THE IMPACT OF HAIL ON TRANSVAAL MAIZE PRODUCTION

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Abstract

Almost a quarter of South Africa's agricultural production is lost annually due to adverse weather. About 9 per cent of this is due to hail damage. This paper examines some spatial aspects of hail damage to maize in the Transvaal, using hail insurance data for the 1981/82 - 1986/87 period. In addition, the effect of hailstorm frequency, size and intensity as well as the susceptibility of maize to hail damage are discussed and hail risk zones delineated. The analyses indicate, *inter alia*, that the highest crop loss occurred in the Belfast, Bethal, Pretoria and Krugersdorp districts and that the likelihood of hail damage (i.e. the hail risk) is highest in the south, south eastern and south central parts of the Transvaal.

Uittreksel

Ongeveer 'n kwart van Suid-Afrika se landbouproduksie gaan jaarliks verlore weens ongunstige weerstoestande. Bykans nege persent hiervan word deur haelskade veroorsaak. Hierdie artikel beskryf enkele ruimtelike aspekte van haelskade met betrekking tot mielieproduksie in die Transvaal deur gebruik te maak van 1981/82-1986/87 versekeringsdata. Daarbenewens word die impak van haelstormfrekwensie, -omvang en -intensiteit asook die kwesbaarheid van die plant bespreek en hoë haelrisiko-sones afgebaken. Die analises toon, onder andere, dat die grootste oesskade in die distrikte van Belfast, Bethal, Pretoria en Krugersdorp voorgekom het en dat die waarskynlikheid vir haelskade (d.w.s. haelrisiko) die grootste is in die suidelike, suid-oostelike en suid-sentrale gedeeltes van Transvaal.

1. Introduction

Crop hail damage is a widespread phenomenon especially in countries such as Argentina, the USA, Canada, Switzerland, Japan, the USSR, Italy and South Africa (Carte, 1977). Recent estimates of annual losses to weather hazards in the United States indicate that damage worth $750 million was the result of hail - with crop loss accounting for $680 million while $70 million originated from property damage (Kessler and White, 1983). According to Carte (1977), an insurance co-operative estimated the 1976/77 hail damage to South African crops to have been in the order of R144 million, i.e. 8,7 per cent of the total crop production. Maize is the crop which suffers most hail damage - with approximately 4 per cent of the crop being destroyed by hail annually (Carte, 1977; Gillooly, 1978). This implies a maize yield loss of about 290 000 tons (R69 million) in terms of the 1986/87 maize production figures (Republic of South Africa, 1988).

Notwithstanding these enormous losses, drought accounts for an even greater proportion of the total annual crop loss. For this reason most agroclimatic research has centred around the drought problem. This article attempts to redress this imbalance by describing some geographical aspects of hail damage. Due to the importance of maize in the agricultural production and its susceptibility to hail damage, the study focuses on identifying high hail risk zones for maize production in the Transvaal.

According to Roth (1949), the long term hail damage to crops depends on (1) the frequency and severity of hailstorms according to location and date and (2) the type of crop, including its stage of growth. Therefore aspects such as the intensity, spatial extent and the seasonal occurrence of hailstorms in the Transvaal need to be examined. However, due to the lack of adequate data relating to the former two aspects, indirect 'measurements' of these have to suffice. Consequently, indices reflecting the magnitude of damage resulting from these hail parameters have been devised. This article describes spatial hail damage patterns and delineates hail risk zones for maize production in the Transvaal.

2. Data

Hail insurance and hail damage data were obtained from Sentraoes Insurance Co. for the 1981/82 to 1986/87 period. The data comprised accumulated weekly summaries of hail damage claims and liability (policies) records for each magisterial district in the Transvaal (excluding self-governing and independent National States). Weekly data records, commencing on 1 April of each year, included the following information : the number of claims processed per week (N_{claims}), the value of these (R_{claims}), the number of hail insurance policies taken out ($N_{policies}$) and their worth ($R_{policies}$), as well as the area of cropland covered by the insurance policies ($ha_{insured}$).

In this study it was assumed that:

(i) R_{claims} reflects the extent of hail damage;

(ii) $R_{policies}$ gives an *indication* of the expected maize yield. (It is a well known fact that many farmers tend to insure their crops to recover input costs only and hence the value of the policies do not necessarily denote the size of the expected crop. This trend is assumed to apply to farmers throughout the area. Moreover, since there is no other method to correlate the two variables, the policies values are use as proxy variables for expected yield.) Thus the ratio of loss paid (R_{claims}) to the amount insured ($R_{policies}$) reflects the ratio of crop yield destroyed to the expected crop production (Roth 1949); and

(iii) N_{claims} is a measure of the frequency of hailstorms and/or the spatial extent of these storms.

District hail damage data are not directly comparable for a number of reasons, *inter alia*, the magisterial districts (as shown in Figure 1) differ in size, as do the areas allocated to maize production. Furthermore, not all farmers take out hail insurance each year - and even if they do - there is no guarantee that they will insure through Sentraoes Insurance Co. However, since the latter is the largest hail insurance company in the southern hemisphere, it is the largest in this country and therefore it is assumed that the majority of farmers who do insure their crops, make use of this firm.

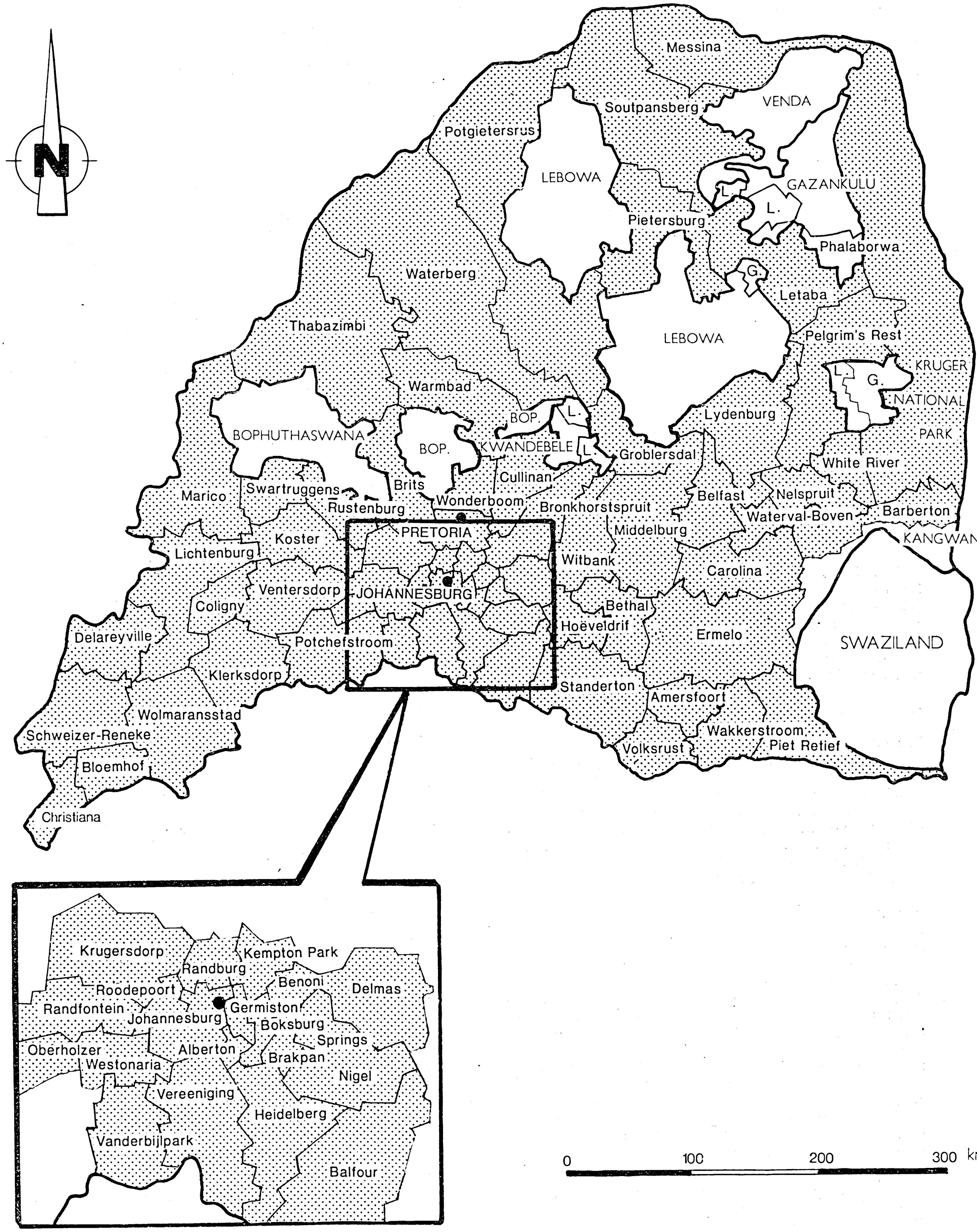

Figure 1: Magisterial districts in the Transvaal

In order to render data spatially comparable, values were either standardised or were given in terms of indices such as the crop loss - or intensity-susceptibility index etc. In the following sections, the spatial characteristics of various relative indicators of hailstorm activity and the resulting crop damage are described. Quintiles have been used to define classes on all maps in order to delineate areas with very high, high, medium, medium-low and low values, respectively, and to allow comparison between maps.

3. Hail damage

3.1 Relative hailstorm frequency and their spatial extent

An index of the relative storm **frequency** which causes hail damage to maize during the growing season is given by the ratio of $N_{claims} : N_{policies}$. This index also reflects the areal **extent** of a damage causing storm because it is likely that a large storm would cause damage to a number of farms - hence increasing the number of hail damage claims submitted to the insurance company. Therefore the $N_{claims}/N_{policies}$ ratio will henceforth be referred to as the **F-E index**. It is assumed that a farmer will submit a hail damage claim whenever any crop loss occurs - irrespective of the extent of the loss. Neither the intensity of the hail, nor the phenological stage of the crop influences the number of claims submitted - but only their value.

Analysis of district F-E index values (Figure 2) shows a concentration of high values in and around the south eastern and southern Transvaal. These districts coincide with areas with the highest point hail day frequency (HDF) i.e. where the long term (and thus the expected) point HDF exceeds 4 days/year (Olivier, 1989). It is also likely that storms in these areas are larger in areal extent than those occurring elsewhere. Low F-E values occur along the fringes of the Transvaal - notably in the Lowveld, extreme northern, north western, western and south western Transvaal and in the vicinity of Pietersburg. This implies that (maize) crop damage in these regions is mainly due to the intensity or the seasonal incidence of the hailstorms.

3.2 Intensity - susceptibility index

The ratio of $R_{claims} : N_{claims}$ gives a relative measure of the damage caused during a storm since it is assumed that a farmer will submit a hail damage claim whenever some crop damage is sustained - irrespective of the amount of the damage. Therefore the greater the $R_{claim} : N_{claim}$ ratio, the greater the intensity of the storm or the more susceptible the plants to hail damage. This ratio (x100) is thus called the **intensity-susceptibility index** (I-S). It is not affected by the frequency of the storms and only minimally by their spatial extent.

In contrast to Figure 2, the most intense and seasonally inopportune hailstorms occur in an east - west zone extending from Swartruggens to Barberton (Figure 3). It is interesting to note that only one of the eight districts with very high I-S values coincides with that of the same category F-E value, namely Springs. Similarly, if regions with index values of zero are ignored, the only district with a very low I-S index value which also has a very low F-E value, is Bloemhof. This apparent mutual exclusivity of I-S and F-E indices seems to indicate that those districts with hail damage resulting from high hailstorm frequency or from large storms are less likely to also experience high intensity storms. Furthermore, hailstorms in these districts occur during a stage when plants are less susceptible to hail damage. Using the χ^2-test, the relationship between I-S and F-E indices in the Transvaal was found to be significant at the 2.5 per cent level. (The r and r_s values of -0,32 and -0,30 respectively, are not statistically significant.) It is thus apparent that different hailstorm characteristics are measured by these two indices.

3.3 Crop hail damage

There are two indices which reflect crop hail damage. Firstly, the ratio of $R_{claims} : R_{policies}$ which gives the proportion of the expected yield which is destroyed and secondly, $R_{claims/ha}$, which simply shows the extent of the hail damage occurring per unit area.

According to Figure 4, crops sustain most hail damage in the Belfast, Bethal, Pretoria and Krugersdorp districts. During the study period, more than 5 per cent of the estimated yield was destroyed annually by hail. The adjacent districts of Middelburg, Delmas, Balfour, Rustenburg and Potchefstroom also lost in excess of 3,5 per cent of the total expected crop. Despite these seemingly low values, they do represent substantial financial losses. Based on the estimated production figures for the 1986/87 season, 52 765 tons of maize were destroyed by hail during this period (Republic of South Africa, 1988). At 1986/87 maize prices - this amounts to a staggering loss of more than R14 million **in these districts alone**. Estimated production figures and the yield lost as a result of hail damage, have been summarised in Table 1.

Table 1 Estimated cost of hail damage to maize (1987).

District	ave. % Crop lost (1981/82-1986/87)	Est. yield (tons)* Feb. 1987	Yield lost (tonnes)
Balfour	4,37	113 386	4 954,97
Belfast	5,60	80 851	4 527,66
Benoni	3,50	70	2,45
Bethal & Hoëveldrif	5,10	299 182	15 258,28
Delmas	4,71	143 436	6 755,84
Krugersdorp	5,91	2 719	160,69
Middelburg	4,05	374 273	15 158,06
Potchefstroom	3,64	52 653	1 916,57
Pretoria	5,02	11 330	568,77
Randfontein	3,55	56 555	2 007,70
Rustenburg	3,67	4 583	168,20
Warmbad	3,95	32 576	1 286,75
Total			52 765,94**

* From Dept Development and Planning, maize estimates - 1987 Area and Crop, RSA.

** @ R270/t = R14 246 803 - Dept Agricultural Economics and Marketing, 1988 Abstract of Agricultural Statistics

The hail damage pattern, as given by $R_{claims/ha}$ (Figure 5), is essentially similar to that of crop loss (r = 0,92), with the east-west zone of maximum damage running through the central and south eastern Transvaal. Average-to-high hail damage thus occurs in a zone extending from about 25°S to 26½°S and from 27°E to the Swaziland/Mozambique border. Anomalously low values of crop hail damage occur in the Bronkhorstspruit and Witbank districts. The former may be explained by the low I-S and F-E index values while the ostensibly low value in the Witbank area is in fact an aberration caused by the selection of the class limits on the maps.

3.4 Comparison of hail damage indices

Correlating district F-E and I-S indices with district crop damage (per cent) give r values of 0,68 and 0,35, respectively. The former correlation coefficient is significant at the 0,001 per cent level of significance and explains a larger proportion of the variance in crop damage than does the I-S index. This overall low correspondence between the I-S and crop damage patterns seems to indicate that intensity and seasonal incidence of hailstorms are not the most important factors as far as crop loss is concerned.

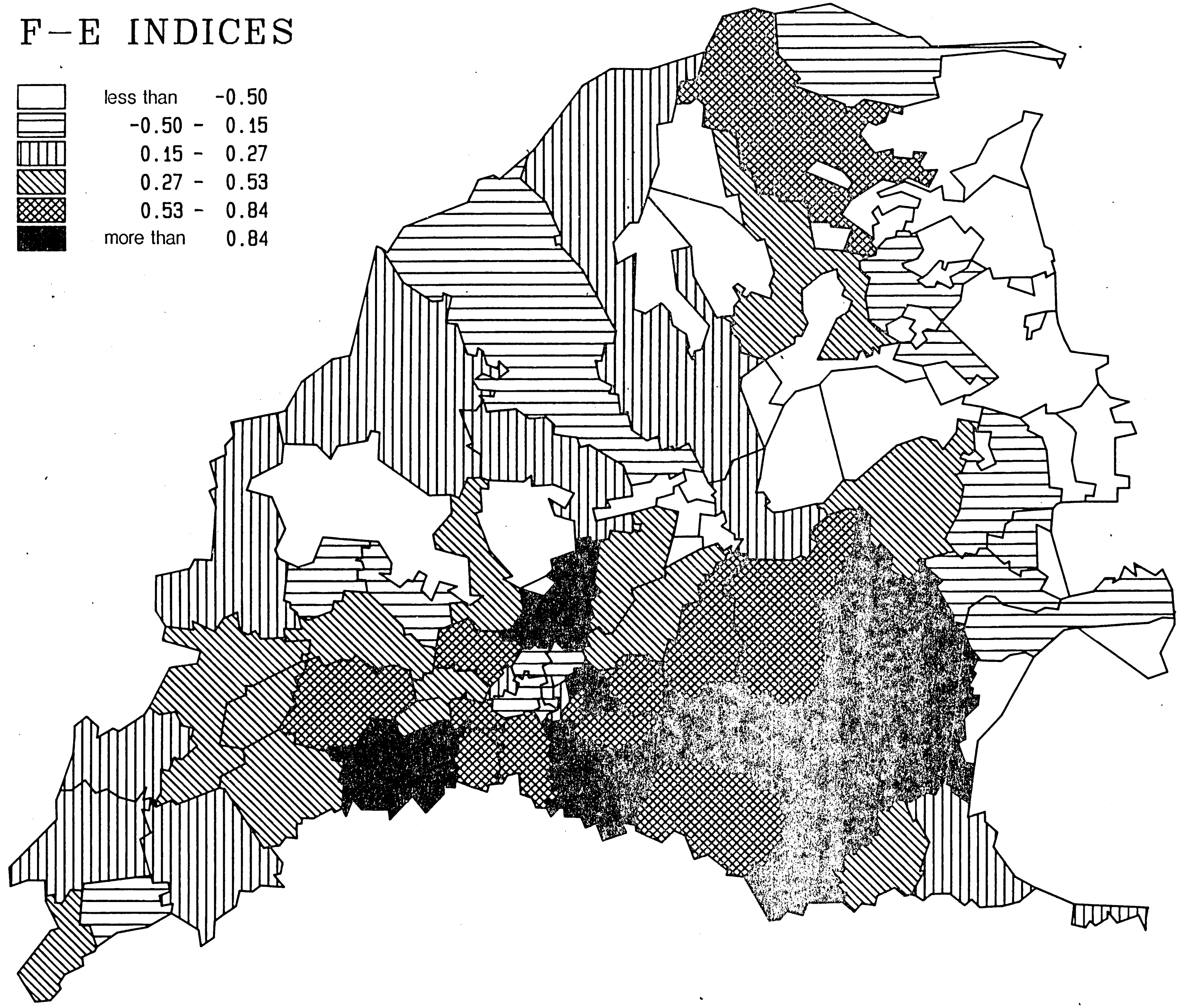

Figure 2: District F-E index ($N_{Claim}/N_{Policies}$) patterns

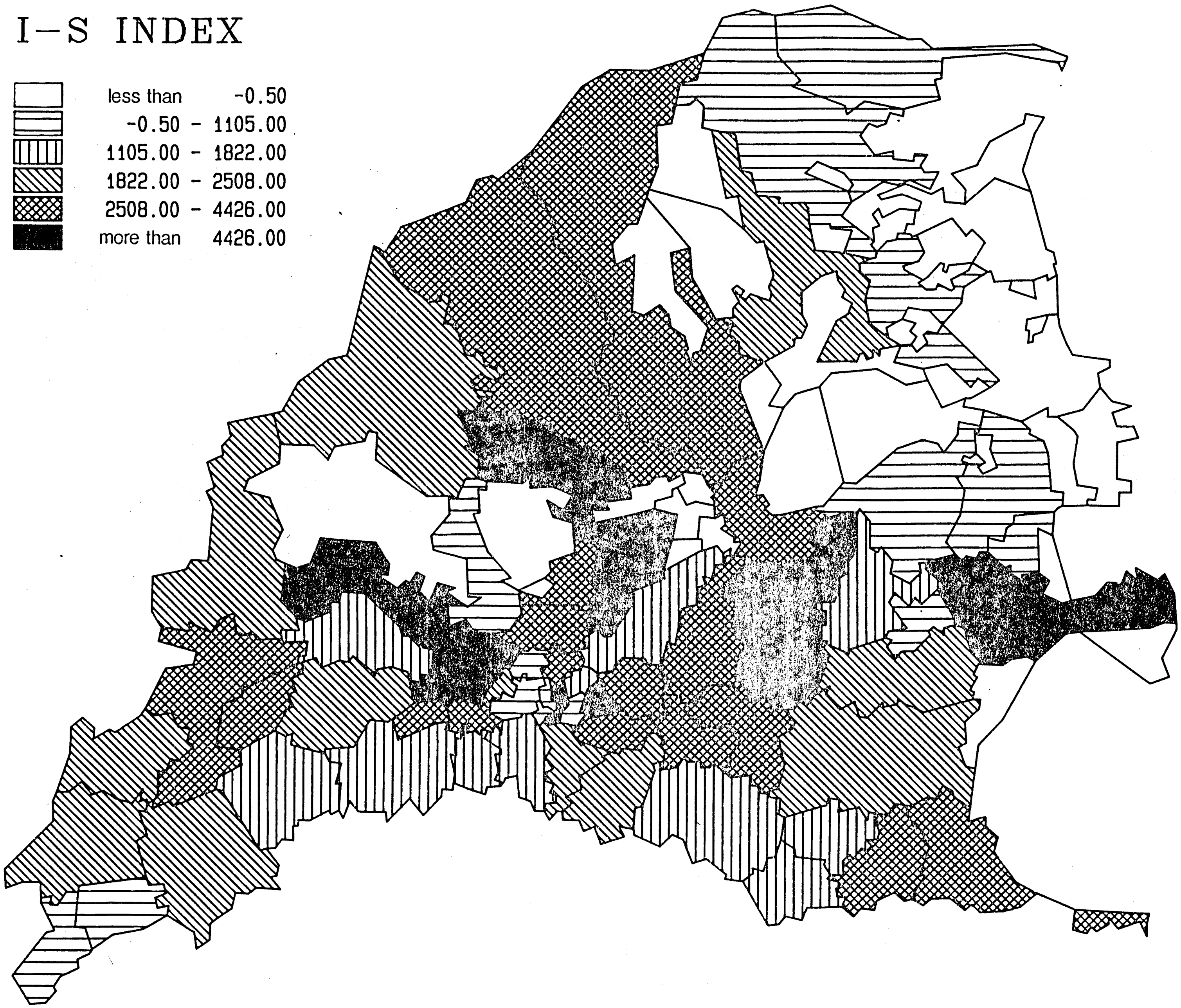

Figure 3: District I-S index ($R_{Claim}/N_{Policies}$) patterns

On the other hand, the correlation between the 1982-1986 point HDF in each district and the district crop damage values is not statistically significant either - which clearly establishes the relatively more important role of the spatial extent of the hailstorm in causing crop damage. These apparently conflicting results suggest that the interrelationships between storm frequency, intensity, spatial extent and the crop susceptibility factors on crop loss are more complicated than expected, necessitating more attention.

The relatively small impact of hail seasonality on crop damage may be explained *vis-á-vis* the spatial differences in peak hail season, together with the seasonal characteristics of hail damage. It has been shown that early hail occurs most often in the eastern parts of the Transvaal but shifts to peak later over the western parts (Olivier, 1989). It is these January and February hailstorms which affect yield most. From this it seems likely that the early peak hail season in the extreme southern and south eastern parts of the Transvaal precedes the critical phenological period - hence resulting in less crop damage in these potentially high-yield areas. It therefore seems probable that different relationships could exist between the I-S index and crop loss in different parts of the region.

That this is indeed the case is clearly shown by Figure 6. Here the district C-L indices have been plotted against district I-S values. It is evident that the districts seem to cluster into three zones, each of which shows some linear tendency. With minor exceptions, all those districts with relatively high C-L/I-S ratios (around 1 : 1000) occur in the southern and south eastern Transvaal, while those with the lower ratio are mostly contiguous in the northern and western Transvaal. A central zone comprising districts extending in a SW - NE band across the study area has a C-L/I-S ratio of approximately 1 : 2000. Swartruggens is the only obvious outlier.

Accordingly, the Transvaal was subdivided into three zones as indicated on the insert in Figure 6. Pearson's product moment correlation coefficient was calculated and regression analysis performed on each in order to determine the strength and nature of the relationship existing between hailstorm intensity, crop susceptibility and the amount of crop loss sustained in each subregion. It seemed probable that those districts that were particularly poorly represented by the data (i.e. <50 policies in six seasons) and/or in which less than 30 claims were recorded during the study period, could cause statistical bias. They were thus excluded from this part of the analysis.

The resulting calculations showed strong links between the I-S index and crop loss in each of these three zones. In the south and south eastern as well as the central Transvaal, correlation coefficients of 0,7 were found. These are significant at the 1 per cent level. A highly significant (α^2 = 0,001) linear relationship exists between I-S and C-L in the western and northern Transvaal (r = 0,92). Thus despite earlier findings (for the entire province) it is clear that a strong linear relationship does exist between the I-S index and crop loss, but that its nature differs from one region to the next.

To determine the relative importance of these two indices (I-S and F-E) in explaining the variance in crop loss, district I-S, F-E and C-L values, for each of the three zones separately, were subjected to stepwise multiple regression analysis. The results show that the I-S and F-E indices together explain 75 per cent, 90 per cent and 91 per cent of the variation in crop loss in the central, northern and western and south-south eastern parts of the Transvaal, respectively. The multiple linear regression formulae are:

Central TVL:
C-L = 1,7077 + 3,81 F-E + 0,0006 I-S. R^2 = 74,91%

N & W TVL:
C-L = -0,673 + 0,000426 I-S + 2,507 F-E. R^2 = 90,45%
S & SE TVL:
C-L = 2,706 + 3,90 F-E + 0,0011 I-S. R^2 = 91,4%.

It must be remembered that all index- as well as crop loss values are the statistical means of six seasons' data. Anomalies in any one season may thus influence the mean to such an extent so as to give an ostensibly 'bad fit' between the index and crop loss values.

4. Hail risk zones

The purpose of this article is, in part, to delineate high hail risk areas for maize production in the Transvaal. For this purpose, either the proportion of crops destroyed by hail i.e. the crop-loss index, or the damage incurred per unit area can be used as estimators of the total crop damage which occurs within a district. However, 'hail risk' pertains to the hail damage which can be **expected** in a certain area - and hence can only be derived from long-term trends. Because the above analyses are based on short-term (1981/82 - 1986/87) data, Figures 4 and 5 showing crop loss cannot be used to define 'hail risk' areas *per se*. Therefore, hail risk was calculated for each district by dividing the crop loss ($R_{claims}/R_{policies}$) by the average number of storms which occurred per year during the 1981/82-1986/87 period (thus determining the crop lost/hail event) and then multiplying this with the long-term mean annual HDF.

District hail risk =
$(\text{Crop Loss}/\text{HDF}_{1981/82\text{-}1986/87}) \times \text{HDF}_{\text{Long-term}}$

District values for the latter factor were obtained by interpolating long-term point HDFs for all Transvaal stations (extracted from WB40 (SAWB, 1986). Inaccuracies due to the effect of the cyclical pattern of annual HDFs which occur in some parts of the Transvaal (Olivier, 1989) as well as short-term hail day anomalies would thus be eliminated.

Figure 7 depicts areas with high, medium and low hail risk. In the interpretation of hail risk it must be borne in mind that a high hail risk area is not one in which a high HDF necessarily occurs - but one in which a high crop loss can be expected in the long term. According to Figure 7, most maize damage due to hail can be expected in the south eastern and southern parts of the Transvaal. This decreases towards the north, north west and the Lowveld. The spatial hail risk pattern is in many respects similar to that of the F-E index and the long-term HDF pattern. Deviations which occur in the Belfast and Volksrust districts might be due to anomalous hail incidence during the 1981-1986 period.

5. Summary and conclusion

Hazard impact assessment and the identification of high risk areas are obviously necessary prerequisites for meaningful crop-related decisions. This study examined the impact of hailstorms on maize production in the Transvaal. Specifically, it focused on identifying and explaining spatial hail damage patterns and delineating zones with low, medium and high hail risk.

The data comprised weekly hail insurance and hail claim summaries for each magisterial district in the Transvaal for the 1981/82 to 1986/87 period. It was assumed that the value of the claims gave an indirect indication of the magnitude of the hail damage; the number of claims reflected both the number of damage-causing hailstorms and their spatial extent; and that the value of the insurance policies was used as a substitute variable to denote the size of the expected yield. The data were standardised in order to render them comparable on an inter-district basis. The resulting indices revealed the underlying causes of hail damage.

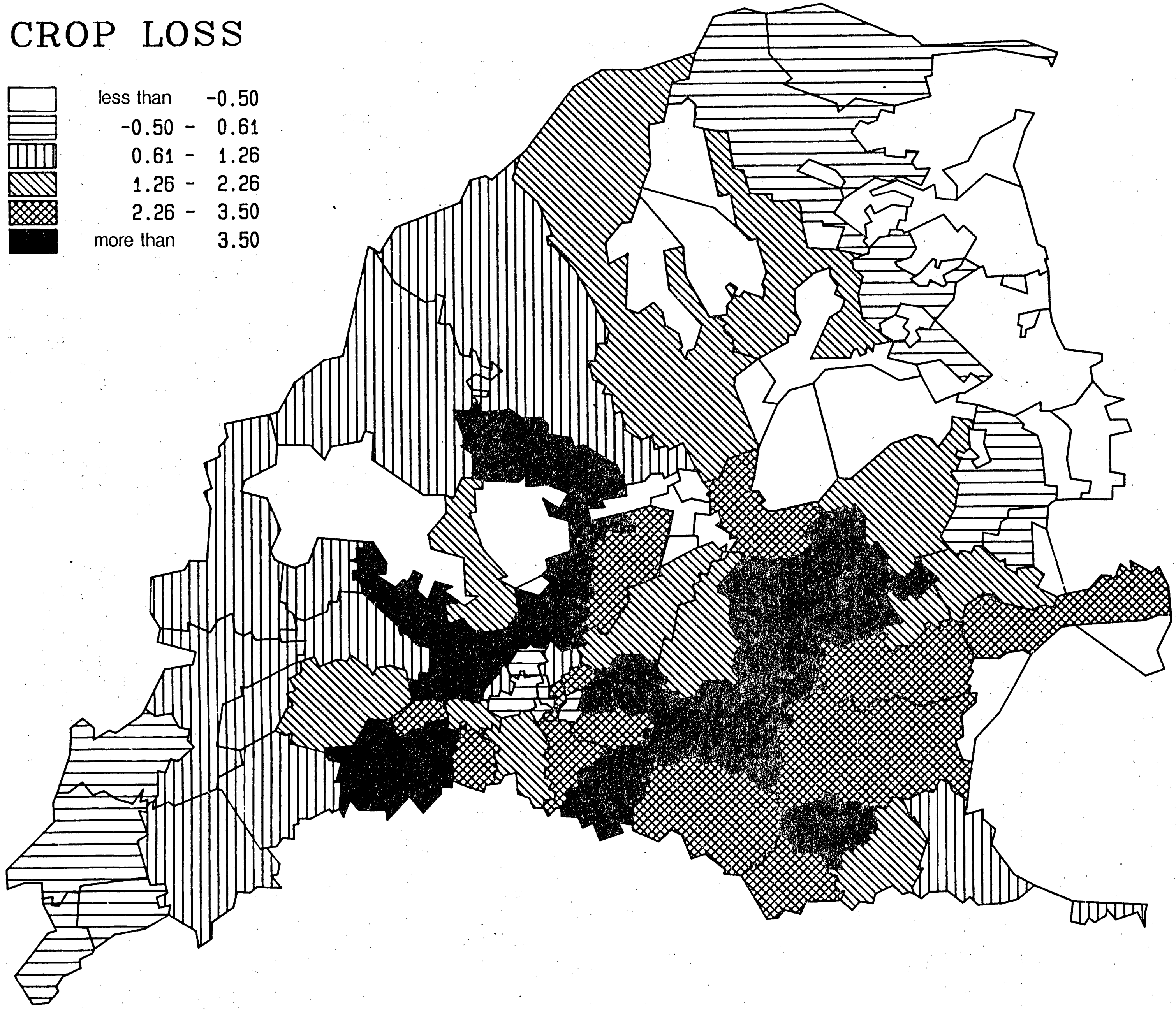

Figure 4: Spatial crop loss ($R_{Claim}/R_{Policies}$) patterns (per cent)

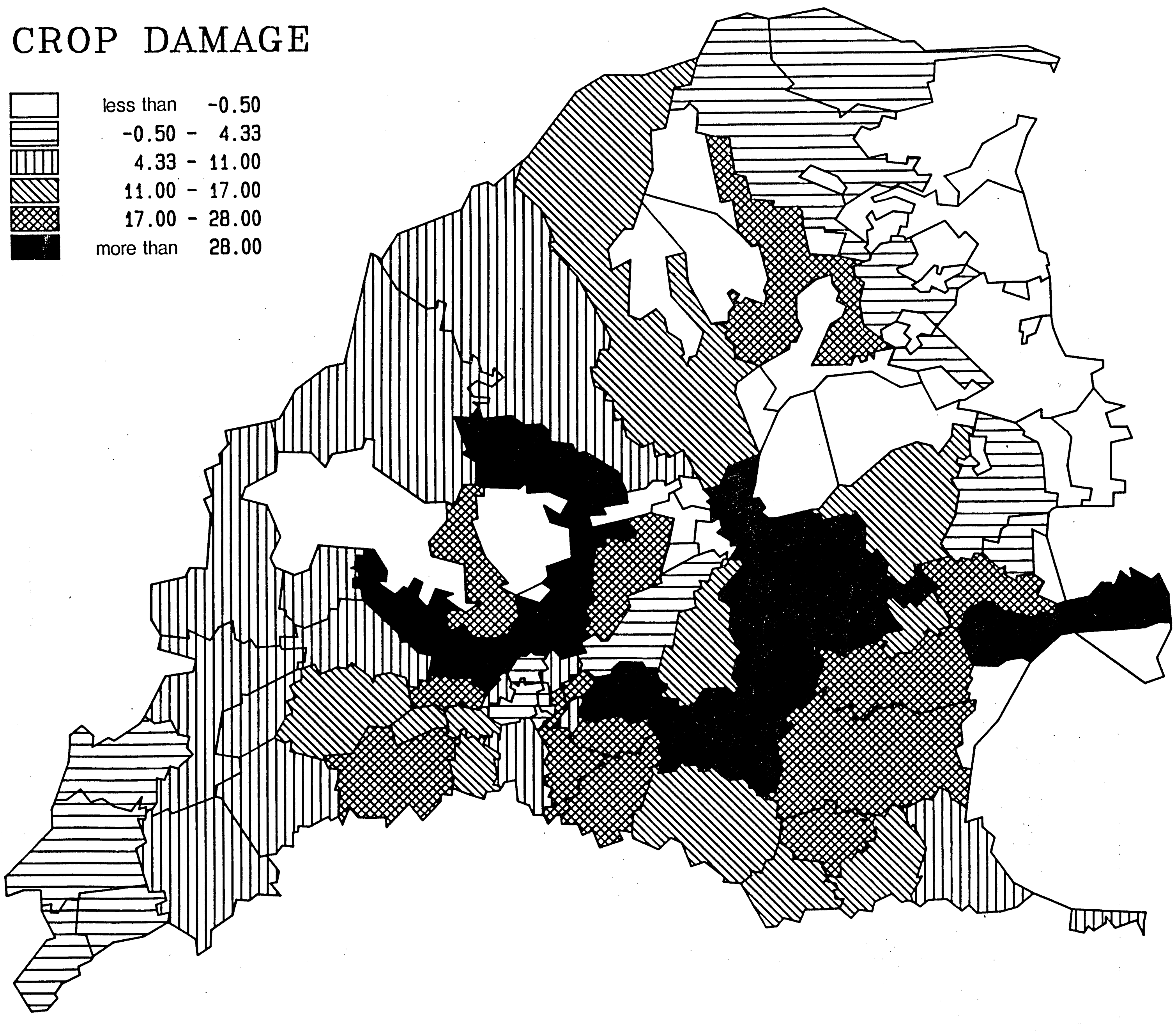

Figure 5: Crop damage in the Transvaal (R/ha)

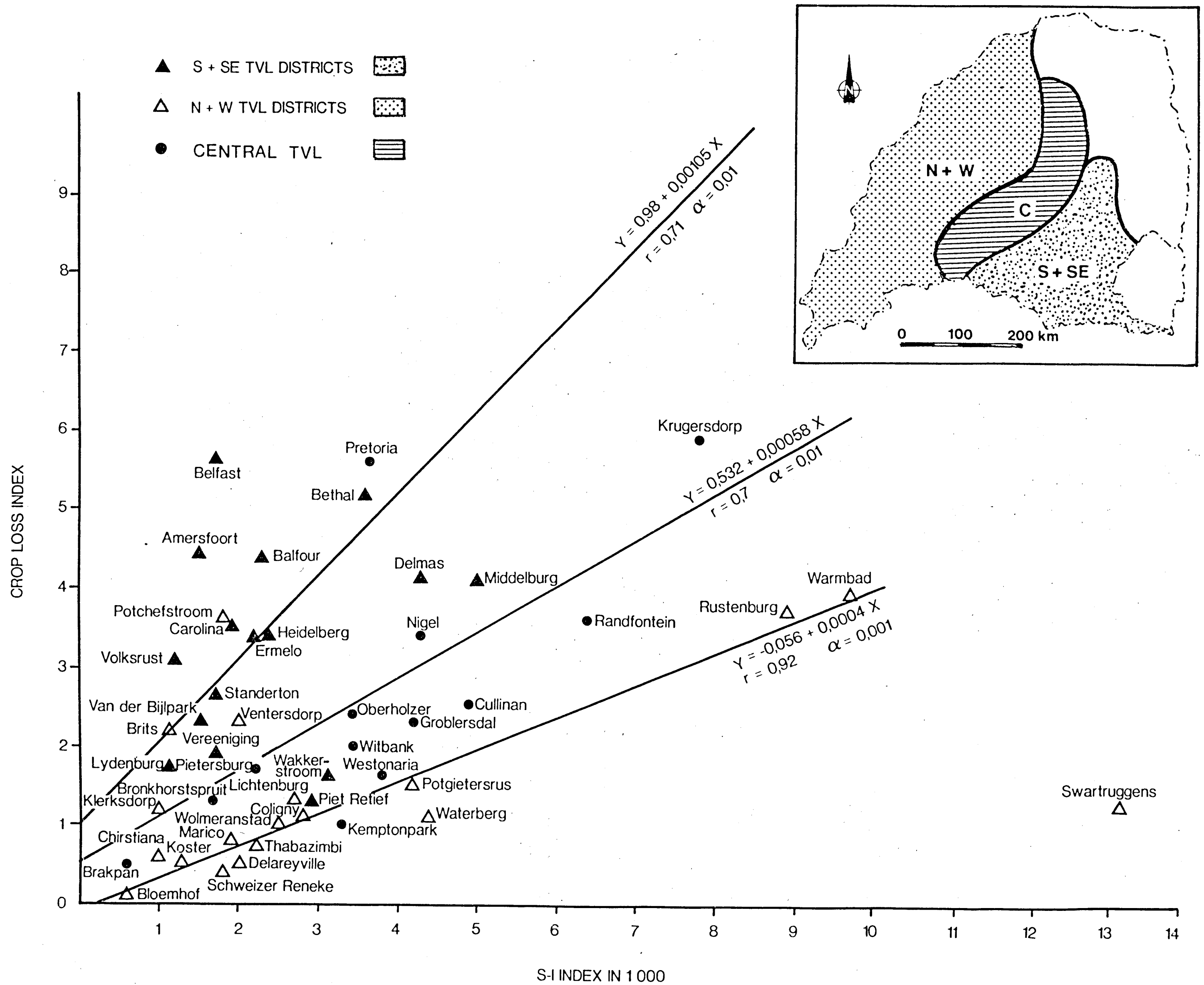

Figure 6: The relationship between crop-loss and I-S indices for all Transvaal districts. The insert shows the three sub-regions used for the analyses

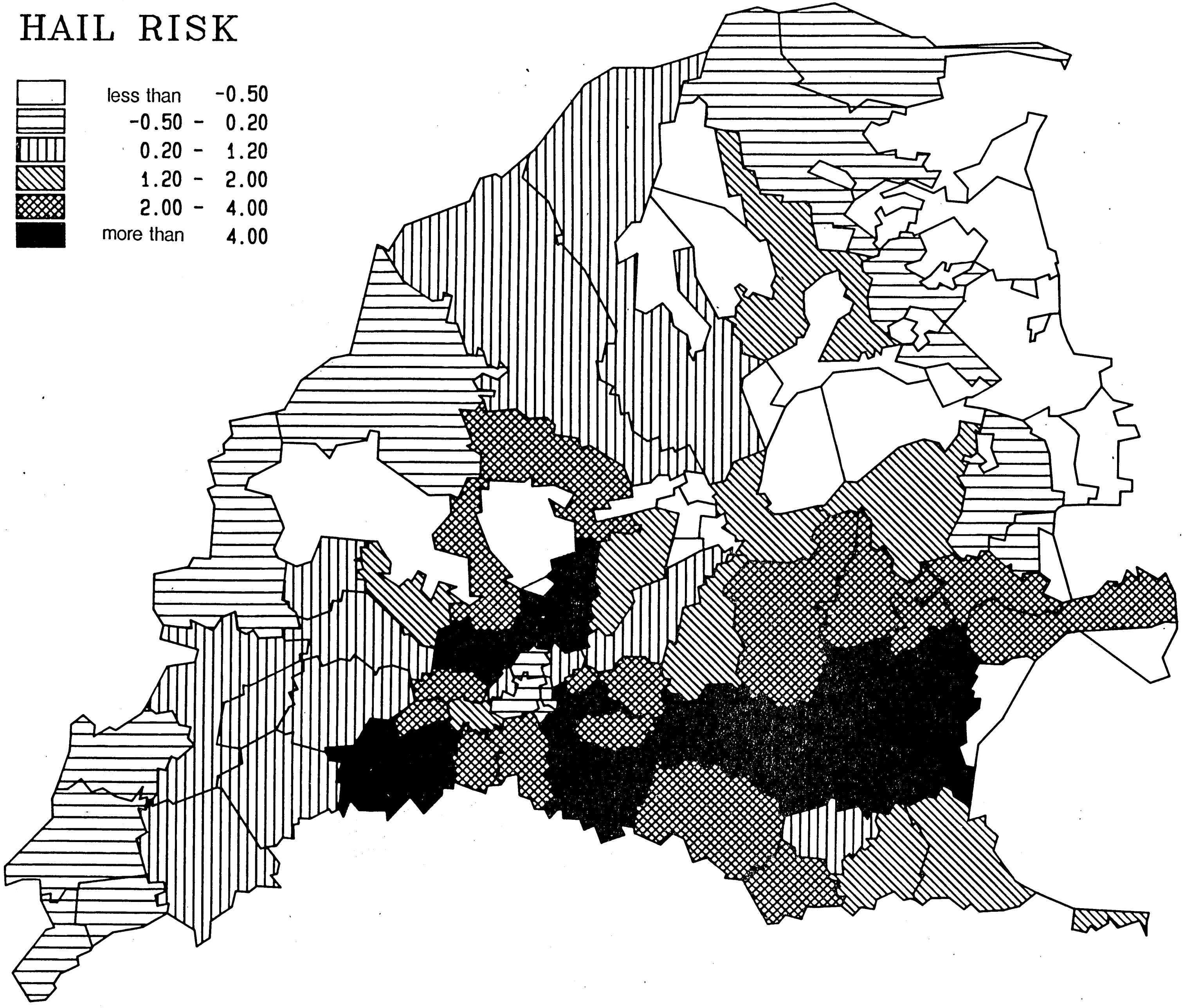

Figure 7: Hail risk zones for maize production in the Transvaal

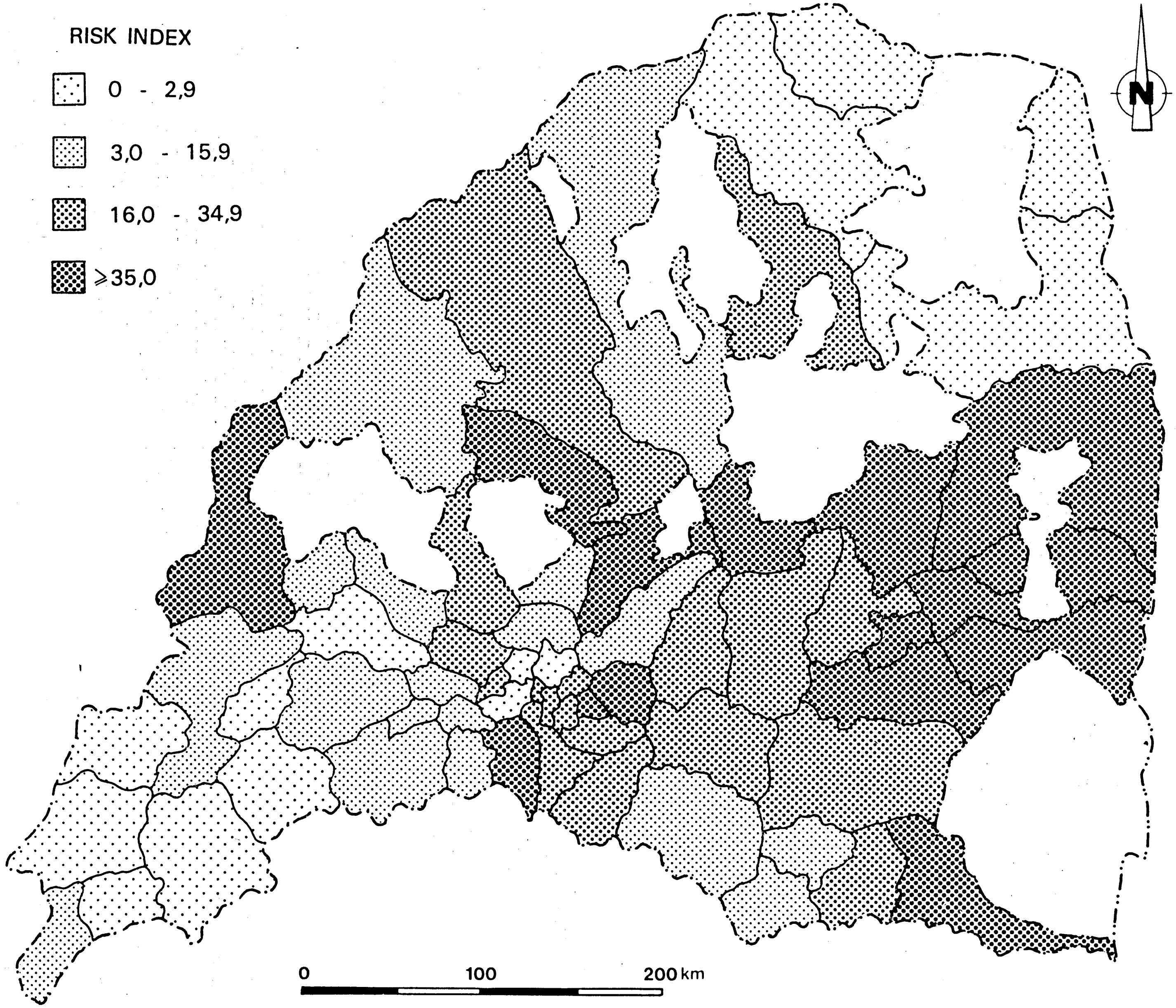

Figure 8: Spatial distribution of agricultural (all crops) hail risk zones as determined from hail insurance data

For instance the ratio of the number of hail claims to the number of policies taken out gave an indication of the frequency of the hailstorms and their areal extent and was called the F-E index. Similarly, the mean value of each claim revealed information concerning the intensity of the storms and/or the susceptibility of the crop to hail damage (and was thus denoted as the I-S index). Crop damage was expressed either as the proportion of the total expected yield which was destroyed (crop lost i.e. value of claims/value of policies) or simply as the damage incurred per unit area insured (in Rand/ha). A distinction was made between hail damage and hail risk. The latter pertains the amount of hail damage which is expected to occur over an extended period of time. District hail risk values were derived by weighting the average yield lost/storm with the relevant long-term mean annual hailstorm frequency.

The analyses revealed that most crop damage (in terms of both the proportion of the crop lost as well as the value of hail damage incurred/ha insured) occurred in the Belfast, Hoëveldrif/Bethal, Delmas, Balfour, Middelburg, Pretoria/ Wonderboom, Krugersdorp, Rustenburg and Potchefstroom districts. Contrary to expectation, these areas were not characterised by the highest hail day frequency. This implies that the intensity of hailstorms and the phenological stage of the plant are relatively more important in terms of hail damage. Since maize is particularly susceptible to hail damage during the tasselling, silking and seed-filling stages, early season hailstorms usually cause less damage than those occurring during mid- and late summer. This is especially important in the north western and western Transvaal where the hail season peaks later than in the eastern and south eastern parts.

When long-term hail frequency patterns were taken into account, it was found that the areas with the highest hail risk did not necessarily coincide with high crop loss zones. Districts with the highest probability of hail damage include Potchefstroom, Krugersdorp, Pretoria/Wonderboom, Hoëveldrif/Bethal, Ermelo and Carolina.

This paper has attempted to describe some impacts of the hail hazard on parts of the agricultural sector. The results may be used to make crop-related decisions which could minimise crop loss due to hail damage. The type of crop to be cultivated or the planting date could be varied towards this end. It should, however, be borne in mind that high hail risk zones will differ from one crop to the next. Figure 8 depicts agricultural hail risk in the Transvaal for all crops. The differences between the risk attached to maize production compared to that for crops farming in general is especially obvious in the Piet Retief, Lichtenburg, Cullinan, Groblersdal and Lydenburg districts as well as in the Lowveld areas (Pilgrimsrest and Witrivier) where tobacco, cotton, sunflowers etc. are relatively more important than maize. As pointed out by Carte (1977) and Gillooly (1978), these crops are also highly susceptible to hail damage.

It should be remembered in mind that the results obtained in this study are based solely on Sentraoes Insurance data. It is of course dangerous to assume that this gives a true insight into the actual situation since there are a number of districts in which very few hail insurance policies were sold by Sentraoes. This might reflect a perception of either low risk and/or low expected benefits from insurance. This aspect (the proportion of crops ensured) has not been examined an may constitute a serious shortcoming. Another aspect which has not received attention here is the change in hail damage climatology over time. This was the subject of an entirely separate study.

According to Hobbs (1977, 104), weather induced reductions in yield have become of crucial political, social and economic importance. It seems self-evident that weather/climate risk analyses should form an integral part of agricultural planning and that more inter-disciplinary research be done involving both climatologists and agriculturalists in order to minimise crop loss.

Note

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