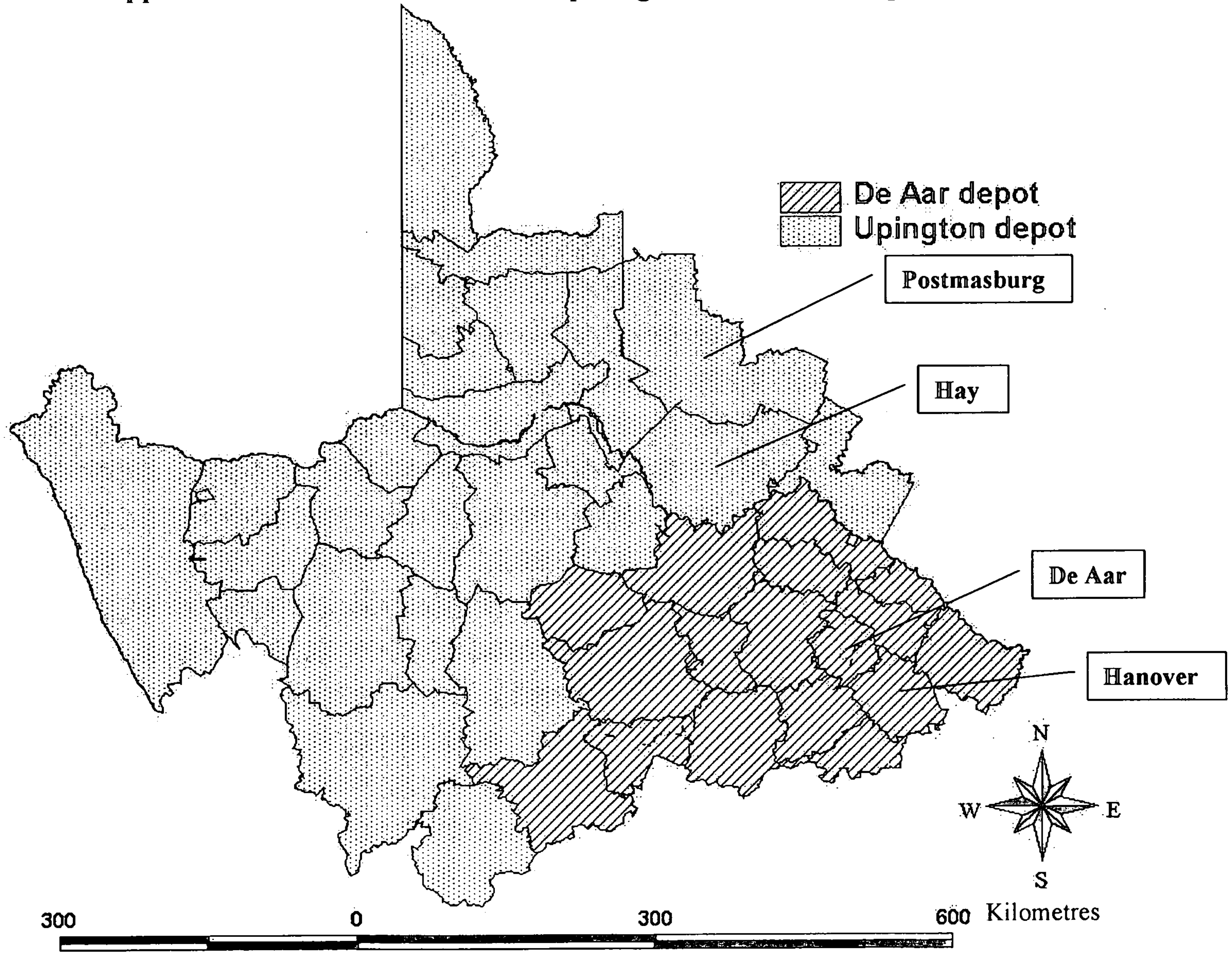
Appendix 3: Hay locust district. Codesets displayed are of farms with an area > 500 ha only.



Appendix 4: Postmasburg locust district. Codesets displayed are of farms with an area > 500 ha only.



Appendix 5: The locust districts composing each of the two depots in South Africa.



Appendix 6: magisterial districts affected by locust outbreaks in 1996/97. Highlighted area is indicated in appendix 5 (locust districts).