A MULTI-FACTOR STUDY OF CABBAGE PRODUCTION IN THE UMLAAS RIVER VALLEY

by

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ABSTRACT

A research and extension programme monitored 59 cabbage crops and many factors associated with cabbage production in the Umlaas River Valley of KwaZulu-Natal, from July 1991 - June 1993. A large data bank was developed, accumulating all information regarding soils, weather patterns, farming practices, management, crop water stress, yields, plant populations, weeds, pests, diseases, soil fertility, leaf nutrient concentrations and the presence of hormone herbicides in the rain. Analysis of this large data bank of information enabled the identification of limiting factors and optimized production practices.

Excessively high or low levels of soil nutrients and soil acidity problems, reduced cabbage yields in the Umlaas River Valley. Identification of critical values and an ideal cation ratio in soils, and recommendations to rectify limiting factors, could drastically improve yields. Wide variation and excesses of soil nutrients were seen from soil analysis of 59 cabbage crops in the Umlaas River Valley. Soil P > 155, K > 486 and Mg > 568 mg l^{-1}, exchangeable acidity > 0.11 $cmol_c$ l^{-1}, acid saturation > 2 % and pH < 4.51 resulted in lower yields. Top yields were found between a certain range of soil nutrient levels and critical values lay within this range. Optimal yields resulted with an ideal ratio of Ca, Mg and K (65:25:10) in plots monitored. A soil acidity complex affected cabbage yields in the Umlaas River Valley. High exchangeable acidity, acid saturation and low pH increased Mn and Zn availability in the soil. Both Mn and Zn were absorbed in large quantities by the plant and maximum levels of 406 mg kg^{-1} and 114 mg kg^{-1} respectively were recorded in most recently mature (MRM) cabbage leaves at headform. Mn concentrations > 100 mg kg^{-1} at headform and 50 mg kg^{-1} at harvest reduced yields.

Nutrient analysis results of a MRM leaf at headform, and a ⅛ head slice of a mature head at harvest, generated leaf nutrient norms and crop removal figures for cabbage. Adequate nutrient levels of MRM leaf at headform were: N = 3.3 - 4.8 %, P = 0.32 - 0.55 %, K = 2.1 - 4.2 %, Ca = 1.3 - 2.5 %, Mg = 0.25 - 0.65 %, Mn = 15 - 100 mg kg^{-1}, Zn = 18 - 60 mg kg^{-1} and Cu = 4 - 100 mg kg^{-1}. Nutrient concentrations above or below adequate ranges resulted in lower yields. Nutrient removal figures were: 1.9 kg N, 0.3 kg P, 2.03 kg K, 0.43 kg Ca, 0.19 kg Mg, 2.8 g Mn, 2.6 g Zn and 0.4 g Cu t^{-1} fresh material. These leaf nutrient norms were developed for reliable identification of soil fertility problems and the crop removals for improved fertilizer recommendations.

A study of fertilization practices showed that most farmers supplied enough ($\pm$ 200kg) N to cabbage crops but used incorrect pre- and postplant proportions (¼ and ¾) for top yields. For maximum yields, ⅔ of the total N should be applied preplant and ⅓ at 4-6 weeks. Topdressings of N should be applied once only and not split as is common practise in the area. Application of P on cabbage crops was proportional to soil requirements but was generally excessive. Sufficient quantities of K were applied but scant attention was given to soil analysis results for K, Ca and Mg requirements. Input costs could be decreased and high yields maintained if soils were fertilized up to critical values and no further nutrients added when soil test values exceeded critical values. Fertilization was not generally based on results of soil analysis and few farmers limed their soils in spite of soil acidity problems. The more acidifying NH_4 containing fertilisers were mostly used in preplant applications. The study recommended using more NO_3 based fertilisers to slow down acidification or, at least, corrective applications of lime.

Good pest and disease control is essential for maximum yields in the Umlaas River Valley. This study identified optimum infection periods and maximum and minimum temperatures for infection by blackrot, clubroot, ringspot, damping-off, sclerotinia, downy mildew and alternaria leaf spot; and evaluated disease effects on yields. Clubroot, blackrot and damping-off significantly reduced cabbage yields. Clubroot incidence was generally associated with soil acidity problems, waterlogged lands or sandy soils subjected to slight over-irrigation. Blackrot was reduced by adequate N and K fertilization, increased with higher concentrations of Mn in most recently mature leaves (MRM) at headform (also associated with soil acidity) and always occurred with the warm, wet conditions of summer.

Aphids and thrips occurred throughout the year; cutworm, bollworm, greater cabbage moth, leafminer and diamond-back moth, occurred mostly during the warmer season; and webworm over the cooler period in autumn. Aphids, thrips and webworm were the most important cabbage pests, causing serious losses especially during the first six weeks after transplanting. Factors such as amounts of fertilizer applied, soil acidity problems, slope of the land,

infiltration rate, soil nutrient status, water stress, leaf concentrations of each element, weeds and disease were all associated with the incidence of various pests. This study highlighted the importance of good management practices, which affect all these aspects of cabbage production, and therefore pest incidence. An awareness of these factors and recommendations made in this study, could improve cabbage management practices in the Umlaas River Valley and therefore, reduce pest infestation.

The study also evaluated relationships between weather patterns, hormone herbicide-like symptoms which occurred simultaneously on various garden trees and shrubs and vegetable seedlings, and pest and disease outbreaks or hormone herbicide symptoms on field crops of cabbage. Hot days with temperatures > 30°C, high VPD and high solar radiation followed by a rapid drop in temperature, high relative humidity and low solar radiation (stress weather cycles) were characteristic of weather conditions with an approaching frontal low in the Umlaas River Valley. All the dates of hormone herbicide-like symptoms on some garden shrubs and trees and vegetable seedlings in the nursery (indicator plants) were correlated with stress weather cycles, however not all stress weather cycles were correlated to these symptoms on indicator plants. It appeared that an unknown factor (Factor X) occurred with these weather cycles, and together with the stress induced by the harsh weather conditions, caused these symptoms on the indicator plants. A Canary creeper (*Senecio tamoides* DC.), fig tree (*Ficus natalensis* Hochst.) and an indigenous Cape chestnut (*Calodendrum capense* (L.F.) Thunb.) showed symptoms of leaf bubbling, twisting, burning, deformities and leaf drop. Lettuce and cabbage seedlings were twisted, etiolated and suffered from downy mildew outbreaks. All trees, shrubs and nursery crops experienced these symptoms 1 - 4 days after the stress weather cycles and Factor X. It is possible that low levels of hormone herbicide (< 25 ng l^{-1}) deposited during dynamic fumigations (associated with approaching frontal lows), were Factor X. However, when examining the relationship between field cabbages and all related factors, no clear correlation could be established between weather patterns, Factor X, cabbage plant health, and pest and disease incidence.

An overall study examined the effects of a range of factors on cabbage yield including:: soil analysis data; management and crop water stress ratings; total nutrients supplied; weed, pest and disease indices; tillage operations; soil characteristics; plant populations; percentage

marketable yield and headmass. Poor water management, high incidence of weeds, pest and disease, excessive nitrogen and phosphorus applied as fertilizer, and too many tillage operations, were associated with low yields. Conversely, good water management, good liming and soil fertility practices, higher levels of soil potassium and better weed, pest and disease control, resulted in higher yields. A greater percentage of marketable cabbage heads was more important than head mass for higher cabbage yields.

The methodology used in this study provided an efficient, reliable method of identifying factors which limited and maximized vegetable crop production and provided data for the compilation of production guidelines for cabbage. The research and extension aspects of this study also provided an opportunity for the rapid transfer of technology to the farmer and excellent farmer participation.

DECLARATION

I hereby declare that the research work reported in this thesis is the result of my own investigation, except where acknowledged.

Signed____________

Derek Askew

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INTRODUCTION

In the early 1980's, the Umlaas River Valley was known as the vegetable basket of KwaZulu-Natal, regularly producing excellent quality vegetables. Vegetables grown in the valley were:

> cabbage, lettuce, tomatoes, carrots, green mealies, brinjal, squash, butternut, cucumbers, peppers, chillies, green beans, dry beans, lima beans and cauliflower.

The Umlaas River Valley lies 25 km south-east of Pietermaritzburg at an altitude of 530 - 795 m above sea level (Dekker, Jeffrey & Scotney, 1980). Hills surround its western and south-eastern boundaries and vegetable production occurs in the valley bottom and on the hill slopes. Bioclimatic Group 10 (Riverine and Interior Lowland; Webster, 1990) predominates in the area with intermittent patches of Bioclimatic Groups 2 (Coastal Hinterland; Webster, 1990) and 6 (Upland; Webster, 1990)(Dekker *et al.,* 1980).

According to Dekker *et al.* (1980), rainfall varies from 600 - 800 mm $annum^{-1}$ with a mean annual temperature of 18°C. In winter, temperatures can drop below 0°C with occasional frost in the lower areas, while summer temperatures can rise to a maximum of 42°C. The mean evaporative demand (Class A pan) always exceeds the mean annual rainfall. The Umlaas River, which flows through the valley, together with the Baynesfield and Thornlea Dams constructed on the river, are the source of irrigation water for farmers in the Umlaas River Valley.

In 1986, plant deformities, increased disease incidence, deterioration of vegetable quality and decreased yields, were observed. Sometimes, whole vegetable crops were ploughed back into the soil, because they were either deformed, diseased, or not suitable for harvest.

These irregularities in vegetable production in the Umlaas River Valley, heralded the start of the hormone herbicide controversy, which raged in Natal from 1987 to 1991. Some farmers alleged that hormone herbicides sprayed on sugar-cane farms in and around the Umlaas River Valley were responsible for the vegetable damage. It was believed that primary or secondary drift of these hormone herbicides, caused plant deformities and was also directly related to the above-normal disease incidence observed on some crops. There were various opinions in the whole hormone herbicide debate: some maintained that hormone herbicides alone were responsible for the damage; others believed that farming practices were responsible, while a third camp suggested a combination of both factors.

Government officials investigated the damage and imposed a ban on hormone herbicides in the immediate area (Government Notice No. R. 1992 of 30 September 1988). This ban was later extended to other areas of Natal as set out in Government Notices No. R. 1918 of 1 September 1989 and R. 2291 of 28 September 1990.

The Government, through the Dept. of Agriculture and Water Supply, formed the Task Group for Hormone Herbicide Research, funding an extensive research programme (Hormone Herbicide Research Programme, 1989), which ended with a historic meeting at Cedara in June, 1991.

In summarising the research presented, it was postulated that various stress factors caused ethylene release in the plant which resulted in plant deformities. Climatic stress factors such as temperature, radiation and sudden changes in vapour pressure deficits (VPD), all associated with cold fronts, increased the production of ethylene and other substances in lettuce (Smith, 1991; van Rensburg, 1991). Ethylene release caused a change in plant appearance and resulted in deformities (Cresswell, 1991). Management factors such as waterlogging could cause plant stress and produced hormone herbicide-like symptoms (van Rensburg, 1991), while high levels of applied nitrogen and phosphate reduced yields (Holcroft, 1991). Yields in winter were improved by fumigation and in summer, by plastic mulch (Holcroft, 1991). The Task Group felt that management practises in the Umlaas River Valley could be improved. The levels of hormone herbicide measured in rain, dew and air samples were very high in 1987 and 1988. However, after the imposition of the ban and its extension to other areas, the levels of hormone herbicide decreased substantially in 1989. Very low levels of hormone herbicide were detected in 1990 and 1991 (Vogel, 1991). It was implied that the high levels detected in 1987 and 1988 were dangerous. Dafel (1991) showed that the levels found in 1990 and 1991 were insufficient to cause the damage observed on the crops in the Umlaas River Valley over that period.

The general consensus was that damage caused to the crops in the 1990 and 1991 seasons was caused by a combination of all these factors (van Niekerk, 1991). All of them: climatic conditions, management practises and hormone herbicides caused stress to the plant, which released ethylene leading to a change in appearance. Furthermore the components of stress were also cumulative (Cresswell, 1991).

During the course of this research work from 1987 - 1991, the farmers requested a better extension service for their area. This coincided with the Government's desire to monitor and assist in the Umlaas River Valley (See 6 of Dr. van Niekerk's announcement (1991)). The formation of a specialist vegetable research and extension programme for the Umlaas River Valley was proposed. Therefore, in January 1991, the Umlaas River Valley Vegetable Project was initiated, and continued until December 1993.

In accordance with the findings of the Task Group for Hormone Herbicide Research, the Minister of Agriculture and Agricultural Development, Dr. van Niekerk (1991) announced various steps which included:

1. The formation of a task group to recommend rules for safe use of hormone herbicides in South Africa.
2. The current ban on aerial application of all hormone herbicides in Natal was to remain in force (Government Notice No. R. 2370).
3. Contravention of label instructions of hormone herbicides was to be enforced and penalties increased.
4. The 2,4-D iso-octyl ester formulations ban in Natal remained in force (Government Notice No. R. 2370).
5. The statutory ban on the use of specified products in the greater Umlaas River Valley area was to remain in force (Government Notice No. R. 2370).
6. A pro-active extension service was to be developed in the Umlaas River Valley based on the scientific facts which came to light. As part of this, the Umlaas River Valley Vegetable Project would continue until its completion.

7. Rain water analysis for hormone herbicides was to be continued.

Although these announcements concluded the work of the Task Group for Hormone Herbicide Research, the Umlaas River Valley Vegetable Project was only just getting started, having begun work in January 1991. Overall, the goal of this project was:

1. To identify the factors limiting the production of vegetables in the Umlaas River Valley, and
2. to identify practices maximizing yields,

to be used as a basis for the development of production guidelines. This was done by accumulating a substantial data base of information. Basic to this information was:

- the classification of soils and preparation of detailed farm plans, showing soil forms, land capability classes etc.,
- a survey of all farming practices,
- the continuous monitoring of crops, weather conditions, farming practices and rain water (for hormone herbicides) in the valley for three years.

All this information was assimilated and used to identify different factors that limited and maximize yields, so that recommendations could be made for current and future cropping. Reactions to all problems were through Study Groups on selected topics, trials, demonstration plots and co-operation with agri. business. In all, 18 Study Groups were conducted during the course of this project.

All vegetable farmers in the Umlaas River Valley area were canvassed to establish their participation in the project. Of all the growers visited, 18 indicated their willingness to be involved, but only thirteen participated actively in the programme. These thirteen farms represented approximately 1263 ha of intensely cultivated, vegetable lands. Predominant soil forms, according to MacVicar (1993), were Hutton (464 ha), Glenrosa (216 ha), Cartref (84 ha), Westleigh (55 ha) and Clovelly (53 ha). Oaklands, Vilafontes, Mispah and Mayo were found on 40 - 50 ha of land each, while Longlands, Shortlands and Inhoek were identified on 30 - 40 ha of land each. Other soil forms each occupied less than 20 ha of land.

Approximately 46 % of soils used for vegetable production were regarded as well drained soils and suitable for intensive agricultural use (Manson, 1991). The remaining 54 % had hydromorphic subsoil horizons and was regarded as unsuitable for annual cropping (Manson, 1991). Nevertheless, most of these poorly drained soils were used with varying degrees of success, for intensive vegetable production. The Binomial soil classification on each farm are found in Appendix 2.

Climate data from a CR 10 Datalogger, situated in the Umlaas River Valley, from July 1991 to June 1993 (Appendix 1a & b), varied from that of Dekker *et al.* (1980). The mean annual rainfall for the period July 1991 - July 1993 (164 mm annum^{-1}), was far below 600 - 800 mm annum^{-1}, with mean seasonal rainfalls of 58 mm in spring, 75 mm in summer, 29 mm in autumn and 3 mm for winter over the two year study period. The drought experienced during 1992 and 1993 almost emptied both the Baynesfield and Thornlea Dams, resulting in severe water restrictions to all users. Total monthly rainfall and mean monthly temperatures are given in Fig. 1.

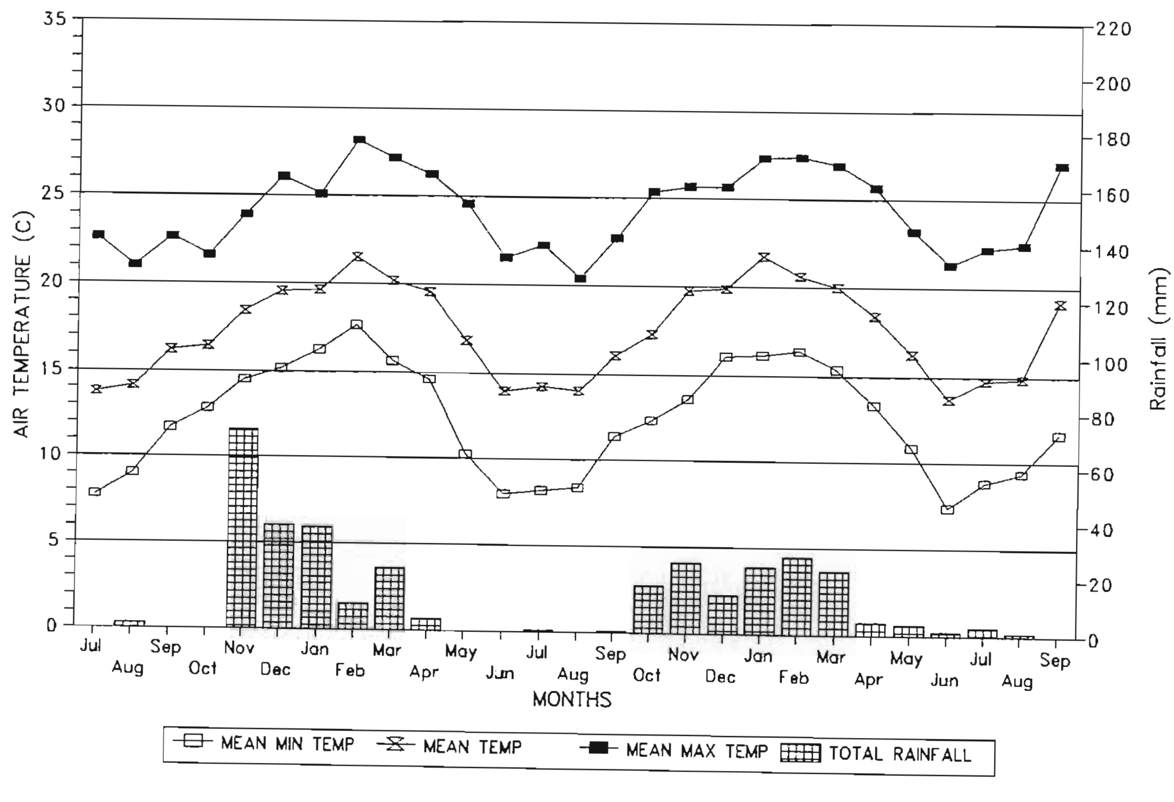

Figure 1 Mean monthly temperatures and total rainfall from July 1991 - September 1993

The mean annual temperature was 17.5°C and monthly maximum and minimum extremes are given in Table 2.

Table 2 Monthly maximum and minimum temperature extremes in the Umlaas River Valley, July 1991 - July 1993

	Monthly maximum extreme (°C)	Monthly minimum extreme (°C)
July	27.34	1.81
August	31.49	1.78
September	34.72	8.63
October	31.79	7.28
November	35.12	7.68
December	33.96	9.83
January	31.64	12.15
February	35.12	13.91
March	36.71	8.23
April	33.57	9.82
May	31.62	4.16
June	26.20	1.41
July	27.53	1.42
August	30.63	0.64
September	36.13	6.99
October	43.91	9.63
November	37.83	8.27
December	31.83	11.57
January	40.00	10.60
February	39.21	9.06
March	33.77	9.84
April	31.60	8.27
May	29.88	7.28
June	27.74	3.77
July	27.72	4.96

The most popular and economically important vegetable crops grown in the Umlaas River Valley were cabbage (490 ha an^{-1}), lettuce (249 ha an^{-1}) and tomato (140 ha an^{-1}). Therefore, although the initial survey and advisory aspects of the project covered all vegetable crops grown, intensive studies dealt only with cabbage, lettuce and tomato crops. Four cabbage cultivar trials (16 cv., 5 reps., 4 x 4 lattice; Appendix 12 b), five lettuce cultivar trials (16 cv., 5 reps., 4 x 4 lattice) and one tomato cultivar trial (18 cv., 3 reps., randomised block design) were conducted in the area. Herbicide trials, under supervision from the project, tested different types of herbicides on cabbage and lettuce. Numerous demonstration plots and other observational trials involving plastic mulch, liming and fertilizer were also conducted on selected farms.

As can be seen, the scope of the project was vast and the volume of data generated, immense. Within the scope of a Ph.D, it was not possible to effectively evaluate all the data generated for all three crops. Therefore, the author chose to write his Ph.D study on cabbage, the most important economic vegetable crop in the Umlaas River Valley.

Only data from cabbage monitor plots and data relating to cabbage monitor plots were used as a basis for this study. All data used in this study and other information w.r.t. cabbage production in the Umlaas River Valley, have been inserted in the appendix, and include reports of cultivar trials, the cabbage farming practices survey, and a draft copy of "Production guidelines for cabbages" etc. (See Appendix).

§ 1, 2, 3, 4, 5, 7 & 8 in this study have been presented in a format ready for submission to various journals. Because of its complicated nature, only § 6 includes tables in the written text. Papers analysing lettuce and tomato studies will be dealt with in the same manner as cabbage, and presented with cabbage results, at a KwaZulu-Natal Farmers Day at Cedara in August, 1995.

This study and the findings presented, cover most quantifiable aspects of cabbage production and include soil characteristics, crop water stress, management ability of each farmer, soil fertility, plant populations, weeds, pests, diseases, mean daily temperatures, hormone herbicides, fertilization practices, soil acidity, stress weather cycles, leaf nutrient concentrations and number of tillage operations. The recommendations from this work are especially applicable in the Umlaas River Valley, but could also be extrapolated to other vegetable producing areas in South Africa.

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GENERAL PROCEDURES

Survey of farming practices

A survey of farming practices of all participating growers accomplished three objectives:

- It familiarised the author with the management practices in the Umlaas River Valley,
- formed the beginning of a data base to accumulate information regarding all aspects of cabbage production, and
- enabled comparisons of farming practices.

The survey covered aspects of cabbage production (Appendix 3 a & b). Information concerning all the following aspects was accumulated :

Planting date	-	time of planting, variety, area planted and source of seedlings.
Land preparation	-	operations, sequence and depth.
Planting methods	-	methods, spacing and depth of planting.
Fertilisation	-	amount, type, when and how applied.
Spray programme	-	amount, type, when and how applied.
Irrigation	-	type (e.g., sprinkler or drip) and amount of water per week.
Labour units	-	planting, weeding, stacking, harvesting and wiring.
Weed control	-	type, amount, when and how applied.
Yield/ha	-	average prices and to whom sold.

Binomial Soil Classification

A binomial soil classification was carried out on each farm that participated in the study. The Soil Survey of the Tala Valley Area (Dekker, Jeffrey & Scotney (1980), aerial photographs, farmer knowledge and field reconnaissance were used to demarcate tentative soil forms (MacVicar, 1993) on each farm. Profile pits of 1.5 m deep and 1.0 m meter wide were sited in the centre of each homogenous soil area. Soil form boundaries were established using an auger. The following parameters were measured in each pit: estimated clay percentage, soil texture, colour, compaction, infiltration, wetness class, available moisture content, restrictions and potential rooting depth. A soil sample was taken from the A horizon of each pit and analyzed by the Soil Physics Laboratory, Agricultural Development Institute, Cedara. Slope percentage, terrain unit and land capability classification were also determined for each soil form.

The following methods were used to measure parameters for the binomial soil classification:

1. Soil texture - as per key overleaf (Manson, 1991).
2. Colour - as seen to correspond with the Munsell Soil Colour Chart, compiled by the Soil and Irrigation Research Institute, Pretoria (1985).
3. Estimated clay percentage - calculated from the sample density of each soil sample, taken in the A horizon of each pit (Manson, Milborrow, Miles, Farina and Johnston, 1993).
4. Compaction - a geological hammer was used to probe each horizon. "Severe" - when much force was required in driving the hammer into the horizon with little or no penetration of the point. "Slight" - when hardly any force was required to scoop away or dig into the soil face. "Moderate" - was an estimate between severe or slight (Spencer, J., pers. com., 6 Saunders Rd., Scottsville, Pietermaritzburg, 3201, South Africa).
5. Infiltration - a clod of soil was chipped out of each horizon and moistened to just below field capacity. Five drops of water from an eye-dropper, were dropped onto the surface and the time determined from when the last drop touched the clod, to when it was absorbed. The permeability was then determined using the key overleaf (Schroeder, 1990).
6. Wetness class - explained from the key, and also includes signs imparted from each horizon, e.g., the presence of well drained horizons as opposed to gleying and E horizons (Smith, 1990).
7. Available Moisture content - calculated from estimated clay % and the potential rooting depth (Manson, 1990).
8. Restrictions - restrictions to cropping, ploughing etc., were determined from observations in each horizon.

9. Potential rooting depth - the depth of the soil that could provide a medium for root development, retain available water, and supply nutrients was determined visually (Schroeder, 1990).
10. Slope % - calculated using an Abney level.
11. Terrain Unit - as per key (Manson, 1991).
12. Land capability classification - determined using all the above according to Smith (1990).

A summary of soil characteristics on each farm can be seen in Appendix 2.

Weather data

A Campbell Scientific CR10 Data Logger was set up by the Agrometeriology Section of the Department of Agriculture, Cedara. The station was placed on the crest of a hill in the centre of the study area. The following parameters were measured every 10 s and averaged over a one hr period.

air temperature (°C)
soil temperature (°C)
saturated vapour pressure (kPa)
vapour pressure (kPa)
solar radiation (Wm^{-2})
mean wind speed (ms^{-1})
mean wind vector magnitude (ms^{-1})
mean wind vector direction (0° - 360°)
rainfall (mm)
battery voltage (V)

Due to mechanical breakdown, some parameters were not measured for a short period during the study, but this did not affect overall accuracy of the data. A summary of all weather data can be found in Appendices 1a and 1b.

BINOMIAL SOIL CLASSIFICATION KEY

1. MASTER HORIZONS

1.1 WELL DRAINED SOILS

The soil forming processes tend to differentiate materials on which they act into layers or horizons. The master horizons generally follow a certain sequence and usually are easy to recognise when looking at a soil profile.

In well-drained soils, the horizon sequence shown in Fig. 1.1 is common.

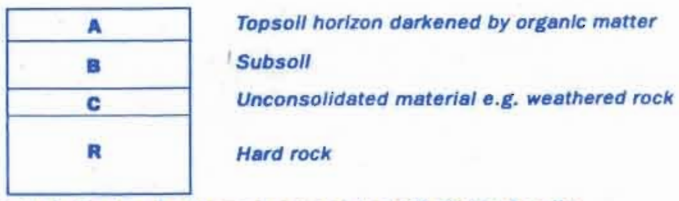

Fig. 1.1 Master horizons common in well-drained soils.

1.2 SHALLOW SOILS

One or more of the horizons in Fig. 1.1 may be absent in a soil profile, for example, the underlying rock may not have weathered deeply enough for a B horizon to form (Fig. 1.2).

Fig. 1.2 Master horizon sequences common in shallow soils.

1.3 POORLY DRAINED SOILS

In soils with restricted drainage two other master horizons occur - the G & E horizons (Fig. 1.3).

The E horizon is a bleached horizon from which iron oxides, organic matter and clays have been removed.

The G horizon, a mineral horizon under an A or E horizon, has grey matrix colours and red, yellow or black mottles, and it is saturated with water for most of the year.

Fig. 1.3 Master horizon sequences common in poorly drained soils.

2. SOIL DEPTH AND EFFECTIVE ROOTING DEPTH

Soil depth may be considered to be the depth to a C or R horizon, which shows little evidence of soil-forming processes. Effective rooting depth, however, is often more limited, as many soil materials can limit penetration by plant roots.

Layers that restrict effective root growth are of 3 main types:

a) Layers presenting a physical restriction to root penetration
b) Layers that become waterlogged in the wet season
c) Layers with chemical restrictions e.g., sub-soil acidity.

3. SOIL TEXTURE

Texture refers to the size of the soil particles that make up the soil matrix. For purposes of soil classification, texture is expressed in terms of the proportions of sand, silt and clay in the soil.

Clay %	Texture
0-6	Sand
7-15	Loamy sand
16-35	Loam
36-55	Clay loam
>55	Clay

4. COLOUR

The colour of the soil is a very important indicator of the nature of the soil.

Red: Uniform red colours indicate a well-aerated soil with good internal drainage.

Yellow: Uniform yellow colours indicate moderate to good drainage.

Grey: Grey colours occur where periodic or permanent water-logging has removed the red & yellow oxides indicating poor internal drainage.

Black: Very dark colours indicate either a high organic matter content or a high proportion of swelling clays.

5. INFILTRATION RATE

Class	Rate (secs.)	Permeability
7	<1	Extremely rapid
6	1-3	Rapid
5	4-8	Good
4	9-20	Slightly restricted
3	21-40	Restricted
2	41-60	Severely restricted
1	>60	Impermeable

6. WETNESS CLASSES

0 = No wetness problem.

1 = Wet for short infrequent periods below 50cm.

2 = Frequent waterlogging above 60cm.

3 = Very wet for most of the season.

7. TERRAIN UNIT

The position of a soil in the landscape affects the way in which water influences its formation. Soil scientists generally refer to a terrain unit (Fig. 7.1) when describing the position of a soil.

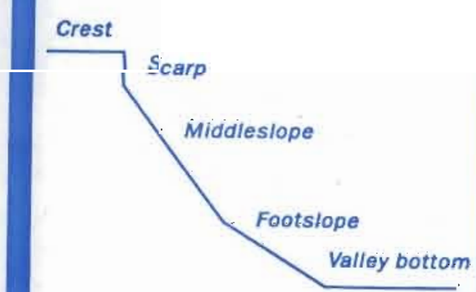

Fig. 7.1 Terrain units used to describe the position of a soil.

LAND CAPABILITY CLASSIFICATION

CLASS I

- Land with few or no limitations or hazards.
- With good management this class is suitable for long, continued cropping.
- None or minimal, conservation practices are necessary.
- Soils are deep or moderately deep and naturally well-drained, with a stable structure and good working properties.
- Slopes are slight and the only limitations are those of maintenance of soil structure and fertility.

CLASS II

- Land subject to moderate limitations or hazards.
- It is suitable for cropping with adequate protection measures, which may sometimes include special management practices.
- Such land needs moderate conservation practices.

CLASS III

- Land subject to severe limitations or risk of damage.
- It is suitable for cropping only with the application of intensive protection measures and special practices which may include long ley rotations with short cropping periods.

Limitations may include:
moderately steep slopes,
high susceptibility to erosion,
soils of low moisture-retaining capacity,
moderately shallow soils,
intractable texture,
inadequate permeability in the lower root zone,
unfavourable physical characteristics in the surface soil,
or moderate wetness.

- Combinations of intensive measures are required to use the land permanently.

CLASS IV

- Land subject to very severe permanent limitations or hazards.
- Suitable for occasional row-cropping in long ley rotations, or for use under perennial vegetation.

Limitations may include:
steep slopes,
shallow soils or soils of very low water-retaining capacity,
high erodability,
unfavourable characteristics in the surface soil,
and severe, but correctable wetness.

- Complex and intensive protection measures and practices would be required during the time under cultivation.

Monitor plots

Monitoring of 59 cabbage crops on 13 farms in the Umlaas River Valley was carried out from June 1991 to July 1993. Monitor plots ($\pm$ 25 m^2) containing newly transplanted cabbage seedlings were selected at random on each farm. A monitor plot was placed at least 20 m from any edge of the planting and included 100 plants (normally 10 rows of 10 plants). Each plot was demarcated with plastic red and white danger tape.

Management practices for each field monitored were standard, with no extra or preferential treatment by the farmer. Plots were placed on fields regardless of soil types. However, we endeavoured to include a wide spectrum of soil types so that comparisons could be made at the end of the monitoring. Records were also kept by the farmer as to what herbicides, pesticides, fungicides and fertiliser were applied, how much and when. When laying out a new monitor plot the following details and measurements were recorded:

farmer's name,
field number,
variety,
transplant date,
row
and plant spacing (Appendix 15).

Weekly visits were made from transplanting through to harvesting. Forms were drawn up to record detailed observations during each visit, namely: weed and pest infestation, disease infection and deviations in plant growth patterns (Appendix 15). With each crop the following factors were rated:

Weeds - estimated percentage of leaf cover and weed type.

Insects - insect type, number of infested plants expressed as a percentage and whether infestation was slight, moderate or severe.

Diseases - type, disease incidence expressed as a percentage of infected plants and whether infection was slight, moderate or severe.

Root development - good, average or poor roots and the presence/absence of nematodes was noted.

Comments were also made regarding general plant health, deformities, deficiencies, available soil moisture and plant stress (Appendix 15).

A soil sample (depth 15 cm)(Manson *et al.*, 1993) and leaf (most recently mature leaf; Hochmuth, Maynard, Vavrina & Hanlon, 1991) samples were taken within the plot at headform. The leaf samples at headform were taken from the most recently matured leaf on the plant and were taken from 10 - 12 cabbages within the plot. Three soil samples were taken from within the plot (depth = 15 cm), mixed and made into one soil sample. The percentage of marketable heads was counted and 10 heads cut and weighed (an X sampling technique across each plot was used) at maturity. From this, estimated yields per hectare could be determined. A ⅛ pie-slice head sample, including core and internal head leaves, was also taken from each of the 10 heads for nutrient analysis (Geraldson, Klacan & Lorenz, 1973). A ⅛ head slice was used for expediency as any larger slice (e.g., a ¼ slice) would have constituted too bulky a sample. Nutrient analysis of headslice samples was also used to estimate crop removals (§ 3). All soil, leaf and headslice samples were analyzed by the Soil Physics Laboratory at Cedara.

Soil analysis

All soil samples were analyzed according to the Analytical Methods Used in the Soil Science Laboratories at Cedara (1986). KCl extraction determined Ca, Mg and exchangeable acidity; NH_4HCO_3 extraction was used for P, K and Zn and KCl suspension determined pH. Total cations and acid saturation were calculated according to Manson *et al.* (1993). Results of soil analysis for each monitor plot can be found in Appendix 4.

Leaf analysis

Samples of the most recently mature (MRM) leaf were taken at headform (Hochmuth *et al.*, 1991) and ⅛ headslice at maturity (Geraldson *et al.*, 1973) from monitor plots of each cabbage crop. These samples were sent to the Soil Physics Laboratory at Cedara for analysis. Samples were analyzed according to the Analytical Methods used in the Soil Science Laboratories at Cedara (1986). Samples were weighed, airdried at 75°C for 24 hr and weighed again to determine percentage dry matter. Thereafter the sample was rotary milled to pass through a 40-mesh screen. The dry ash method with HCl was performed on Hunters apparatus to determine leaf K, P, Ca, Mg, Cu, Zn and Mn. Wet-ashing with a block digester determined leaf N (Analytical Methods Used in the Soil Science Laboratories at Cedara, 1986). Results of all leaf and headslice analysis can be found in Appendices 9 & 10 respectively.

Pests

A pest severity index (PI) was developed to account for the effects of each pest on yield (Table 1). The incidence (% plants infected) of pests within each category (slight, moderate or severe) over the whole cropping period was totalled. Each total was multiplied by its relevant multiplication factor (Table 2) and the products then added together for a final total, to show the severity index for a specific pest. Each severity index was then added together to give an overall PI for that crop.

The multiplication factors (Table 2) and parameters for severity assessments (Table 1) were developed from field observations so that yield effects of each pest were comparable. Field observations found that, e.g., a severe infestation of diamond-back moth (*Plutella xylostella* L.) affected marketable yield the same as a moderate infestation of bollworm (*Heliothis armigera*, Hubner), but not as much as a severe infestation of webworm (*Hellula undalis* F.)(Table 1 and 2). Damage varied according to pest, pest population per plant and the age of the plant. This was considered in the determination of pest severity indices. Pest indices for each monitor plot can be found in Appendix 7.

Table 1 Parameters for severity assessments of cabbage pests in the Umlaas River Valley

Pest	Assessments		
	Slight	Moderate	Severe
Aphids	1-5 $plant^{-1}$	6-20 $plant^{-1}$	> 20 $plant^{-1}$
Cutworm	small bite out of stem (< ¼ of stem)	medium bite of stem (¼-½ of stem)	large bite out of stem (>½ of stem)
Diamond-back-moth	1 windowpane/eaten hole $plant^{-1}$	1-5 windowpane/ eaten holes $plant^{-1}$	> 5 windowpanes/ eaten holes $plant^{-1}$
Greater cabbage moth	1 eaten hole $plant^{-1}$	1-5 eaten holes $plant^{-1}$	> 5 eaten holes $plant^{-1}$
Bollworm	1 hole $plant^{-1}$	1-3 holes or 1 worm $plant^{-1}$	> 3 holes or > 2 worms $plant^{-1}$
Thrips	< 5 $plant^{-1}$	5-20 $plant^{-1}$	> 20 $plant^{-1}$
Leafminer	≥ 1 tunnel $plant^{-1}$		
Cabbage webworm	1 worm outside the growing point (GP)	1 worm inside GP but GP not yet eaten	GP eaten

Table 2 Multiplication factors used for pest severity indices of cabbages in the Umlaas River Valley

Pest	Severity of pests		
	Slight	Moderate	Severe
Aphids	0.1	0.4	0.8
Cutworm	0.1	0.5	1
Diamond-back-moth	0.1	0.4	0.6
Greater cabbage moth	0.1	0.6	0.8
Bollworm	0.1	0.6	0.8
Thrips	0.01	0.05	0.1
Leafminer	0.01		
Cabbage webworm	0.1	0.7	1

Disease

Literature regarding measurement of disease was inappropriate given the extensive nature of our study. Some diseases, e.g., damping-off (*Pythium* spp. or *Rhizoctonia solani* Kuhn.) or sclerotinia rot (*Sclerotinia sclerotiorum* (Lib.) de Barry), resulted in plant deaths or a non-marketable product whenever prevalent (Flint, 1987). Other diseases e.g., ringspot (*Mycosporela brassiciola* (Duby) Oud.) and downy mildew (*Peronospera parasitica* (Pers. ex Fr.) Fr.) reduced yields with increasing leaf area affected (Agrios, 1988). Therefore for most accurate results, both incidence and severity of diseases (slight, moderate and severe) of each crop was recorded on a weekly basis.

As with pests, a disease severity index was developed to account for the effects of each disease on yield. The incidence (% plant infected) of disease within each category (slight, moderate or severe) over the whole cropping period was totalled. Each total was multiplied by its relevant factor (Table 4) and the products then added together for a final total, giving the severity index for a specific disease. Each severity index was then added together to give an overall disease index for that crop. Both Table 3 and 4 were developed from literature and observations in the field. Disease indices for each monitor plot can be found in Appendix 8.

Table 3 Parameters for severity assessments of various diseases of cabbage in the Umlaas River Valley

Disease	Assessments: Slight	Moderate	Severe
Ringspot	< 2 lesions plant^{-1}	2-5 lesions plant^{-1}	> 5 lesions plant^{-1}
Downy mildew	5% leaf area	25% leaf area	50% leaf area
Alternaria leaf spot	< 2 lesions plant^{-1}	2-5 lesions plant^{-1}	> 5 lesions plant^{-1}
Black rot	small tip lesion of leaf	lesion extends to ⅓ down of main leaf vein	lesion extends ⅔ main leaf vein
Clubroot	≤ 3 galls on roots	most roots have galls	no roots - solid mass of galls
Damping-off			stem girdled
Sclerotinia			white mycelia and/or sclerotia
Bacterial soft rot			any bacterial slime

Table 4 Multiplication factors used for disease severity indices of cabbages in the Umlaas River Valley

Disease	Severity of disease: Slight	Moderate	Severe
Ringspot	0.01	0.05	0.2
Downy mildew	0.01	0.05	0.2
Alternaria leaf spot	0.1	0.3	0.7
Black rot	0.1	0.6	0.8
Clubroot	0.1	0.8	1
Damping-off	1	1	1
Sclerotinia	1	1	1
Bacterial soft rot	1	1	1

Assessment of plant water stress for each crop monitored

Monitor plots were subjected to all normal farming practices, e.g., weeding, spreading of fertiliser, chemical spraying, moving of irrigation pipes, etc.. Placement of tensiometers in monitor plots would have been too costly in terms of numbers required and damages incurred. Therefore, a "feel and appearance" technique (Mottram, 1982) and visual observations (wilted plants, soil around roots of weeds, etc.) were used during the weekly visits to ascertain available soil moisture. An assessment of crop water stress based on weekly observations, knowledge of farm irrigation practices and prevailing water restrictions was developed using a rating of 0 - 10 (Appendix 11). Estimated crop yield ha^{-1} was not considered in the determination of each crop water stress rating. The parameters for the different ratings were as follows:

0 - soil maintained at or near field capacity from transplant to maturity, consistent and adequate irrigation supplied to supplement rainfall.

2 - adequate available soil moisture throughout most of the crop, slight over-irrigation, inconsistency or insufficient water supplied to supplement rainfall.

4 - little available soil moisture, irrigation inconsistent and insufficient to supplement rainfall, dry soil observed ± three times, crops wilted once or twice.

6 - little available soil moisture, irrigation was often inconsistent and insufficient to supplement rainfall, dry soil observed ± five times, crops wilted ≥ three times and plants stunted.

8 - very poor soil moisture, irrigation ± three times, soil mostly dry and plants often wilted, little or no rain.

10 - irrigated once only after transplanting with no rain.

Management aptitude

The management scale of Burger (1971) was used to determine management aptitude of all participating farmers. This scale was well correlated to actual management observed on each farm and therefore a good indicator of the level of management exercised on each monitor plot (Appendix 11).

Hormone herbicide indicator plants

Unusual incidents occurred on a Canary creeper, a wild fig tree and an indigenous Cape chestnut, simultaneously with field or nursery crops on the farm of Mr M Wild. It was noticed that visible symptoms (bubbling, twisting, leaf drop, deformities, burning etc.) on the creeper, fig and chestnut, were often correlated to similar symptoms in the nursery and the lands and/or disease or pest outbreaks. Adverse weather conditions seemed to be associated with these symptoms and correlated outbreaks. There were no dangerous excesses of fertiliser applied and soil nutrient status was acceptable, although soil P and K levels were high. The status of soil-borne pathogens was not known and no analysis of plant material for hormone herbicide was done. The correlation of deformities on the indicator plants and disease outbreaks in crops was very interesting. It was thought possible, that very low or sub-lethal doses of hormone herbicides present in the rain or atmosphere could lower plant resistance to pests and diseases (various reports and papers have been published internationally). This hypothesis was substantiated by preliminary on-site trials with low levels of hormone herbicides in 1992. The severity of downy mildew infection was worse on seedlings sprayed with hormone herbicides and indicator plants showed the bubbling, twisting, symptoms etc.. Replication of the same trial in 1993 failed to produce similar results.

To determine the causes of these incidents, the canary creeper, indigenous Cape Chestnut and the Fig tree were designated as indicator plants and the farmer reported any hormone herbicide-like symptoms and related problems in nursery and field crops, to the author. These dates were later correlated to weather patterns and any problems on field cabbages (§ 7). The report of all incident dates and associated symptoms can be found in Appendix 14.

Rain samples for hormone herbicide analysis

Concurrently to this study, all rain samples were collected by officials of the Department of Agriculture and tested at Umgeni Water for numerous hormone herbicides. Analysis could detect levels above 25 ng l^{-1} H_2O of the following active ingredients:

dicamba, MCPA, MCPB, 2,4,5-T, 2,4-D, 2,4-DB, trichlopyr and picloram.

Statistical analysis

Multiple stepwise regression, correlation analysis, summary statistics, frequency histograms, and box-and-whisker plotting, were all determined using Statgraphics Version 5 (Statgraphics, 1991).

Technical assistance

With assistance from John Spencer in the initial stages, Richard Daniels, the field officer of the Umlaas River Valley Vegetable Project, conducted the soil surveys and drew all farm plans. With supervision and assistance from the author, Richard Daniels also monitored all crops. He had temporary assistance from Gerald Lamusse, Warwick Bullock and Rob Osborne. The automatic weather station was set up by Karl Monnik of Cedara, who also collected and processed all the weather data. All the data generated in this study were placed on the computer by Moira Millard and Richard Daniels, under the supervision of the author.

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1. CRITICAL SOIL VALUES AND OTHER SOIL NUTRIENT FACTORS AFFECTING CABBAGE CROPS IN THE UMLAAS RIVER VALLEY, KWAZULU-NATAL

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Abstract

Wide variation and excesses of soil nutrient levels and other soil parameters were seen from soil analysis of 59 cabbage crops in the Umlaas River Valley. Soil P > 155, K > 486 and Mg > 568 mg l^{-1}, exchangeable acidity > 0.11 $cmol_c$ l^{-1}, acid saturation > 2 % and pH < 4.51 resulted in lower yields. Top yields were found between a certain range of each soil nutrient level and critical values for each element lay within this range. Observations of optimal yields with an ideal ratio of Ca, Mg and K in the soil, were noted and verified with the critical values.

Keywords Cabbage, P, K, Ca, Mg, acid saturation, pH, critical values, cation saturation ratio.

Introduction

The Umlaas River Valley, otherwise known as Tala Valley, was the seat of the hormone herbicide controversy which raged in KwaZulu-Natal from 1986 to 1991. The controversy concerned the use of hormone herbicides in the area and involved farmers, chemical companies and the Government (Preston-Whyte, 1994). The Government set up and funded a Task Group to identify the causes of vegetable crop failures. The Task Group for Hormone Herbicide Research conducted extensive hormone herbicide research as well as trials to test different growing techniques. The findings of this work were presented in June, 1991, at Cedara (Working Group for Herbicide Damage, 1991). They concluded that a combination of climatic, management and hormone herbicide from spray drift, caused damage to vegetable crops and poor returns to growers. Hormone herbicides alone could not be blamed. Complementary to this research, the Umlaas River Valley Vegetable Project, a Government funded research and extension project, was initiated to determine factors limiting vegetable production in the valley. The project was based in the Department of Horticultural Science, University of Natal. Extensive soil and farming practice surveys were conducted; crops, weather conditions and presence of hormone herbicides in rain samples, were monitored from June 1991 to July 1993. All data relating to fertilisation and spraying practices on 59 monitor cabbage (*Brassica oleracea* L. var. *capitata* Alef.) crops were gathered. From these data it was possible to identify the factors limiting the production of vegetables and to establish optimum production practices in the Umlaas River Valley. These results are recorded in a series of papers, each examining a factor or combination of factors which affect the yield of that crop, for submission to various journals.

Holcroft, Smith & Dicks (1991) noted wide variation in Tala Valley soil phosphorus (P) levels (20 - 800 mg l^{-1}). Askew (unpublished data) found large ranges in soil nutrient levels from soil samples taken during a binomial soil classification in Umlaas River Valley (e.g., P = 1 - 760 mg l^{-1} and potassium (K) = 22 - 957 mg l^{-1}). It was suspected that improper fertilisation practices with resultant extremes and imbalances (Sumner & Farina, 1986) of soil nutrients could be a possible limiting factor in cabbage production. Therefore, the goal of this paper was:

- to determine whether extremes or imbalances of soil nutrient levels adversely affected yield,
- to identify optimum ranges of soil P, K, calcium (Ca), magnesium (Mg), zinc (Zn), exchangeable, acid saturation, pH and total cations,
- and to identify critical values for producing cabbage crops in the Umlaas River Valley.

Procedures

Monitoring of 59 cabbage crops on 13 farms in the Umlaas River Valley was carried out from June 1991 to July 1993. Monitor plots (± 25 m^2) containing newly transplanted cabbage seedlings were selected at random on each farm. A monitor plot was placed at least

20 m from any edge of the planting and included 100 plants (normally 10 rows of 10 plants). Each plot was demarcated with plastic red and white danger tape. Weekly visits were made from transplanting through to harvesting. Forms were developed to record detailed observations during each visit. On these forms, weed and pest infestation, disease infection (§ 4 & 5) as well as deviations in plant growth patterns, were recorded. A soil sample (depth 15 cm)(Manson, Milborrow, Miles, Farina and Johnston, 1993) and leaf (most recently mature leaf, Hochmuth, Maynard, Vavrina & Hanlon, 1991) samples were taken within the plot at headform. The percentage of marketable heads was counted and 10 heads cut and weighed (using an X sampling technique across each plot) at maturity. From this, estimated yields per hectare could be determined.

The soil samples were analyzed by the Soil Physics Laboratory, Cedara Agricultural Development Institute. KCl extraction determined Ca, Mg and exchangeable acidity; NH_4HCO_3 extraction was used for P, K and Zn, and KCl suspension determined pH (Analytical Methods Used in the Soil Science Laboratories at Cedara, 1986). Total cations and acid saturation were calculated according to Manson *et al.* (1993).

Disease, pest and water stress problems were identified in 18 crops grown over the two-year period. Analysis excluded these plots in order that cabbage yields would reflect soil fertility and acidity problems only.

Soil calibration studies are the most accepted method to determine the point at which a crop response to fertilizer is no longer expected (critical values; Kidder, 1993). However, it was impossible to implement classical soil calibration studies as in factorial field experiments, in our extension programme. Another accepted type of soil calibration study was adopted using single plot studies, of one replication, on many different sites (Evans, 1987; Sumner, 1987). Single plot studies preferred similar management, fertilisation practices, time of soil sampling and similar soils in the same geographical area (Evans, 1987: Sumner, 1987). The nature of this study involved data accumulation, analysis, identification of problems and reactive extension work; in the project it was necessary to monitor and collect data for cabbages grown on many different soil types on 13 farms in the same geographical area, so that agronomic practices, soil factors and the crops themselves, could be compared. Therefore, the study could not satisfy all the criteria for single plot calibration studies; the same geographical area was used which limited soil variation, and the soil sampling method was consistent; however different management practices and fertilisation could not be avoided. Given the variation in these different "plot" sites and the need to determine soil nutrient optima, both the DRIS "mean of a high yielding population" (Sumner, 1986) and the boundary line method (Webb, 1972) were considered appropriate analysis methods. The DRIS "mean of a high yielding population" was not considered significantly different from soil optima developed with the boundary lines method (Walworth, Letzsch & Sumner, 1986). Given this plus distribution of each parameter versus yield and only 59 data points, the DRIS "mean of a high yielding population" (Sumner, 1986) was deemed the more reliable analysis method. The high yielding population chosen for this study represented all crops with yields $\geq$ 70 t ha^{-1}. Using this method the normal research approach of examining crop response to one or two nutrients at a time (Sumner & Farina, 1986) was also avoided. Instead, the interplay between nutrients was examined, as well as the individual effect of each nutrient to improve yields. Each parameter was plotted against yield to determine critical values for sample density, P, K, Ca, Mg, Zn, exchangeable acidity, total cations, acid saturation and pH.

A yield response model showing maximum yields at various soil parameter ranges was also developed for the Umlaas River Valley. Maximum and minimum values (ranges) of each parameter with corresponding yields greater than 40 t ha^{-1} were identified. This was repeated at 50, 60, 70, 80, 90 and 100 t ha^{-1} to identify achievable yields for given parameter ranges and to illustrate reduced yields with lower and higher extremes of each parameter. Multiple stepwise regression determined those factors which exercised most influence over cabbage yields.

Results

The number of crops monitored per soil form (MacVicar, 1993) were as follows: Hutton - 17, Mayo - 4, Vilafontes - 3, Inhoek - 3, Longlands - 3, Clovelley - 2, Cartref - 2, Glenrosa - 2, Shortlands - 1, Griffin - 1, Westleigh - 1, Mispah - 1 and Wasbank - 1.

A wide variation of soil nutrient levels and soil acidity parameters was evident from the soil analysis results of 41 cabbage crops (Table 1). Soil clay percentage showed a unimodal and symmetrical distribution with values ranging from 10 - 60 % clay. Soil P had a left skewed distribution with a range of 0 - 285 mg l^{-1} and a high coefficient of variation (CV = 75 %)(Table 1). Soil K had a slightly left skewed distribution and a maximum point range of 639 mg l^{-1}. Soil Ca and Mg were unimodal and symmetrical, with ranges of 1883 and 519 mg l^{-1} respectively. CV's of Ca and Mg were low compared to other parameters in Table 1. Soil Zn, exchangeable acidity and acid saturation showed strongly left skewed distributions on a frequency polygon with ranges of 70.1 mg l^{-1}, 1.19 $cmol_c$ l^{-1} and 21 % respectively. Total cations and pH showed a more symmetrical distribution and ranges of 12.99 $cmol_c$ l^{-1} and 2.68 respectively. Variation was high within soil Zn (CV = 106 %), exchangeable acidity (CV = 132 %) and acid saturation (CV = 152 %) and was lowest with sample density (CV = 7 %) and pH (CV = 12 %)(Table 1).

The variations seen were large, but expected for this type of study on differing soils and variable fertilisation practices. Of greater concern were some of the high levels of P (285 mg l^{-1}), K (714 mg l^{-1}), Mg (568 mg l^{-1}), Zn (71.6 mg l^{-1}), and exchangeable acidity (1.12 $cmol_c$ l^{-1}) and low pH (3.84 - KCl) in Table 1 as compared with the Fertrec norms shown in Table 3. These soil parameter extremes could indicate a waste of fertiliser or possible yield reductions due to nutrient imbalances or toxicities.

All soil nutrient levels and soil acidity parameters, showed a normal distribution when plotted against yield. This normal distribution was adapted in a linear plateau type model showing possible yields within maximum and minimum values of each soil parameter (Fig. 1). An optimum value for each parameter was identified between points A and B (Table 3) but generally, yields $\geq$ 100 t ha^{-1} occurred anywhere between points A and B (Fig. 1). Yields of at least 100 t ha^{-1} were recorded when the minimum and maximum values of each parameter in Table 2 corresponded with A and B in Fig. 1 respectively. Similarly, yields $\geq$ 60 but < 70 t ha^{-1} were possible at points E and F and $\geq$ 50 but > 60 t ha^{-1} at point C and D. An examination of Table 2 shows the A and B points for each parameter at $\geq$ 100 t ha^{-1} e.g., between 47 and 155 mg l^{-1} of P, yields $\geq$ 100 t ha^{-1} were achieved and at 10 and 285 mg l^{-1} of P, yields of $\geq$ 50 and < 60 t ha^{-1} was achieved (Points C and D). Therefore

Fig. 1 also showed yield reductions when soil nutrient levels and soil acidity parameters were above or below a given range.

Highest yields resulted with high levels of soil P (range = 47 - 155 mg l^{-1}), K (range = 248 - 486 mg l^{-1}) and Mg (range = 220 - 568 mg l^{-1}) and a low acid saturation ($\leq$ 2 %). Soil parameter levels above or below the maxima or minima shown in Table 2 resulted in lower yields e.g., soil with K value < 75 and > 714 mg l^{-1} had yields below 50 t ha^{-1}. The same applied to all soil nutrient levels and soil acidity parameters in Table 2.

Fig. 2 shows the correlation (R^2 = 0.82, t-value = 34.04, $P < 0.001$) between acid saturation and yield after the rejection of outliers. The dotted line A, clearly illustrates the reduction in yield with acid saturation above 2 % (Fig. 2). Soil exchangeable acidity (R^2 = 0.80, t-value = 33.97, $P < 0.001$) and pH (R^2 = 0.33, t-value = -1.03, $P < 0.001$) showed a similar correlation with yield.

Regression analysis revealed that acid saturation, exchangeable acidity, pH, Ca and total cations individually had highly significant effects ($P \leq 0.01$) and Mg a significant effect ($P \leq 0.05$) on yield, with R^2 values of 0.32, 0.30, 0.23, 0.17, 0.16 and 0.14 respectively. Soil P, K and Zn individually, had no significant effects on yield with low R^2 values (R^2 = 0.7, 0.3 & 0.0 respectively). Soil P (P = 0.02) and K (P = 0.05) together had significant effects on cabbage yields (R^2 = 0.15, F-ratio = 3.46, P = 0.04 for the model). A multiple regression of all cation elements versus yield could account for 33 % of yield variation (R^2 = 0.33, F-ratio = 4.43, P = 0.005 for the model). Multiple regression gave the following model for yield:

$$\text{yield} = 5.37 - [-0.15]\,P + [0.04]\,K + [-1.44]\,\text{acid saturation} + [14.78]\,pH$$

This model also showed that P (t-value = -2.62, P = 0.01), K (t-value = 1.62, P = 0.11), acid saturation (t-value = -1.57, P = 0.12) and pH (t-value = 1.88, P = 0.07) could account for 45 % (R^2 = 0.45, F-ratio = 7.31, $P < 0.001$ for the model) of the variation in yield.

Yields $\geq$ 100 t ha^{-1} had high P levels with corresponding high K, Ca, Mg and pH and lower exchangeable acidity and acid saturation (Table 2). Conversely, high yielding soils with lower P values had correspondingly lower values of K, Ca and Mg. This indicates the presence of a nutrient balance or basic cation saturation ratio affecting yields. In the determination of a general relationship between Ca, Mg, K and Na, Bornman, Ranwell, Venter & Vosloo (1989) used the formula:

$$\frac{100\,Ca}{S} : \frac{100\,Mg}{S} : \frac{100\,K}{S} : \frac{100\,Na}{S}$$

where Ca, Mg, K and Na are converted to equivalent cmol(+) kg^{-1} values and S = Ca + Mg + K + Na. Fertrec soil analysis does not supply soil Na results and soil Na is characteristically low in KwaZulu-Natal soils (De Villiers, J.M., pers. com., Department of Agronomy, University of Natal, P. Bag X01, Scottsville, 3209). Therefore, the exclusion of Na from the formula would not affect the resultant ratios very much. The ratio of Ca, Mg and K in this study was 64:26:9. This was almost identical to the norms of Bornman *et al.* (1989) (65:25:10).

The means of all soil nutrient levels and acidity parameters from cabbage monitor plots with yields $\geq$ 70 t ha^{-1} are shown in Table 3 (The DRIS "mean of a high yielding population" (Sumner, 1986)). Their corresponding maximum and minimum values at yields $\geq$ 70 t ha^{-1} are shown in Table 2. These means (Table 3) provide estimates of soil critical values in the Umlaas River Valley. Table 3 also compares the critical values of the Umlaas River Valley with norms used by Smith (pers. com., c/o Lakehead University, Department of Biology, 955 Oliver Rd, Thunder Bay, Ontario P7B 5E1) and Fertrec (Manson *et al.*, 1993). The Umlaas River Valley norms for optimal cabbage yields are slightly higher than Smith norms and much higher than Fertrec norms.

Discussion

This study has identified values of soil nutrient levels and soil acidity parameters (i.e., critical values) at which maximum cabbage yields occurred in the Umlaas River Valley. It has also identified soil parameter levels at which yields $\geq$ 100 and < 100, 90, 80, 70, 60 and 50 t ha^{-1} were expected. Parameter values above or below the maximum and minimum levels resulted in lower yields. Acid saturation above 2 % was a limiting factor in cabbage production. Great variation in soil parameter values was evident. Excesses and imbalances in the values of the soil nutrient levels and acidity parameters could have reduced cabbage yields. The observation of a nutrient balance or cation saturation ratio similar to Bornman *et al.* (1989) could indicate the accuracy of our means (Table 3) and question the use of/little use of cation ratios for fertilizer recommendations in South Africa.

Critical values for each soil parameter, otherwise known as soil optima (Walworth *et al.*, 1986) are shown in Table 3. Highest cabbage yields in the Umlaas River Valley were observed when values of each soil parameter were closer to the critical value. Although maximum cabbage yields could be achieved at the critical values (Table 3), the critical values were not necessarily the economic threshold values for that soil e.g., Table 2 shows yields $\geq$ 100t ha^{-1} for soil P values from 47 - 155 mg l^{-1} and soil K values from 248 - 486 mg l^{-1}. However, the highest yields were still achieved at the critical values for P and K (i.e., 88 and 338 mg l^{-1} respectively). In many respects, Table 2 with Fig. 1 and Table 3 reflects a similar point raised by Sumner (1987). The linear plateau model fit in Fig. 1 using data form Table 2, shows yields $\geq$ 100 t ha^{-1} with P levels of 47 - 155 mg l^{-1}; however higher yields (e.g., 120 t ha^{-1}) could be obtained at the critical value in Table 3 i.e., 88 mg l^{-1}. Therefore why not target the critical value and higher yields? If these critical values are a good indicator of soils in the Umlaas River Valley, then the only argument for not raising soil nutrient values to the critical values in Table 3, would be a low nett return. Olson, Anderson, Frank, Grabouski, Rehm & Shapiro (1987) found that very high application rates of nitrogen (N) were not justified economically and showed no significant differences in yield. A similar principle could apply in bringing soil levels up to critical values. Manson (pers. com., Soil Physics Laboratory, Department of Agriculture, Natal Region, P Bag X9059, Pietermaritzburg, 3200) indicated that workers in KwaZulu-Natal have found critical values as determined by the boundary lines technique (Webb, 1972; Walworth *et al.*, 1986) were too high. The economic threshold has been found $\pm$ 1/3 below the critical values identified by boundary lines (Manson, pers. com.). This does not seem logical when use of the critical value could give a 10 - 20 t ha^{-1} increase above "economic" thresholds. Threshold values used by Fertrec at Cedara, critical values as determined by boundary lines or "means of a high yielding population", and critical values as determined in field fertilizer trials, all need to be compared in terms of yield response and economics.

Richards (1983) found no yield response to P above 30 ppm, while Smith & Bennet (1984) showed a response up to 40 ppm of P . Based on this research, Fertrec currently uses critical P values of 27 - 50 mg l^{-1} for clay to sandy soils and 200 mg l^{-1} for K (Table 3) based on ammonium bicarbonate (AMBIC 2) extract from the soil (Manson *et al.*, 1993). The sample density of a soil affects the amount of available P (Manson *et al.*, 1993). The critical value of P in Table 3 had an equivalent sample density of 1.14 g ml^{-1}. For this sample density, Fertrec would recommend 41 mg l^{-1} as the critical P value (Manson *et al.*, 1993) in comparison to 88 mg l^{-1} identified in this work. The results of this study indicate that the Fertrec norms could be raised from 27 - 50 mg l^{-1} to 27 - $\geq$ 88 mg l^{-1}. Hochmuth, Hanlon, Hochmuth, Kidder & Hensel (1993) reported no relative yield response above 30 mg kg^{-1} and regarded soil K above 60 mg kg^{-1} as very high for vegetables on Florida soils. However, these critical values were determined using the Mehlich-1 (double-acid) extractant method (Hochmuth *et al.*, 1993). The correlated values using ammonium acetate extractant considered > 66 and > 100 mg l^{-1} for P and K as high. However, it must be remembered that South African soils differ from Florida soils in many respects. Furthermore, the work on which Fertrec based its P and K critical levels, and that of Richards (1983) and Smith & Bennet (1984), did not consider various levels of K, Ca and Mg in their experiments. Had the soil K levels in these trials been increased to $\geq$ 400 ppm, I speculate that a yield response up to $\geq$ 80 ppm could have resulted. Furthermore, I suggest that the P-K balance was a limiting factor (Sumner & Farina, 1986) in these trials. This could explain the higher critical values observed in this study when compared to Smith or Fertrec soil optima (Table 3).

In reviewing these apparent discrepancies, the validity of these data and method of analysis must be questioned. In collecting data for single plot calibration studies, Sumner (1987) emphasized the importance of soil analysis by the same technique and minimal variability between soils in terms of mineralogy and chemistry. He also stated that soils should be sampled an equivalent time after fertilizer application, so that analysis results would reflect nutrients available to the crop. The soil sample in the present study was always taken at headform which was normally two to three weeks after topdressing, and analysis was always performed by Cedara. Although different soil forms (MacVicar, 1993) were examined in the study area, they were in the same geographical area (Dekker, Jeffrey & Scotney, 1980).

With differences in soil form (MacVicar, 1993) this data could show slight variability and a lack of diagnostic precision. Nevertheless accuracy of the data cannot be far wrong, and the differences between the Umlaas critical values and the threshold values used by Fertrec (Table 3) indicate the need for further soil calibration studies. To verify the findings of this study further data from similar soil forms could be collected and critical values assessed.

The recorded high levels of P, K, Mg, Zn, exchangeable acidity and acid saturation and low pH in Table 1 far exceeded the averages and norms in Table 3 and the ranges presented in Table 2. Although the higher levels occurred in the right tail of a left skewed distribution, they were related to lower yields. Most research does not emphasize calibration tests at excessive nutrient levels because maximum crop response occurs at relatively low levels (Hochmuth *et al.*, 1993). The practice is not practical, would waste fertilizer and constitute an environmental hazard (Olson *et al.*, 1987). Therefore typical yield response curves of yield versus soil values of such data are exponential in nature and will never indicate a toxic level (Melsted & Peck, 1977). However, excessive levels of soil nutrients are related to declining yields (Baker, 1977; Melsted & Peck, 1977; Sumner, 1987; Kidder, 1993) and will show a quadratic yield response curve with both high and low soil nutrient levels. Given the large range in soil nutrient levels in the Umlaas River Valley (Holcroft *et al.*, 1991; Askew, unpublished data; Table 1) and yield reductions due to nutrient imbalances and toxicities (Sumner & Farina, 1986; Mengel & Kirkby, 1987; Lorenz & Maynard, 1988), yield effects of high and low levels of soil nutrient levels were expected. Comparisons of values from Table 2 and Fig. 1 show highest yields possible at maxima and minima of each soil parameter. Yield response from low to critical levels of soil nutrients is well documented (Hochmuth *et al.*, 1993) and reduced yields at lower levels of soil nutrient expected. The yield reductions at higher soil values are notable and given the left skewed distributions of most soil nutrient levels and soil acidity parameters, were a limiting factor in cabbage production for some farms in the Umlaas River Valley. Soils with less than the minimum value for the targeted yield as shown in Table 2 should reach the minimum value for that nutrient after the application of fertilizer. Conversely soils with more than the maximum value for the targeted yield should not receive any of that nutrient at least until below the maximum level. For economic and environmental reasons (Olson *et al.*, 1987) and maximum yield response, excessive nutrient levels should be decreased after all fertilization to at least the critical values identified in Table 3.

Acid saturation > 2 %, low soil pH and high soil exchangeable acidity were other factors limiting cabbage production in the Umlaas River Valley (Table 2, Fig. 2). Fig. 2 clearly illustrates cabbage response to increasing levels of saturation in the Umlaas River Valley. Richards (1983) and Smith & Bennet (1984) documented cabbage yield reduction with high exchangeable acidity. At present, Fertrec uses acid saturation > 5 % for liming recommendations to rectify exchangeable acidity for cabbage crops (Manson *et al.*, 1993). § 2 deals more comprehensively with soil acidity problems experienced in the Umlaas River Valley but liming above 2 % acid saturation is recommended for all cabbage crops in this highly weathered, low soil pH area.

Excesses and resultant imbalances of nutrients and acidity parameters, above or below the range stated in Table 2 (at specific sample densities), could be responsible for reduction in cabbage yields. Interesting phenomena regarding soil-nutrient interactions were seen during this study. In some cases, monitor plots with soil K $\geq$ 500 mg l^{-1} had Ca deficiencies (seen in leaf analysis) and reduced yields in spite of Ca $\geq$ 1200 mg l^{-1}. The displacement of Ca by K (Mengel & Kirkby, 1987) could have caused these deficiencies and lower yields. Similarly, monitor plots in summer with high P ($\geq$ 90 mg l^{-1}), K at $\pm$ 500mg l^{-1}, Ca at $\pm$ 1300 mg l^{-1} and Mg at $\pm$ 250 mg l^{-1} showed P, Ca and Mg deficiencies in leaf analysis and lower yields. It is speculated that displaced Ca and Mg formed unavailable calcium and magnesium phosphates with the highly available phosphate (Wild, 1988) resulting in deficiencies and hence, lower yields. Both phenomena were recorded on many occasions.

As seen in Table 2, high yields at high P had corresponding high values of K, Ca, Mg and pH and low exchangeable acidity and acid saturation. Likewise high yields at lower P values had corresponding lower values of K, Ca, Mg and Zn. Furthermore, the ratios between Ca, K, and Mg were almost identical to those of Bornman *et al.* (1989). The interactions in the preceding paragraph and the balance seen in Table 2 promotes the use of the basic cation saturation ratios approach in fertilizing for optimal cabbage yields. American literature shows much debate on the merit of two different soil test interpretation methods; the "basic cation saturation ratio" (BCSR) concept or the "sufficiency level" (Eckert, 1987) otherwise known as the "crop nutrient requirement" (CNR) system by Hochmuth & Hanlon (1989). The BCSR holds that there is an optimum ratio of Ca, Mg an K in the soil at which maximum yields occur (McLean, Hartwig, Eckert & Triplett, 1983; Eckert, 1987). The sufficiency level concept identifies a critical level for each nutrient at which the maximum yield response occurs (McLean *et al.*, 1983; Eckert, 1987; Hochmuth & Hanlon, 1989). In 1981, private laboratories in the north-central region of USA still preferred BCSR while universities opted for the sufficiency levels (Liebhardt, 1981). Eckert (1987) reported that most US universities used sufficiency levels while some used a combination of both. Many workers doubt the existence of a BCSR (Olson *et al.*, 1982; McLean *et al.*, 1983; Kidder, 1993) and find BCSR recommendations difficult to interpret, expensive and not justified by research (Eckert, 1987). However, there is a place for BCSR; McLean (1977) said the concept worked best in highly weathered soils of low pH (e.g., Umlaas River Valley) requiring major adjustments in fertility. This study has corroborated the presence of an ideal cation balance in soil affecting cabbage yields in the Umlaas River Valley. To produce a high yielding cabbage crop, a farmer must not only be aware of individual nutrient levels but also of their ratio and interactions.

In conclusion, this study recommends the use of the critical values in Table 3 for interpretation of cabbage crop requirements on soils in the Umlaas River Valley. Excessively high and low levels of all soil nutrient levels and soil acidity parameters are associated with reduced cabbage yields. Therefore, none of a specific nutrient should be applied when soil test values exceed the critical values. Conversely, where soil test values are below the critical values (Table 3) and highest yields are desired, the application of that specific nutrient until the critical level is reached, is recommended. For yields $\geq$ 100 t ha^{-1} the minimum threshold levels in Table 2 are recommended. Where acid saturation exceeds 2 %, the application of lime is recommended. Farmers in the Umlaas River Valley should also realize the need of an ideal cation ratio for achieving maximum cabbage yields on their farms.

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Table 1 Mean, maximum and minimum values for soil analysis data and yield ha^{-1} from cabbage monitor plots in the Umlaas River Valley, 1991 - 1993

Parameter	Range of values				
	Mean	Minimum	Maximum	SE	CV
Yield ($t\ ha^{-1}$)	56	0	116	4.42	61
Sample density	1.15	0.89	1.49	0.02	9
P ($mg\ l^{-1}$)	92	10	285	10.73	75
K ($mg\ l^{-1}$)	312	75	714	24.92	51
Ca ($mg\ l^{-1}$)	1080	281	2164	77.60	46
Mg ($mg\ l^{-1}$)	273	49	568	22.92	54
Zn ($mg\ l^{-1}$)	11.37	1.5	71.6	1.89	106
Exchangeable acidity ($cmol_c\ l^{-1}$)	0.19	0	1.12	0.04	133
Total cations	8.63	2.61	15.6	0.55	41
Acid saturation (%)	3.41	0	21	0.81	152
pH (KCl)	4.78	3.84	6.52	0.09	12

2 Minimum achievable yields within specified soil nutrient and acidity parameter ranges and yield reductions above or below the maximum and minimum values, respectively in the Umlaas River Valley, 1991 - 1993

Soil nutrient levels and acidity parameters																			
Sample density		P		K		Ca		Mg		Zn		Exchangeable		Total cations		Acid sat.		pH	
g ml^{-1}						mg l^{-1}								cmol$_c$ l^{-1}		%		(KCl)	
min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
0.89	1.29	10	285	75	714	436	2164	106	568	1.5	71.6	0	0.77	3.78	15.6	0	17	3.95	6.52
0.98	1.29	20	285	137	714	436	2164	107	568	1.5	44.9	0	0.53	3.78	15.6	0	10	4.03	6.52
0.98	1.29	27	285	149	714	452	2164	108	568	1.5	44.9	0	0.52	3.78	15.6	0	8	4.05	6.52
0.98	1.22	28	285	149	714	717	2164	151	568	6.3	44.9	0	0.21	6.4	15.6	0	2.6	4.21	6.52
1.12	1.22	47	155	248	714	741	1952	151	568	6.3	44.9	0	0.11	6.4	15.3	0	2	4.51	6.52
1.12	1.18	47	155	248	486	741	1952	220	568	6.3	44.9	0	0.11	6.97	15.3	0	2	4.51	6.52

Table 3 Critical values of soil nutrient levels and acidity parameters at which maximum cabbage yields occurred on 59 monitor plots in the Umlaas River Valley compared with other soil fertility norms.

	Umlaas River Valley	Source of norms Smith[a]	Fertrec (Cedara)[b]
SD (g ml^{-1})	1.14		
P (mg l^{-1})	88	60 - 80	27 - 50
K (mg l^{-1})	338	200 - 250	200
Ca (mg l^{-1})	1204	1200 - 1500	
Mg (mg l^{-1})	302	100 - 250	100
Zn (mg l^{-1})	10.7		1.5
Exchangeable acidity($cmol_c$ l^{-1})	0.09		
Total cations ($cmol_c$ l^{-1})	9.46		
Acid saturation (%)	1	<5	<5
pH (KCl)	5.01		

[a] Norms used by Prof I E Smith, derived from experience and used for fertilizer recommendations

[b] Norms used by Fertrec for cabbage fertilizer recommendations (Manson *et al.*, 1993)

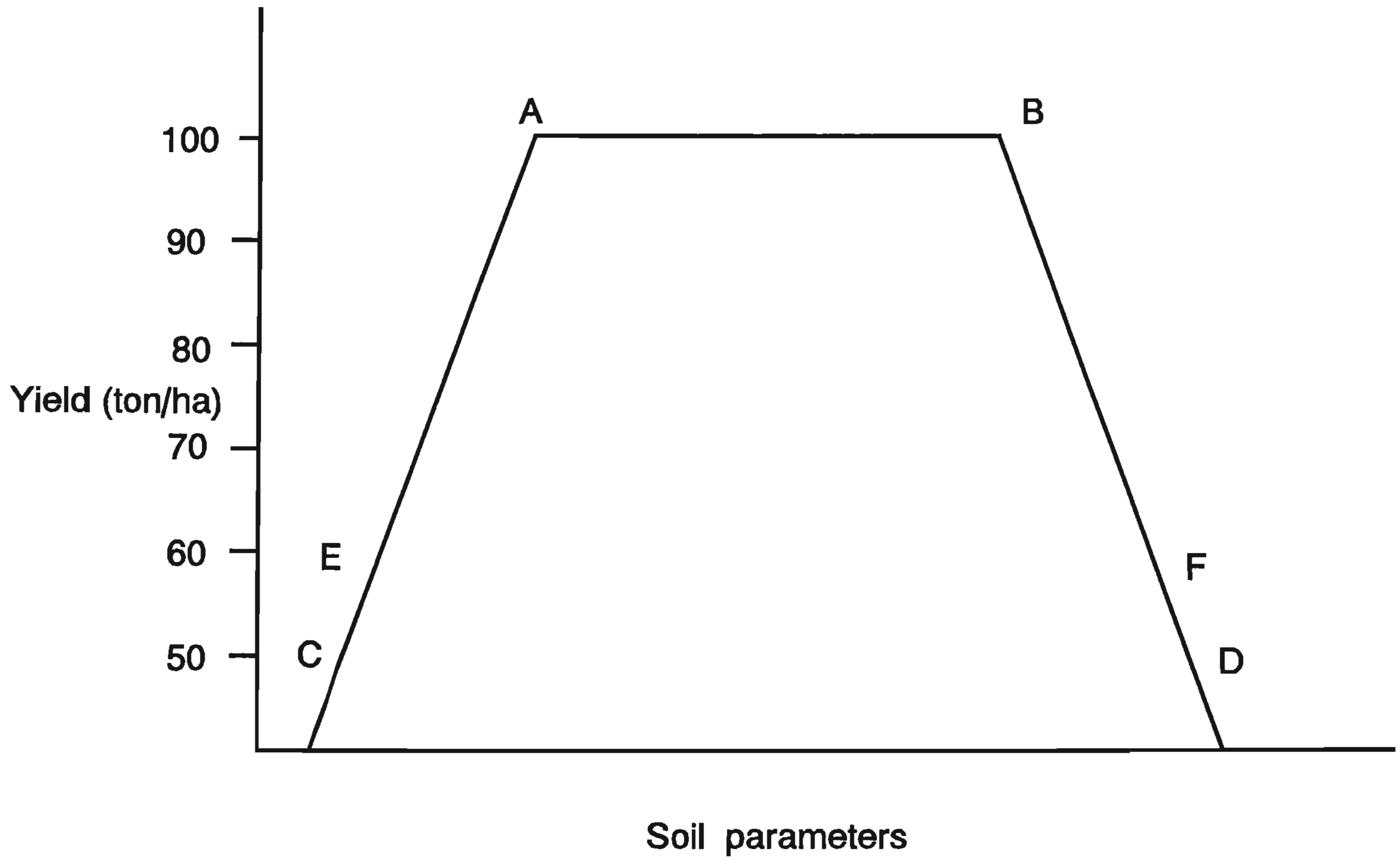

Figure 1 A model showing cabbage yield response for max. and min. values of soil nutrients and acidity parameters

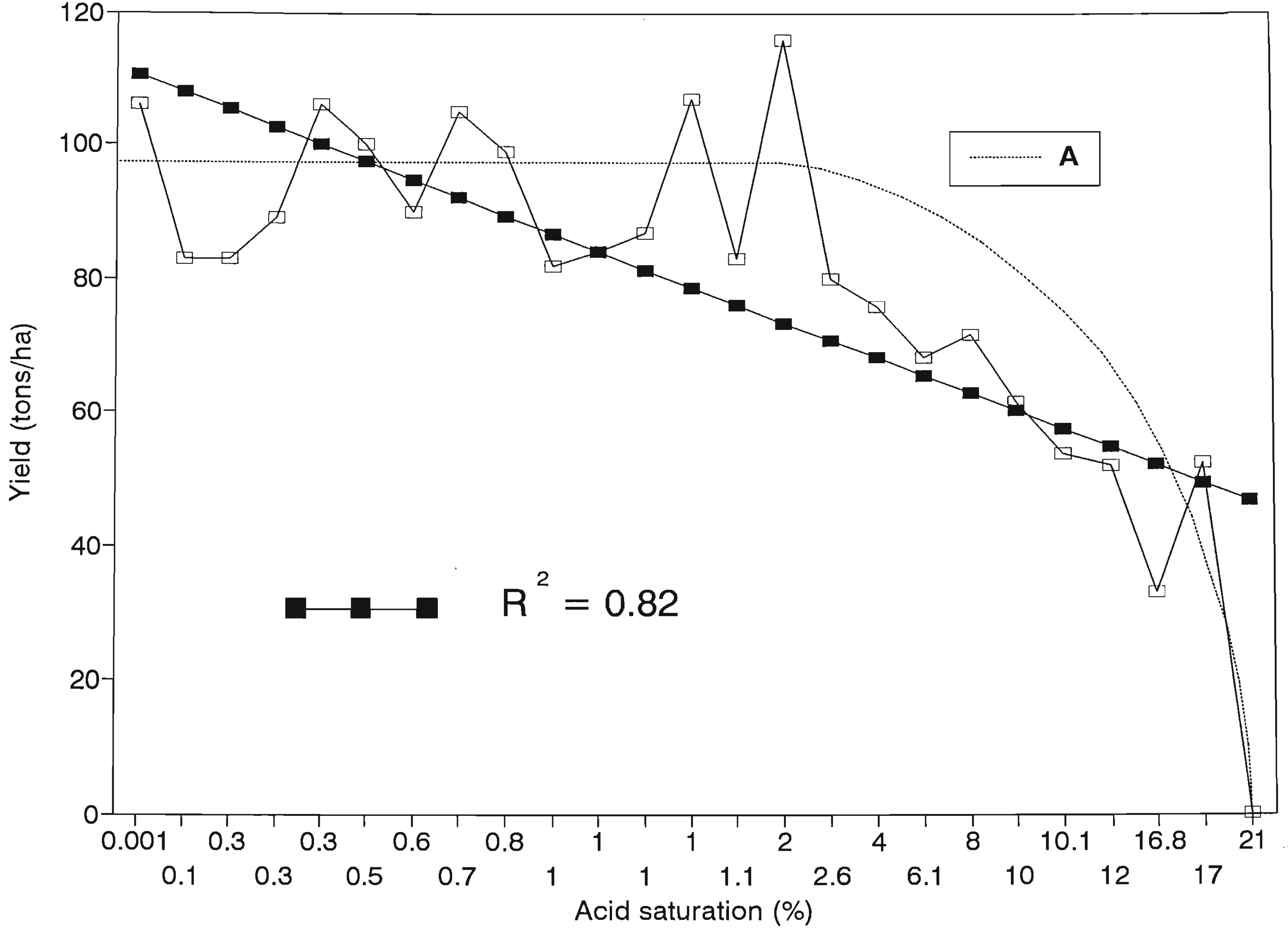

Figure 2 Cabbage yield response to soil acid saturation in the Umlaas River Valley, 1991 - 1993

2. A SOIL ACIDITY COMPLEX AFFECTING CABBAGE PRODUCTION IN THE UMLAAS RIVER VALLEY, KWAZULU-NATAL, SOUTH AFRICA

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Abstract

Research in the Umlaas River Valley, KwaZulu-Natal showed the presence of a soil acidity complex affecting cabbage yields. High KCl exchangeable acidity and acid saturation and low pH increased Mn and Zn availability in the soil. Both Mn and Zn were absorbed in large quantities by the plant and maximum levels of 406 mg kg^{-1} and 114 mg kg^{-1} respectively were recorded in MRM cabbage leaves at headform. Mn concentrations > 100 mg kg^{-1} at headform and 50 mg kg^{-1} at harvest, reduced yields.

Keywords : Manganese toxicity, zinc, acid saturation, exchangeable acidity, cabbage, liming, pH.

Introduction

A soil acidity complex affecting plant growth is well documented (Robinson, 1983; Rowell, 1988; Tisdale, Nelson & Beaton, 1990). Aluminium (Al), boron (B), copper (Cu), manganese (Mn) and zinc (Zn) all become more available at a lower soil pH (Lorenz & Maynard, 1988; Tisdale *et al.*, 1990). Aluminium and manganese toxicities are synonymous with soil acidity problems (Robinson, 1983). Brassicas are fairly tolerant to high concentrations of Al which are lethal to other crops (e.g., sugar beet and barley) but are highly succeptable to Mn toxicities (Hewitt, 1948, 1949). Mn toxicities stunt plant growth, cup leaves and produce irregular interveinal chlorosis especially at leaf margins (Hewitt,

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1947). Hewitt (1948) found that an Al toxicity would accentuate symptoms of Mn toxicity on brassicas. The inter-related and separate effects of excess Mn or Al, deficiencies of Ca, Mg and molybdenum (Mo) and low pH affect most crops including cabbage (*Brassica olereacea* L. var. *capitata* Alef.) (Hewitt, 1953).

Cabbage research conducted in the Umlaas River Valley from June 1991 to July 1993 suspected the presence of a soil acidity complex affecting yields. Soil classification and soil samples on 13 farms in the Umlaas River Valley showed many soils with low pH. Furthermore, very few farmers limed their soils and had in previous years applied high rates of ammoniacal fertilizers. These practices had undoubtedly contributed to the observed low soil pH's (Fey, Manson & Schutte, 1990; Warman, 1990). Given the toxic effects of Mn on acid soils, the higher cabbage yields correlated with lower leaf Mn and Zn concentrations (Smith, Demchak & Ferretti, 1986) and the above-mentioned conditions in the study area, it was suspected that low soil pH, high exchangeable acidity and acid saturation resulted in lower cabbage yields. This paper evaluates the effects of pH, exchangeable acidity and acid saturation on cabbage yield and correlates these findings with leaf concentrations of various nutrients.

Procedures

Research monitored 59 cabbage crops in Umlaas River Valley from June 1991 to July 1993 (§1). Leaf (MRM leaf) samples at headform and ⅛ head slices at harvest (Geraldson, Klacan & Lorenz, 1973) and soil samples (at depth 15 cm; Manson, Milborrow, Farina, Miles & Johnston, 1993) were taken within each plot and analyzed by the Soil Physics Laboratory at Cedara Agricultural Development Institute (§ 1). Soil samples were analyzed according to § 1. The MRM leaf samples at headform and ⅛ headslice at harvest were weighed before and after drying and the percentage of dry matter was determined. The dry ash method with HCl was performed on Hunter's apparatus to determine leaf K, P, Cu, Zn and Mn. Wet ashing was performed using a block digester to determine leaf N (Analytical Methods used in the Soil Science Laboratories at Cedara, 1986). Plots were harvested and heads weighed at maturity so that estimated yields could be related to various factors affecting production (§ 1).

Disease, pest and water stress problems were identified in 18 crops grown over the two year period. Analysis excluded these plots so that cabbage yields would reflect soil acidity problems only. Furthermore, some farmers did not mix their lime in the soil profile or applied Calmag + B® as a soil drench after planting. This resulted in inaccuracies in correlation between yield, leaf and headslice trace element concentrations and soil factors. Therefore some data points were regarded as outliers and excluded from analyses as stated in the Results.

Correlation analysis compared soil parameters and nutrient levels of headform (MRM leaf) and harvest (⅛ headslice) samples. Through regression analysis, the nutrient concentrations of MRM leaves at headform and a ⅛ headslice at maturity were related to yield, to determine upper critical levels of Mn and Zn. Multiple stepwise regression was used to determine the effects of soil parameters on headform and harvest Mn and Zn levels. Hereafter, all leaf samples taken at headform will be referred to as MRM leaf and all ⅛ headslices at harvest as headslice.

Results

Previous work (§ 1) reported strong correlation between acid saturation (R^2 = 0.82, t-value = 34.04***), exchangeable acidity (R^2 = 0.80, t-value = 33.97***) and pH (R^2 = 0.33, t-value = -1.03***) versus yield. Yield reductions occurred at acid saturations > 2 %, exchangeable acidity > 0.11 $cmol_c\ l^{-1}$ and pH < 4.5 (KCl)(§ 1).

An analysis of all MRM leaf (headform) and headslice (harvest) nutrient concentrations versus soil exchangeable acidity, acid saturation and pH showed only Zn and Mn had correlations (R values) > 0.5. Therefore, further analysis of this soil acidity complex included only Zn and Mn. Table 1 shows correlations between MRM leaf and headslice concentrations of Zn and Mn and highly correlated soil parameters. MRM leaf concentrations of Zn and Mn and headslice Zn showed strong correlation to the soil acidity factors (namely exchangeable acidity, acid saturation and pH) (Table 1). Correlation between exchangeable acidity, acid saturation, pH and headslice Mn was weak (R = 0.37, 0.39 and 0.45 respectively)(Table 1).

It was notable that MRM leaf Zn showed poor correlation with available soil Zn but a high correlation to exchangeable acidity, acid saturation and pH (Table 1). An average correlation between MRM leaf Zn and Mn and soil Ca and Mg was expected and found (Table 1). The correlation between Mn and Zn in MRM leaf and headslice samples was good, with R values of 0.68 and 0.62 respectively. Correlations between headslice Mn and Zn were lower than in MRM leaf. This was expected because mean dry matter percentage and mean nutrient concentrations (mg kg^{-1}) were lower for headslice samples (Table 2).

Umlaas River Valley research on 41 cabbage crops showed high concentrations of Mn at headform (average = 103 mg kg-1) (MRM leaf) and lower concentrations at harvest (headslice)(Table 2). Average concentrations of Zn in MRM leaf and headslice samples were acceptable according to the Hochmuth, Maynard, Vavrina & Hanlon (1991) norms. However, both Mn and Zn were present at high concentrations on many occasions (Table 2).

Regression analysis in Table 3 showed that excessive levels of Mn or Zn in the leaf have at least a highly significant effect on cabbage yields. Of note were the high R^2 values (including outliers) of Zn in MRM leaf (R^2 = 0.40) and Mn in headslice (R^2 = 0.52)(Table 3) when compared to yield. Similarly, when R^2 values excluded outliers the result was exceptional, especially for Mn in MRM leaf and headslice (Table 3). Multiple stepwise regression with yield as the dependant variable and all leaf nutrients as independents, showed headslice Mn and MRM leaf Zn could account for 37 % of the variation in the yield (Mn: t-value = -3.16**, Zn: t-value = -2.62*). Further analysis with soil parameters and leaf nutrient concentrations as independent variables showed MRM leaf Mn (t-value = -2.93**), soil K (t-value = 2.04*) and exchangeable acidity (t-value = -2.30*) could account for 45 % of yield variation.

Observed data (excluding outliers) were plotted against yield (Table 3) and showed upper critical levels of MRM leaf and headslice Mn and Zn. Yield reductions were seen with MRM leaf concentrations of Zn > 38 mg kg^{-1} and headslice concentrations >40 mg kg^{-1}. Similarly Mn concentrations > 100 and 50 mg kg^{-1} (MRM leaf and headslice respectively) resulted in lower yields (Table 3).

Table 1 showed high correlations between MRM leaf Zn and Mn and some soil parameters. Therefore, it was not surprising that stepwise multiple regression with parameters from soil analysis should explain 76 % of variation in MRM leaf Mn (Fig. 1). Acid saturation and to a lesser extent, sample density and pH played a major role in Mn availability and uptake by the plant (Fig.1). At maturity, sample density (t-value = 2.89**) and pH (t-value = -3.61***) could account for 35 % of the variation in Mn uptake by the plant.

Similarly acid saturation, soil P, pH and soil K affected Zn uptake (Fig. 2). These soil parameters accounted for 70 % of the variation in Zn uptake by the plant at headform (Fig. 2). At maturity, soil pH accounted for 44 % of the variation in Zn uptake (t-value = -5.39***).

Discussion

This study shows that acid saturation, exchangeable acidity and pH reduced cabbage yields in the Umlaas River Valley. It also shows that high exchangeable acidity, acid saturation or low pH in soils were largely responsible for high Zn and Mn concentrations in cabbages. These data showed a significant yield reduction in cabbages when upper critical limits of Mn and Zn were exceeded. Levels of Mn > 100 mg kg^{-1} in MRM leaves at headform and 50 mg kg^{-1} in a ⅛ headslice at harvest were toxic to the plants and resulted in lower yields. Levels of Zn > 38 mg kg^{-1} in MRM leaves at headform and 40 mg kg^{-1} in a ⅛ headslice at harvest were correlated to lower yields but not necessarily harmful to the plants. Corrective liming of the soils, the use of less ammoniacal fertilisers, and farmer knowledge of acidifying effects of ammonia based fertilizers and pig manure (Warman, 1990), could reduce soil acid saturation, exchangeable acidity levels and raise pH. This would reduce Mn and Zn availability in the soil resulting in decreased plant uptake and higher yields (Smith *et al.*, 1986).

Cabbage yields in the Umlaas River Valley were reduced when soil tests showed acid saturations > 2 %, exchangeable acidity > 0.11 $cmol_c\ l^{-1}$ and pH < 4.5 (§ 1, Fig. 1 and 2). Smith & Bennet (1984) and Richards (1983) observed higher cabbage yields with lower levels of acid saturation and Smith *et al.* (1986) reported a positive yield response to liming by raising soil pH levels. At present Manson *et al.* (1993) (Fertrec) use percentage acid saturation to determine liming requirements and recommend liming above 5 % acid saturation. This study has shown that permissable acid saturation of soils in the Umlaas River Valley should be reduced to $\leq$ 2 %.

Hewitt (1953) found that inter-related and separate effects of excess Mn and Al, deficiencies of Ca, Mg and Mo, low pH and waterlogging affected cabbages. Al concentrations of leaf tissue were not determined in leaf analysis so no conclusion could be reached on its correlation to leaf and soil parameters measured. However, leaf symptoms seen in cabbages were characteristic of Mn toxicity, not Al toxicity as recorded by Robinson (1983). § 1 showed that acid saturation was the main factor affecting Mn and Zn uptake in cabbages. Therefore, it is speculated that high exchangeable acidity and associated exchangeable Al and low soil Ca and Mg were indirectly responsible for the yield reduction of cabbage in the Umlaas River Valley (where acid saturation is determined according to Manson *et al.*, 1993).

In KwaZulu-Natal, Fertrec bases its liming recommendations on acid saturation. Acid saturation had the highest correlation with plant Mn concentrations and hence toxicity in cabbages. Therefore liming according to acid saturation would reduce leaf Mn and Zn (Hemphill & Jackson, 1982). Previous work (§ 1) showed that acid saturation > 2 % and pH < 4.5 reduced cabbage yields. Liming to acid saturation < 2 % and pH > 4.5 would reduce soil exchangeable acidity and lower the incidence of yield reduction due to Mn toxicities.

This study shows that low exchangeable acidity, high acid saturation and low pH are largely responsible for the high levels of Mn and Zn observed in cabbages in the Umlaas Valley. Fig. 1 and 4 and Table 1 proved that a soil acidity complex affected plant Mn and Zn concentrations. Although it was known that Mn and Zn become more available at lower soil pH and that Mn toxicity problems are synonymous with soil acidity problems (Robinson, 1983; Lorenz & Maynard, 1988; Tisdale *et al.*, 1990), such high correlations (R = 0.75, 0.71 and -0.62)(Table 1) between leaf Zn and soil exchangeable acidity, acid saturation and pH were unexpected. However, Davies & Jones (1988) reported that solubility of Zn increased as pH decreased. Therefore the high correlation between leaf Zn and soil acidity factors seems justified.

The poor correlation between MRM leaf and headslice Zn and soil Zn was noted in Table 1. Tisdale *et al.* (1990) reported that total Zn concentrations in soil were not a criterion of its availability to plants. The lower correlation between headslice Mn and soil parameters was also expected (Table 1). The effects of other variables such as plant population and cultivar on head size and mass were more significant at harvest than at headform. At 7 to 8 weeks (MRM leaf, headform) the effect of these factors was hardly noticeable but by maturity head mass and size varied significantly between monitor plots (Smith & Hapelt, 1984). Thus, different plant populations and cultivars on each monitor plot diluted the effects of soil exchangeable acidity, when correlated with leaf nutrients at harvest. However, the effect of Mn on yield was enhanced at harvest having R^2 values of 52 and 89 % with inclusion and exclusion of outliers respectively (Table 3). This demonstrates the cumulative effect of increasing Mn g^{-1} of plant tissue on yield. The average negative correlation between MRM leaf Mn and soil Ca ($R = -0.58$) and Mg ($R = -0.57$) was also expected. Low soil Ca and Mg are indicative of acid soils (Rowell, 1988).

Frequency distributions of MRM and headslice Mn were both unimodal and symmetrical (Table 2) with many crops having concentrations that were more than the upper critical limits mentioned in Table 3. The effects of excess Mn concentrations in the plant on yield were also seen in Table 3 with correlations of 0.83 (R^2 value) for MRM leaf and 0.89 (R^2 value) for headslice samples. Cabbage yields decreased rapidly when plant Mn exceeded upper critical concentrations (100 mg kg^{-1} for MRM leaf and 50 mg kg^{-1} for headslice). Thus plant Mn concentrations had a strong effect on cabbage plant growth in the Umlaas River Valley and upper critical limits should be regarded as toxic in our area. Hochmuth *et al.* (1991) stated the following norms for cabbage Mn levels at eight weeks: < 20 mg kg^{-1} was deficient, 20 - 40 mg kg^{-1} was adequate and > 40 mg kg^{-1} was high. Robinson (1983) showed upper leaf critical concentrations of Mn as 500 mg kg^{-1} but said that this varied with species.

An upper critical leaf concentration for Zn was not ascertained from literature, however, Hochmuth *et al.* (1991) regarded < 30 mg kg^{-1} as deficient, 30 - 50 mg kg^{-1} as adequate and

> 50 mg kg^{-1} as high for Zn concentrations in cabbage at eight weeks (MRM leaf) and > 40 mg kg^{-1} (wrapper leaf) as high at harvest. Data presented in Table 2 showed a right skewed frequency distribution of MRM leaf Zn with most points between 30 - 50 mg kg^{-1}. Headslice Zn concentrations had a unimodal and symmetrical frequency distribution with most concentrations occurring between 15 - 35 mg kg^{-1}.

The correlation (excluding outliers) between yield and Zn concentrations was good (R^2 = 0.68 and 0.40 for MRM leaf and headslice respectively)(Table 3). Similarly the correlation between Zn and Mn was above average (R = 0.68 and 0.62 for MRM leaf and headslice respectively). Acid saturation, soil P, soil K and pH were responsible for 70 % (R^2 = 70 %) of the variations in MRM leaf Zn levels (Fig. 2). Thus, the same soil acidity complex affecting the uptake of Mn was responsible for the uptake of Zn. However, the maximum concentrations of Zn were not as excessive as those of Mn (Table 2) and correlations with yield (Table 3) were mostly lower than Mn. Little literary evidence of Zn toxicity in brassicas, low leaf concentrations and a lower correlation than Mn with yield leads to the surmise that yield reductions, although associated with high levels of Zn in the plant, were rather caused by Mn toxicity. There was insufficient evidence to prove that high concentrations of Zn were harmful to cabbages. Other work by Askew (unpublished data) analyzed the effects of all leaf nutrients on yield. This showed that MRM leaf concentrations of Zn contributed 12 % of the total accountable variation in yield (R^2 = 0.34) while headslice Mn was responsible for 24 % of the variation in yield. Therefore, we speculate that high levels of Zn had only a slight role in reducing cabbage yields, if any.

In conclusion, continual cultivation, inadequate liming practices and the continued application of ammoniacal based fertilizers, could have contributed to the slow acidification of the soils in the Umlaas River Valley over the years. The acid soils resulted in increased Mn and Zn availability in the soil. This Mn and Zn was absorbed by cabbage plants and excessive levels of Mn were toxic to cabbages and reduced yields. This soil acidity complex and its resultant Mn toxicity in cabbages can be rectified by liming to acid saturation < 2 % and maintaining soil pH above 4.51.

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Table 1 Correlation table (R values) of Zn and Mn concentrations at headform and harvest versus various soil acidity parameters

	Soil acidity parameters[a]					
	Ca	Mg	Zn	Exchangeable acidity	Acid Saturation	pH
Headform (MRM leaf)						
Zn	-0.32	-0.47**	-0.24	0.75***	0.71***	-0.62***
Mn	-0.58***	-0.57***	-0.22	0.83***	0.83***	-0.67***
Harvest (Headslice)						
Zn	-0.28	-0.36*	-0.10	0.59***	0.60***	-0.66***
Mn	-0.36*	-0.38*	-0.21	0.37*	0.39*	-0.45**

[a] Numbers followed by *, ** and *** are significant at the $P \leq 0.05$, 0.01 and 0.001 levels respectively

Table 2 Manganese and zinc concentrations (mg kg^{-1}) of samples of 41 cabbage crops taken at headform (MRM leaf) and harvest (headslice)

	Time of sampling			
	Headform (MRM leaf) (Avg. DM % = 10.6 %)		Harvest (Headslice) (Avg. DM % = 7.3 %)	
	Mn	Zn	Mn	Zn
Mean	103	42	37	30
Minimum	24	15	19	16
Maximum	406	114	103	54
SE	14.01	3.57	3.44	1.49
CV(%)	87	54	54	29

Table 3 Regression analysis of Mn and Zn at headform (MRM leaf) and harvest (headslice) versus yield and upper critical leaf concentrations (mg kg^{-1})

	Regression analysis (R^2)		
	Including outlier	Excluding outlier	Upper critical leaf concentration (mg kg^{-1})
		Yield (t ha^{-1})[a]	
Headform (MRM leaf)			
Zn	40***	68***	38
Mn	20**	83***	100
Harvest (Headslice)			
Zn	20**	46***	40
Mn	52***	89***	50

[a] Numbers followed by ** and *** are significant at the P ≤ 0.01 and 0.001 levels respectively

Variables	Coefficients	t-values
Sample density	199.43	2.67*
Acid saturation	12.25	5.55***
pH	-42.68	-2.50*

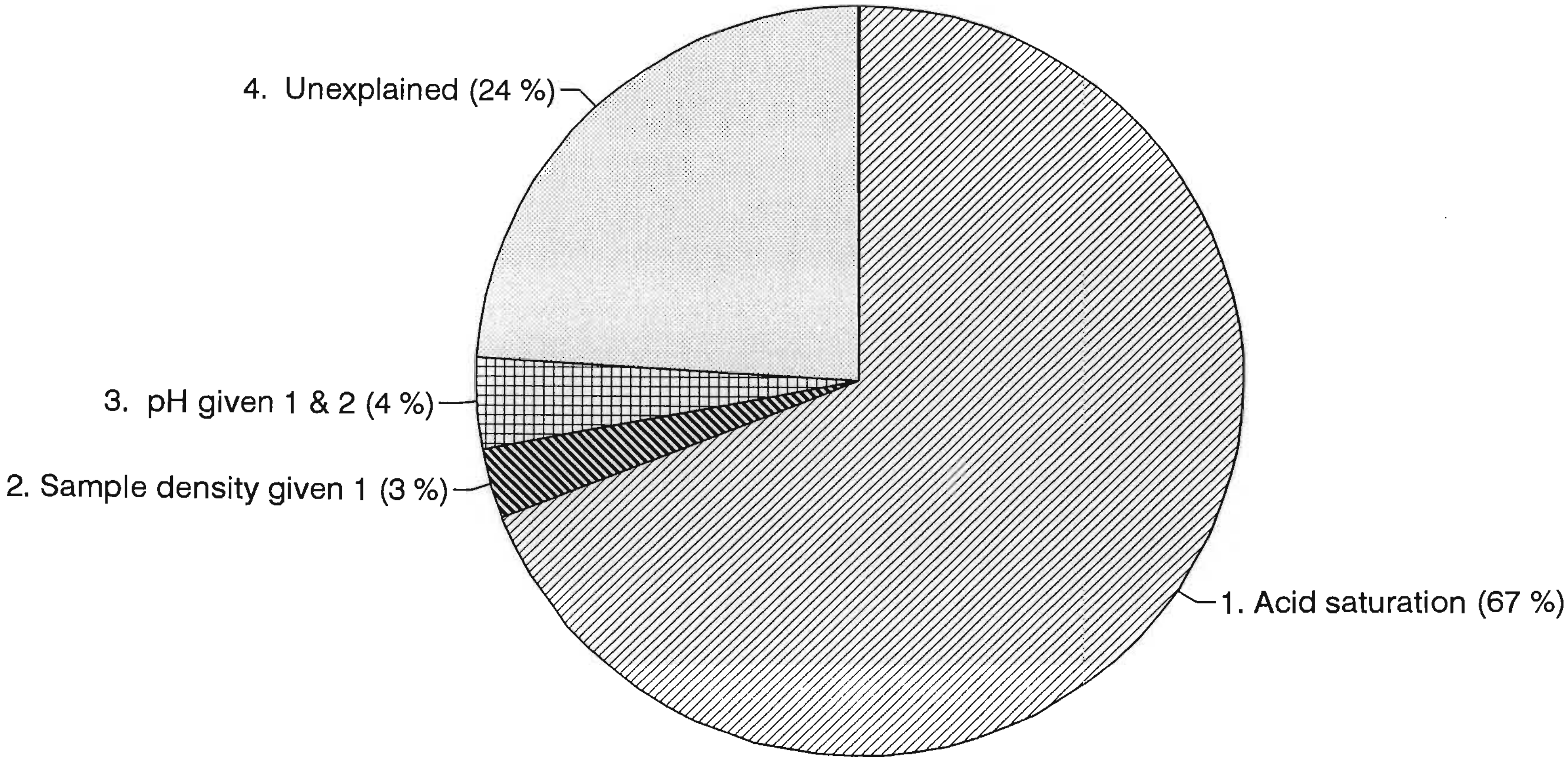

Figure 1 Soil analysis parameters affecting leaf Mn concentrations of cabbage at headform

Variables	Coefficients	t-values
Acid saturation	1.35	2.20*
Soil P	0.18	5.42***
Soil K	0.04	-3.15**
pH	-15.76	-3.37**

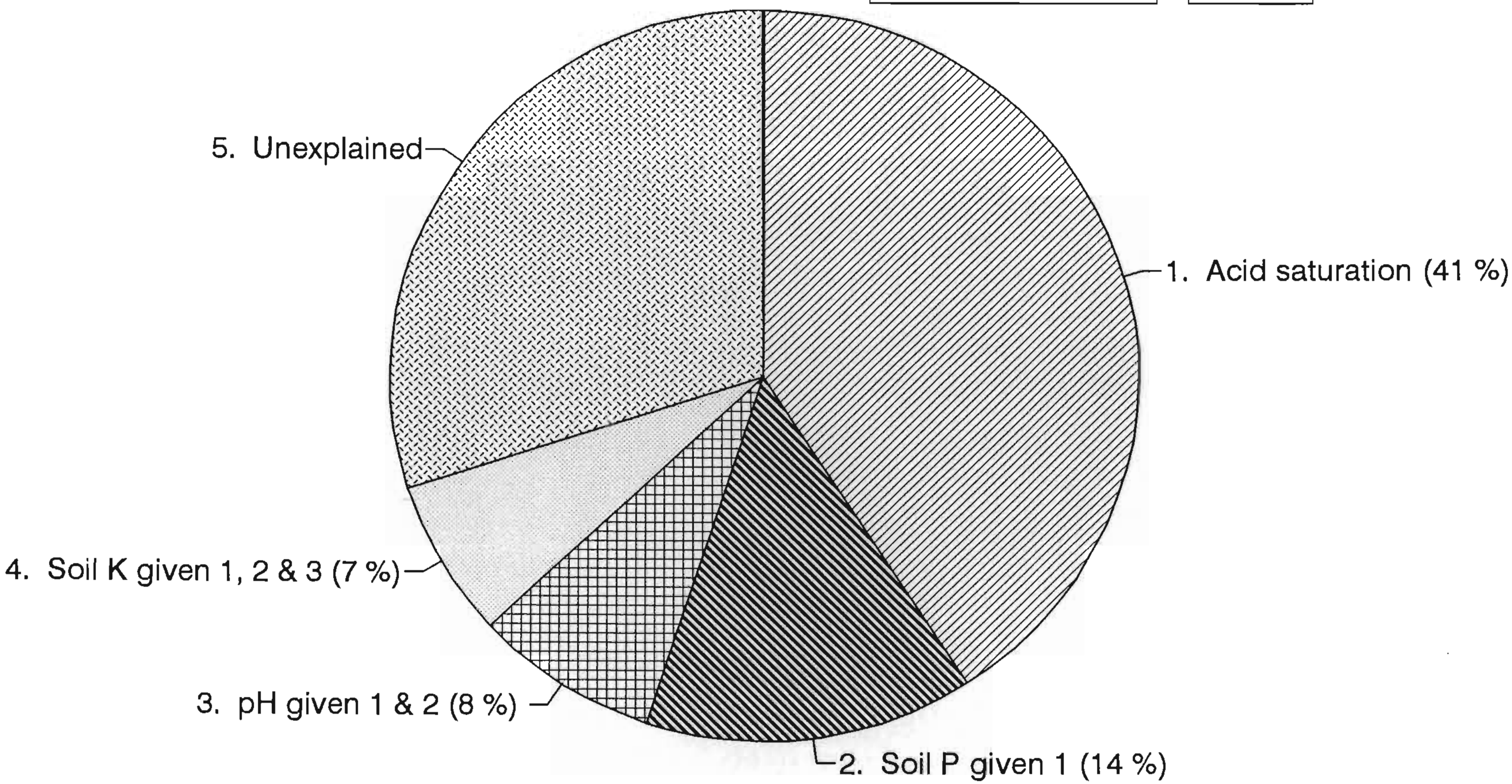

Figure 2 Soil analysis parameters affecting leaf Zn concentrations of cabbages at headform

3. LEAF NUTRIENT NORMS AND CROP REMOVAL FIGURES FOR CABBAGE IN THE UMLAAS RIVER VALLEY, KWAZULU-NATAL

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Abstract

Research on 59 cabbage crops identified deficient, adequate and high levels of nutrients at headform and harvest and generated crop removal figures for cabbage production in the Umlaas River Valley. A most recently mature (MRM) leaf at headform and a ⅛ head slice of a mature head at harvest were used as samples. Adequate nutrient levels of MRM leaf at headform were: N = 3.3 - 4.8 %, P = 0.32 - 0.55 %, K = 2.1 - 4.2 %, Ca = 1.3 - 2.5 %, Mg = 0.25 - 0.65 %, Mn = 15 - 100 mg kg^{-1}, Zn = 18 - 60 mg kg^{-1} and Cu = 4 - 100 mg kg^{-1}. Nutrient concentrations above or below adequate ranges resulted in lower yields. The ⅛ head slice of mature heads at harvest also generated nutrient norms as well as the following nutrient removals t^{-1} of fresh material: 1.9 kg N, 0.3 kg P, 2.03 kg K, 0.43 kg Ca, 0.19 kg Mg, 2.8 g Mn, 2.6 g Zn and 0.4 g Cu. The nutrient norms were developed for reliable identification of soil fertility problems and the removals for improved fertilizer recommendations.

Keywords : nutrient removals, cabbage, nitrogen, phosphorus, potassium, calcium, magnesium, manganese, zinc, copper, leaf concentrations

Introduction

During the hormone herbicide controversy in the Umlaas River Valley of KwaZulu-Natal from 1986 - 1991, there were allegations that incorrect fertilisation practises caused deformities on various crops (Smith pers. com.; c/o Lakehead University, Department of Biology, 955 Oliver Rd, Thunder Bay, Ontario P7B 5E1). However, in evaluating these allegations, it was difficult to ascertain whether a crop had deficient, adequate or excessive nutrient levels, or whether too much of a particular nutrient was applied as fertilizer. Limited research and much guesswork prevailed because available leaf nutrient norms and removal figures showed great variation according to soils, climate, country and fertilisation practices (Geraldson, Klacan & Lorenz, 1973; Greenwood, Cleaver, Turner, Hunt, Niendorf & Loquens, 1980 a, b & c.; Welch, Tyler & Ririe, 1985; Hochmuth, Maynard, Vavrina & Hanlon, 1991). Norms produced by Ankerman & Lange (undated) seemed the best available and were used by the Horticultural Science Department at the University of Natal. In 1991, Hochmuth *et al.* published norms for Florida which, according to our observations, appeared more appropriate for the Umlaas River Valley.

Similarly, nutrient removals for cabbage (*Brassica oleracea* L. var. *capitata* Alef.) were unspecific and showed a great range (Spencer, J., pers. com.; 6 Sanders Rd, Scottsville, Pietermaritzburg, 3201). Bornman, Ranwell, Venter & Vosloo (1989) estimated cabbage removals as 2 - 6 kg nitrogen (N), 0.3 - 0.9 kg phosphorus (P), 3 - 6 kg potassium (K) and 0.4 kg magnesium (Mg) t^{-1} fresh mass. In layman's terms, this meant that a 100 t ha^{-1} crop of cabbage would remove 200 - 600 kg N, 30 - 90 kg P and 300 - 600 kg K ha^{-1}. Work by Greenwood *et al.* (1980 a, b & c) reported NPK removals for summer cabbage as 211, 21 and 180 kg ha^{-1} respectively (Anon., 1980 - New NPK Predictor). Peck (1978) calculated removals ha^{-1} as P = 22, K = 152, calcium (Ca) = 157, Mg = 25, sulphur (S) = 67 (kg), zinc (Zn) = 0.17 and manganese (Mn) = 0.38 (mg kg^{-1}). Spencer (pers. com.) estimated NPK removals for cabbage at 4.4, 0.53 and 3.6 kg t^{-1} fresh mass, respectively.

These variations in leaf nutrient norms and crop removal figures caused farmers to doubt figures given by fertilizer representatives and could have led to previous erroneous interpretations of leaf samples and the application of incorrect amounts of fertilizer. To identify crop nutrient problems and establish correct fertilisation procedures, the development of local nutrient norms and removals for cabbage was clearly necessary.

Therefore, this study identified deficient, adequate and excessive leaf nutrient levels and established nutrient removal figures of cabbages for use in the Umlaas River Valley.

Procedures

Fifty nine cabbage crops were monitored by cabbage research in the Umlaas River Valley from June 1991 to July 1993 (§ 1). Methodology and discussion regarding the nature of the research programme are found in § 1. Samples of the most recently mature (MRM) leaf were taken at headform (Hochmuth *et al.*, 1991) and ⅛ headslice at maturity (Geraldson *et al.*, 1973) from monitor plots of each cabbage crop. Samples were analyzed according to the Analytical Methods Used in the Soil Science Laboratories at Cedara (1986). Samples were weighed, airdried at 75°C for 24 hr and weighed again to determine percentage dry matter. Thereafter the sample was rotary-milled to pass through a 40-mesh screen. The dry ash method with HCl was performed on Hunter's apparatus to determine leaf K, P, Ca, Mg, copper (Cu), Zn and Mn. Wet ashing with a block digester determined leaf N (Analytical Methods Used in the Soil Science Laboratories at Cedara, 1986). Average headmass, percentage marketable heads $plot^{-1}$ and plant population were used to calculate marketable yields ha^{-1}.

Frequency distributions of leaf nutrient concentrations at headform and harvest were established using frequency polygons and box and whisker plots (Statgraphics Version 5 Reference Manual, 1991). XY scatterplots of yield or average headmass versus each nutrient were used to identify deficient, adequate and high nutrient levels at headform and harvest. Hereafter, norms developed from yield versus nutrient concentration are called YIELD NORMS and norms from average headmass versus nutrient concentration are called HEADMASS NORMS. The following criteria were used for deficient, adequate and high nutrient levels at headform and harvest of HEADMASS NORMS: concentrations of each nutrient with an average headmass of > 2.5 kg were adequate; concentrations with an average headmass < 2.5 kg were regarded as deficient or high.

The mean yield for all crops monitored in the Umlaas River Valley was 56 t ha^{-1} (§ 1, Table 2). Nevertheless, yields of > 90 or ± 70 t ha^{-1} respectively, were regarded as good and average for the area. Yields limited to < 70 t ha^{-1} were suspected of having some type of limiting factor e.g., management or water stress, which could affect nutrient uptake and growth. Therefore, leaf concentrations with a calculated yield of 90 t ha^{-1} were adequate for

YIELD NORMS. Concentrations with related yields < 70 t ha^{-1} were regarded as deficient or high. A line joining the maximum yield or headmass at each concentration level produced a linear plateau model similar to § 1.

Cabbage crops monitored in this study had populations of 28 000 - 64 000 plants ha^{-1} and a large variation in average headmass was seen. This was due to plant population effects (Smith & Hapelt, 1984) and different management techniques. Smith and Hapelt (1984) increased plant populations of cabbages with resultant higher yields but smaller heads. Conversely, lower plant populations showed larger heads but lower yield ha^{-1}. YIELD NORMS were based on yield ha^{-1} and included variation due to plant population, marketable yield and headmass. Conversely, HEADMASS NORMS were based on larger heads found mostly on lower plant populations and did not take other factors into account. As such, YIELD NORMS provided a better estimate of leaf nutrient norms than HEADMASS NORMS. Therefore, YIELD NORMS presented in Table 1 and 2 were used in Table 3.

Crop removals were calculated from means of all nutrient concentrations in ⅛ head-samples with corresponding yields ≥ 70 t ha^{-1}.

Results

Fig. 1 and Fig. 2 show XY scatterplots of Mg at headform versus the average head mass and yield ha^{-1} respectively. These figures illustrate the methods used for assessing deficient, adequate and high levels of each nutrient at headform and harvest. This method was similar to the "boundary line" approach used by Webb (1972) but used visual estimation to determine maximum yield/head mass at specific concentrations of Mg in the leaf samples. A line, bisecting points denoting the maximum headmass or yield for each concentration, produced "boundary lines" at which maximum values for a given nutrient concentration could be identified. At concentrations of 0.33 - 0.55 % Mg, average headmass was > 2.5 kg. Also at concentrations < 0.32 % and > 0.55 % average headmass was < 2.5 kg (Fig. 1) hence these Mg concentrations were regarded as deficient or high respectively. Similarly in Fig. 2 we saw yields > 90 t ha^{-1} between 0.27 - 0.65 % Mg and yields below 70 t ha^{-1} at Mg concentrations < 0.25 % and > 0.7 % (i.e., deficient and high in Mg respectively).

Fig. 1 and Fig. 2 also showed differing yields or average headmass at the same leaf concentration, however this did not affect the accuracy of our norms and was expected using this model (Sumner, 1987). Variation in yield was due to factors such as soil, management, pests, diseases and water stress.

The frequency distribution (Table 1) showed the leaf nutrient concentrations between which 50 % of the recorded values lay. It was a useful indicator of leaf optima and always lay within the adequate ranges of YIELD and HEADMASS NORMS (Table 1 and 2).

Table 1 shows YIELD and HEADMASS NORMS for all measured elements. Slight differences were seen between the two sets of norms. YIELD NORMS were probably more accurate than HEADMASS NORMS because yield ha^{-1} took into account the plant population, average headmass and percentage marketable heads. Indeed, adequate leaf nutrient ranges of N, P, K, Ca and Cu in YIELD NORMS were ≤ HEADMASS NORMS thus showing better precision. However, adequate nutrient ranges for Mg, Mn and Zn were larger with YIELD than HEADMASS NORMS (Table 2). In Table 2, adequate leaf nutrient ranges of YIELD NORMS ≤ HEADMASS NORMS for all nutrients.

Table 3 compares norms used by other workers with those of this study. The Robinson (1983) norms represent the lower critical leaf concentrations while the Ankerman & Lange (undated) norms were averages. The Jenkin (pers. com.; Nitrochem (PTY) LTD, Box 45, Howick, 3290) and Hochmuth *et al.* (1991) norms represented an adequate range of nutrient concentration and, as such, were better for comparative purposes. The Jenkin norms for cabbages in Natal, showed the best similarity with Umlaas norms (Table 3). Only the upper critical range of Ca was higher than Umlaas norms. The Hochmuth *et al.* (1991) norms also compared favourably with Umlaas norms with upper concentrations of N slightly higher than Umlaas and other norms. The Ankerman & Lange (undated) norms, even as averages were comparable to Umlaas norms for Ca, Mg, Mn, Zn and Cu, but low for N and high for P and K (higher than all the other norms, Umlaas norms included). Umlaas harvest norms were included in Table 3, but not compared because a ⅛ headslice of a cabbage head was sampled, not a mature or MRM leaf.

Nutrient removals were expressed as kg t^{-1} fresh mass of cabbage with average dry matter percentage of 7.21 % (Table 4). Table 4 shows that a target yield of 100 t ha^{-1} removes 190 kg N, 30 kg P, 203 kg K, 43 kg Ca, 19 kg Mg, 0.28 kg Mn, 0.26 kg Zn and 0.04 kg Cu ha^{-1} in the Umlaas River Valley.

Discussion

Farmers in the Umlaas River Valley now have access to cabbage leaf norms and removal figures developed in their area. Uncertainty regarding excessive or low leaf nutrient levels and the amounts of nutrient removed by a cabbage crop, are now a thing of the past. Cabbage research conducted in the Umlaas River Valley identified adequate levels of nutrients in MRM leaves at headform and ⅛ head slice samples at harvest. Nutrient concentrations above or below the adequate ranges were associated with lower yields. These ranges were also very similar to those used by some advisors in KwaZulu-Natal and other researchers. This study also estimated cabbage nutrient removals for use in fertiliser recommendations in the Umlaas River Valley. These norms, sampling techniques and removals for cabbage could also be used in other areas of KwaZulu-Natal and South Africa.

This study emphasized the importance of this project as an extension exercise. Farmers in the Umlaas River Valley had previously been accused of overfertilisation of their vegetable crops (Wild, pers. com.; Box 85, Umlaas Rd, 3730). Although some farmers applied > 20 t ha^{-1} of chicken manure per crop (Holcroft, Smith & Dicks, 1991) and excessive amounts of fertiliser (Askew, unpublished data), sometimes, it was fertiliser representatives who told farmers to apply higher fertiliser rates (Carr-Hartley, pers. com.; Box 154, Umlaas Rd, 3730) in the early 1980's. When faced with these accusations, farmers asked for information regarding crop removals and leaf nutrient norms. In reply, they were shown leaf nutrient norms and removal figures which varied greatly, depending on the source of information. Understandably, farmers in the Umlaas River Valley desired more definite figures for assessment of soil nutrient uptake and crop nutrient needs. This study has generated definite and specific cabbage leaf nutrient norms and removals for use in the Umlaas River Valley. This knowledge resulted in improved fertilisation practices on some farms and identification and correction of soil problems where necessary (§ 2 & 4), and is recommended for future use.

Cabbage leaf or head nutrient concentrations within the Umlaas norms (Table 1, 2 & 3) realised yields ≥ 90 t ha^{-1} while those above or below the adequate levels at headform and harvest (Tables 1, 2 & 3) were associated with yields below 70 t ha^{-1}. Thus this study has identified adequate element ranges for optimum cabbage yields and deficient and toxic (yield reducing) levels of each element. Lower critical leaf concentrations as measured by Robinson (1983) were very similar to the Umlaas lower values (Table 3). Greenwood *et al.* (1980 a, b & c) showed increased yield and leaf N concentrations with increased N application up to a maximum and thereafter a decline with further applications. Excessive soil nutrient levels result in high leaf concentrations for that element and a decrease in yield (Baker, 1977; Sumner, 1987; Kidder, 1993).

This study recommends the use of Umlaas norms in the Umlaas River Valley and authenticates the use of Jenkin norms in Natal. Alternately, the Hochmuth *et al.* (1991) adequate values and Robinson (1983) lower critical leaf concentrations were acceptable for the Umlaas River Valley. Jenkin norms (Table 3) were a combination of international norms, local trials and observations in Natal collected and used by Mr B Jenkin (Nitrochem), an agronomist in Natal. The only real differences in Umlaas and Jenkin norms was the higher upper level for Ca (Jenkin norms, Table 3) and the upper critical level for Mn (Umlaas norms, Table 3). The acid soils, Mn toxicity problems and low soil Ca levels (§ 1 & 2) in the Umlaas River Valley as compared with the rest of Natal, could explain these discrepancies. Previous studies show that cabbages can tolerate leaf Mn ≤ 100 mg kg^{-1} and produce yields > 100 t ha^{-1} with leaf Mn ≤ 100 mg kg^{-1} (§ 2). However, leaf Mn in a MRM leaf at headform above 100 mg kg^{-1} resulted in a yield decline (§ 2).

Cabbage nutrient removals presented in Table 4 were more specific than those of Bornman *et al.* (1989), lower than Spencer (pers. com.), similar to Greenwood *et al.* (1980) and variable in comparison to Peck (1978). It was notable that a 100 t^{-1} crop of cabbage in the Umlaas River Valley removed 43 kg of Ca and 19 kg of Mg ha^{-1}. Peck (1978) reported removals of 157 and 25 kg ha^{-1} for Ca and Mg respectively. Little attention was previously given to Ca and Mg removal in normal fertilisation practises in the Umlaas River Valley.

This changed during our work in the area with careful attention being given to Ca and Mg amounts in fertiliser programmes.

We recommend yearly analysis of vegetable production land and the use of crop removals to maintain soil nutrient status at the critical values reported in § 1. Most vegetable farmers in the Umlaas River Valley submit soil samples once a year for analysis at the Soil Physics Laboratory at Cedara. This enables adequate evaluation of soil fertility status in spite of intensive vegetable production. Costs of analysis, time consumed while awaiting results and little change in soil fertility status over one year make soil analysis before each crop unnecessary, unattractive and uneconomical. To fit in with this system our research recommends the soil critical values (identified in § 1) as cut-off levels above which no fertilizer is applied. Removals for the previous crop e.g., cabbage would be used to restore the soils to the critical values. Thus critical values would be maintained by the addition of removals from the previous crop, until the soils were tested again. This concept is similar to the sufficiency approach mentioned in American literature, and is also cheaper and more environmentally friendly (Olson, Anderson, Frank, Grabouski, Rehm & Shapiro, 1987).

The sampling methods and analytical laboratory used in this study are farmer friendly for cabbage growers in the Umlaas River Valley and other areas of KwaZulu-Natal. For suspected nutrient deficiencies and toxicities of cabbages, a collection of ten MRM leaves at headform or ⅛ headslices of the mature affected cabbages are recommended. These samples should be placed in a plastic bag, and kept cool for immediate delivery to the Soil Physics Laboratory at Cedara. The norms generated by this study or Jenkin Norms can be used to evaluate element concentrations and identify problems.

In conclusion this study supplied vegetable growers in the Umlaas River Valley with locally developed cabbage leaf norms and removal figures. These could be used for the reliable identification of nutrient deficiencies and toxicities in cabbage and improvement of overall fertilization practices. For future problems, the study also recommended a simple sampling method and use of the Soil Physics Laboratory at Cedara (or the same analytical techniques), for reliable analysis results and interpretation. The norms and removals generated in this study could also be suitable for other areas of KwaZulu-Natal and possibly, South Africa.

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Table 1 Cabbage leaf nutrient frequency distributions for YIELD and HEADMASS NORMS at headform in the Umlaas River Valley, 1991 - 1993

	Frequency Distribution (of 50 % of values)	NORMS					
		HEADMASS			YIELD		
		Deficient <	Adequate	High >	Deficient <	Adequate	High >
Leaf nutrient							
N (%)	3.9 - 4.5	3.5	3.5 - 4.8	5	3.3	3.3 - 4.8	5
P (%)	0.4 - 0.5	0.36	0.36 - 0.7	0.7	0.3	0.32 - 0.55	0.65
K (%)	2.7 - 3.4	2	2.1 - 4.6	5	2	2.1 - 4.2	4.5
Ca (%)	1.45 - 1.75	1.2	1.2 - 2.7	2.7	1.2	1.3 - 2.5	2.5
Mg (%)	0.4 - 0.53	0.32	0.33 - 0.55	0.55	0.25	0.27 - 0.65	0.7
Mn (mg kg^{-1})	40 - 100	20	20 - 100	100	15	15 - 100	100
Zn (mg kg^{-1})	25 - 42	15	18 - 50	60	15	18 - 60	60
Cu (mg kg^{-1})	4 - 8	3	4 - 12	15	3	4 - 10	15

Table 2 Cabbage leaf nutrient frequency distributions for YIELD and HEADMASS NORMS at harvest in the Umlaas River Valley, 1991 - 1993

	Frequency Distribution (of 50 % of values)	NORMS					
		HEADMASS			YIELD		
		Deficient <	Adequate	High >	Deficient <	Adequate	High >
Leaf nutrient							
N (%)	2.4 - 2.9	1.5	1.5 - 4	4	1.5	1.5 - 3.3	3.5
P (%)	0.36 - 0.42	0.2	0.2 - 0.65	0.7	0.3	0.3 - 0.55	0.6
K (%)	2.6 - 3.0	1.8	1.8 - 4	4	2	2.2 - 3.5	4
Ca (%)	0.46 - 0.59	0.4	0.4 - 1.15	1.2	0.35	0.35 - 0.75	0.8
Mg (%)	0.24 - 0.27	0.18	0.18 - 0.3	0.3	0.18	0.18 - 0.3	0.3
Mn (mg kg^{-1})	20 - 40	20	20 - 70	70	20	20 - 70	70
Zn (mg kg^{-1})	22 - 37	18	18 - 50	50	18	18 - 50	50
Cu (mg kg^{-1})	4 - 6	2	2 - 8	10	2.5	3 - 8	10

Table 3 Comparisons of leaf nutrient norms for cabbage developed in this study and other workers

	Norms					
					This study	
	Robinson[1] (1983)	Jenkin[2] (pers. comm)	Hochmuth[3] *et al.* (1991)	Ankerman[4] & Lange	Headform	Harvest
Nutrient						
N (%)	3.5	3 - 4	3 - 6	3.3	3.3 - 4.8	1.5 - 3.3
P (%)	0.35	0.3 - 0.5	0.3 - 0.6	0.63	0.32 - 0.55	0.3 - 0.55
K (%)	2.0	3 - 4	2 - 4	4.8	2.1 - 4.2	2.2 - 3.5
Ca (%)		1.5 - 3.5	1.5 - 2	2.1	1.3 - 2.5	0.35 - 0.75
Mg (%)	0.2	0.25 - 0.45	0.25 - 0.60	0.36	0.25 - 0.65	0.18 - 0.3
Mn (mg kg^{-1})	20	25 - 50	20 - 40	70	15 - 100	20 - 70
Zn (mg kg^{-1})	20	20 - 30	30 - 50	38	18 - 60	18 - 50
Cu (mg kg^{-1})	5	5 - 10	3 - 7	8	4 - 10	3 - 8

Lower critical leaf concentration of mature leaf

Head half formed, young wrapper leaf

8 weeks after transplanting, MRM leaf

Average value of cabbage leaf

Table 4 Nutrient removals for cabbage crops in the Umlaas River Valley, KwaZulu-Natal (based on 7.21 % DM)

Nutrient	Removal (t^{-1} fresh mass)
N	1.90 kg t^{-1}
P	0.30 kg t^{-1}
K	2.03 kg t^{-1}
Ca	0.43 kg t^{-1}
Mg	0.19 kg t^{-1}
Mn	2.8 g t^{-1}
Zn	2.6 g t^{-1}
Cu	0.4 g t^{-1}

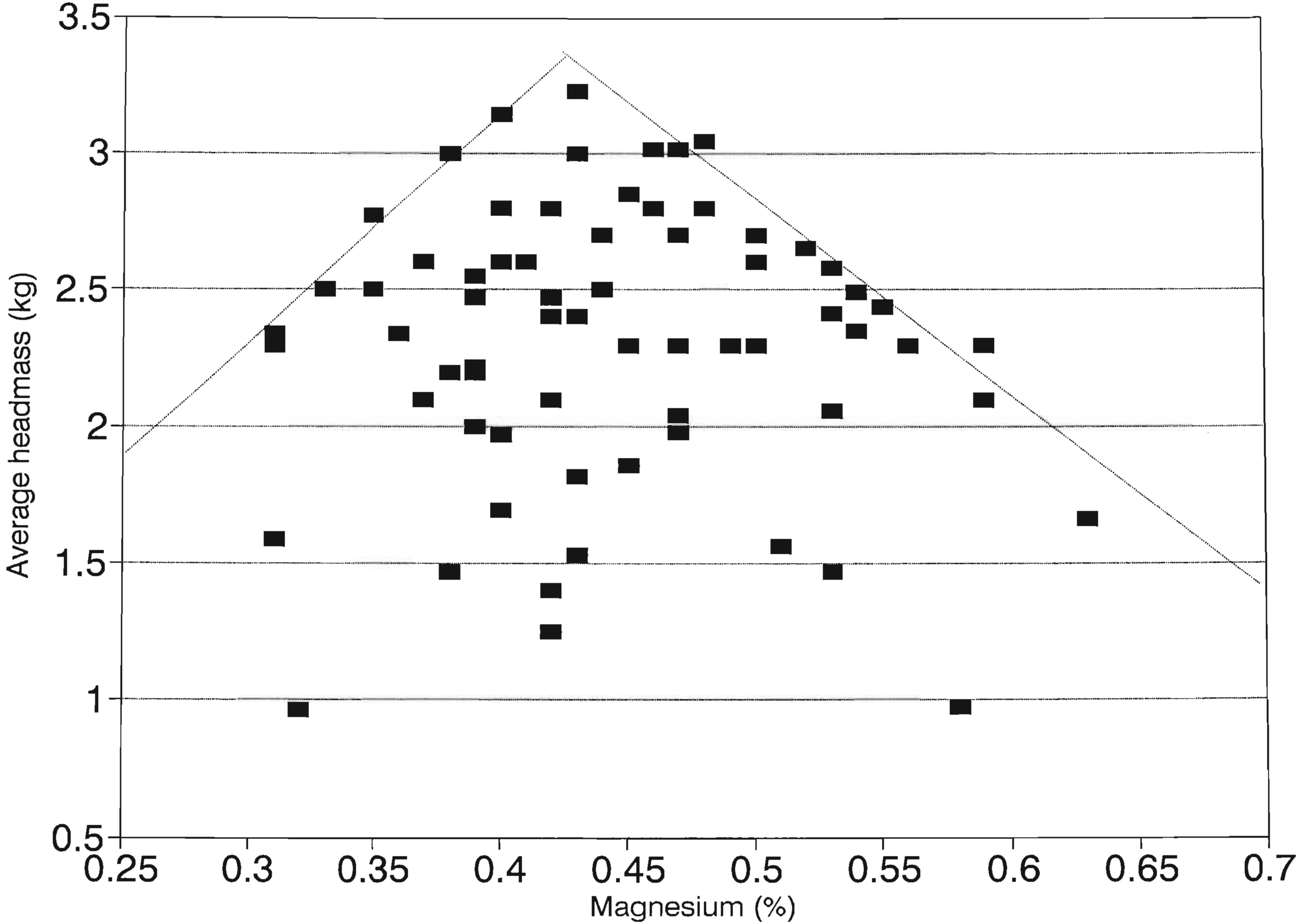

Figure 1 XY scatterplot of Mg leaf concentrations at headform and average cabbage headmass

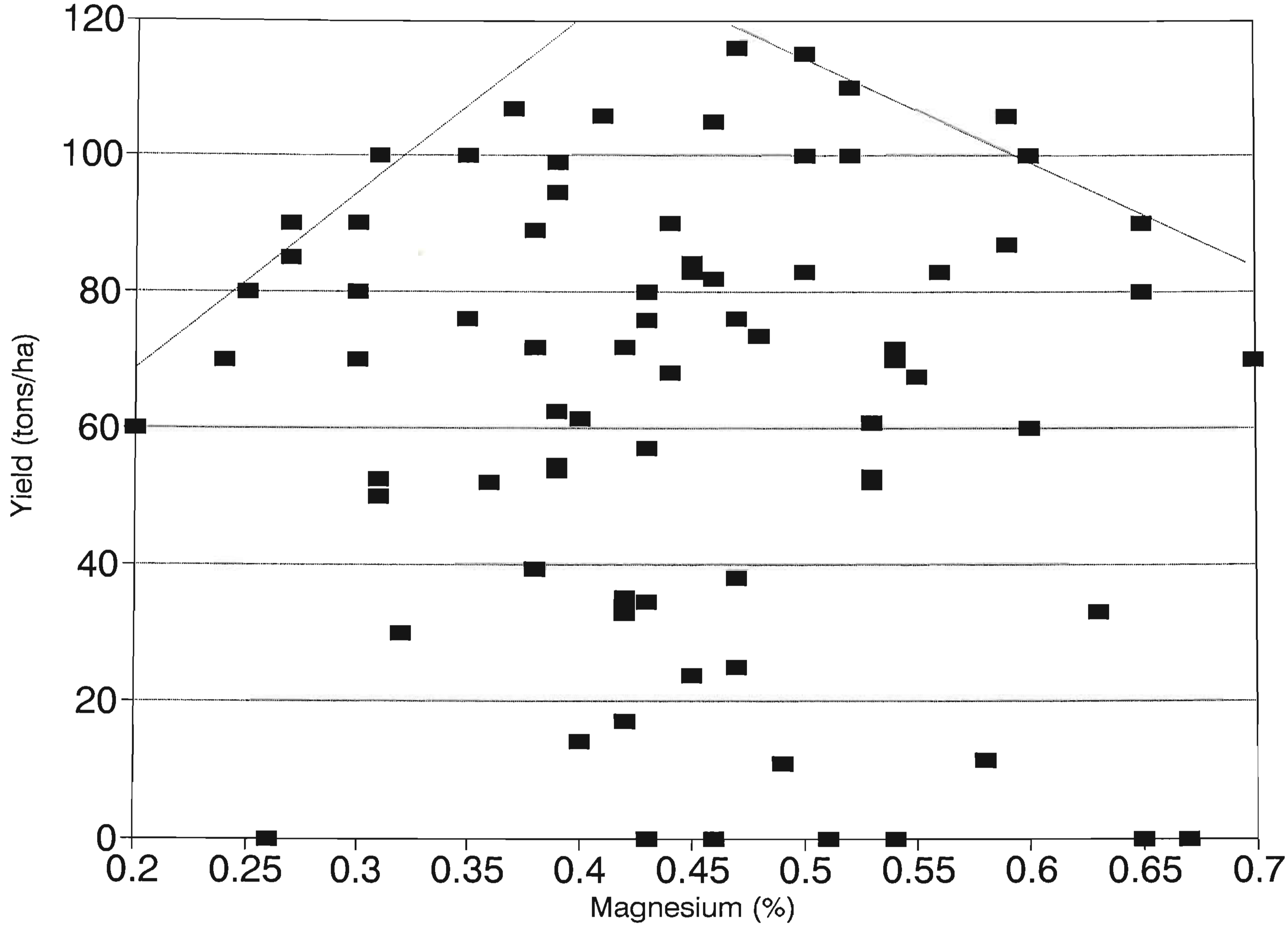

Figure 2 XY scatterplot of Mg concentrations in a 1/8 headslice at harvest and cabbage yields

4. A STUDY OF FERTILIZATION PRACTICES ON CABBAGE IN THE UMLAAS RIVER VALLEY, KWAZULU-NATAL

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Abstract

A research and extension project identified limiting factors in fertilization practices for cabbage production in the Umlaas River Valley, KwaZulu-Natal. Most farmers supplied sufficient ($\pm$ 200kg) N to cabbage crops but used incorrect pre- and postplant proportions (¼ and ¾) for top yields. For maximum yields, ⅔ of the total N should be applied preplant and ⅓ at 4 - 6 weeks. Topdressings of N should be applied once only and not split, as is common practise in the area. Application of P on cabbage crops was proportional to soil requirements but was generally excessive. Sufficient quantities of K were applied but scant attention was given to K, Ca and Mg requirements from soil analysis. Input costs could be decreased and high yields maintained, if soils were fertilized up to critical values and no further nutrients added when soil test values exceeded critical values. Fertilization was not based on soil analysis results and few farmers supplied lime to their soils, in spite of soil acidity problems (this was partially because lime was only recommended above soil acid saturation of 5 %). Most farmers used the more acidifying NH_4 containing fertilisers in preplant applications. We recommend using more NO_3 based fertilisers to slow down acidification or at the least, corrective applications of lime. Some farmers in the Umlaas River Valley still do not perceive soil analysis results to be that crucial for achieving optimum yields, good soil fertility and lower input costs.

Keywords: nitrogen, phosphorus, potassium, calcium, magnesium, fertilization, topdress, lime, critical soil values

Introduction

The Umlaas River Valley was the centre of the hormone herbicide controversy in KwaZulu-Natal where many allegations were made concerning the causes of vegetable crop deformities. An extension and research project conducted in the Umlaas River Valley from 1991 to 1993 monitored all aspects of vegetable production. To identify factors limiting cabbage production a large data base of information from 59 different cabbage crops was generated. This resulted in the establishment of critical soil values for optimum yields (§ 1), identified the presence of a soil acidity complex affecting yields (§ 2) and authenticated leaf nutrient norms and crop removal figures (§ 3). § 1, 2 & 3 showed that all soil parameters had considerable effects on cabbage yields. The types and amounts of fertilizers applied to soils affect soil nutrient status (Tisdale, Nelson & Beaton, 1990), soil acidity (Fey, Manson & Schutte, 1990) and yields (Hochmuth, Hanlon, Hochmuth, Kidder & Hensel, 1993). Therefore all data regarding fertilizer inputs were recorded and used in this paper to discuss fertilization practices of the Umlaas River Valley farmers in the light of § 1, 2 & 3, and recommendations made by the Soil Physics Laboratory at the Agricultural Development Institute at Cedara (Fertrec).

Most farmers in the Umlaas River Valley make use of the Soil Physics Laboratory at (Fertrec) for soil analysis. At present Fertrec recommends 200 kg nitrogen (N) ha^{-1} for cabbage (*Brassica oleracea* L. var. *capitata* Alef.) production (Smith & Hapelt, 1984; Manson, Milborrow, Miles, Farina & Johnston, 1993). This amount of N seems consistent with N recommendations in other research. Greenwood, Cleaver, Turner, Hunt, Niendorf & Loquens (1980 b) recommended 182 kg N ha^{-1} for optimum yields of summer cabbage. Csizinszky & Schuster (1993) observed higher yields for spring and fall cabbage at 205 - 260 kg N ha^{-1}. Zebarth, Freyman & Kowalenko (1991) reported a positive yield response up to 500 kg ha^{-1} for N, but that percentage recovery was lower at the higher rates ($\pm$ 30 % lost at 500 kg ha^{-1}). Anon. (1984) recommended 150 - 250 kg of N ha^{-1} (MAFF Recommended standard rates) in the UK. Cabbages also respond to top dressings of N. Smith, Demchak & Ferretti (1990) reported highest yields with banding and sidedressing of N while Wiedenfeld (1986) observed higher cabbage yields with a preplant application of N when conditions were cool and dry, or with slow release fertilizers or multiple dressings when

conditions were wet and hot. Smith & Hapelt (1984) tried many different combinations of N and different topdressing times in KwaZulu-Natal and found that N applied ⅔ preplant and ⅓ at four weeks produced the highest cabbage yields.
Phosphorus (P) recommendations for cabbages vary according to residual P in soil analysis (Peck, MacDonald & Hemmat, 1987). Fertrec determines P requirements according to Manson *et al.* (1993):

$$\text{P recommendations (kg ha}^{-1}) = (\text{Optimum P value - soil P}) \times \text{PRF}.$$

where PRF is the amount of P needed to raise the soil for a given sample density by 1 mg l^{-1}. Present Fertrec optimum values are 27 - 50 mg l^{-1} for high clay to sandy soils respectively. Fertrec always recommends a minimum of 40 kg P ha^{-1} unless soils exceed 120 mg l^{-1} of P. Hochmuth *et al.* (1993) consider soil P at 31 - 60 mg kg^{-1} as high and > 60 mg kg^{-1} as very high on Florida soils. Further application of P on soils testing high and very high for P showed no crop response, therefore Hochmuth *et al.* (1993) recommend no P above 30 mg kg^{-1} of soil. Work by Greenwood *et al.* (1980 a) resulted in P response values in the New NPK Predictor and showed little response to P application when soil P values exceeded 25 mg l^{-1} (Anon., 1984).

As with P, potassium (K) fertilization should be adjusted to supplement residual soil K, supplying enough for cabbage demands. Fertrec determine K requirements according to the formula:

$$\text{Recommended K (kg ha}^{-1}) = (\text{Optimum K - soil K}) \times 2.5$$ (Manson *et al.*, 1993).

Optimum K for cabbages in KwaZulu-Natal is 200 mg l^{-1} (Manson *et al.*, 1993). With K for cabbage at 200 mg l^{-1}, soils with $\geq$ 100 mg l^{-1} of K would require $\geq$ 250 kg of K ha^{-1}. No K is recommended for cabbages when soil K exceeds 200 mg l^{-1} (Manson *et al.*, 1993). The New NPK Predictor showed no cabbage yield response above 150 mg l^{-1} of soil K (Anon., 1984) and Hochmuth *et al.* (1993) regarded soil K values of 61 - 125 and > 125 mg kg^{-1} as high and very high respectively. Hochmuth *et al.* (1993) also did not recommend the application of any K when soils tested high or very high for K.

Fertrec (Manson *et al.*, 1993) made no quantitative recommendation to correct low levels of calcium (Ca) and magnesium (Mg) in the soil, as these were associated with acid soils and could be corrected by liming. They recommended at least 50 mg l^{-1} of Mg in the soil and a K:Mg ratio less than 4:1. Sulphur (S) at 100 kg ha^{-1} was also recommended prior to establishment of cabbage seedlings.

This paper examines actual fertilisation practices on all cabbage crops monitored during this research and extension project and makes speculations regarding fertilizer effects on soil parameters and yields. It also compares farmer practices with those recommended by Fertrec. As part of the extension programme, this study identified inappropriate fertilization practices in the valley and made the necessary corrective recommendations.

Procedures

Fifty-nine cabbage crops were monitored in the Umlaas River Valley from June 1991 to July 1993 (§ 1). Soil samples were taken at headform and analyzed by the Soils Physics Laboratory at Cedara according to Analytical Methods Used in the Soil Science Laboratories at Cedara (1986)(§ 1). Yields ha^{-1} were estimated (§ 1, 2 & 3) and the type and amounts of fertiliser applied were recorded by the farmer. The element breakdown of each fertilizer was calculated from its description e.g., 2:3:2 (30), where total nutrients (N:P:K) represent 30 % of the total mass, present in a 2:3:2 ratio respectively. Amounts of N, P & K applied before transplanting (preplant), topdressed (postplant) and totals and total Ca, Mg and S were calculated from these records. Means and ranges of each above-mentioned element were calculated and frequency histograms used to show the percentage of cabbage crops receiving "x" amount of each element. Multiple stepwise regression and correlation analysis examined relationships between yield and soil nutrient status, versus amounts of N, P, K, Ca, Mg and S applied in the fertilizer programmes.

Results

Table 1 shows an average of 61 kg ha^{-1} N applied preplant on cabbages in the Umlaas River Valley. Preplant applications of N were low; 56 % of crops received < 50 kg ha^{-1}, 27 % got 50 - 100 kg ha^{-1} and only 12 % got 100 - 150 kg ha^{-1} (Fig. 1). More N was applied postplant than preplant (averages = 137 and 61 kg ha^{-1} respectively, Table 1) with 73 % of cabbage crops receiving 100 - 250 kg ha^{-1} of N after transplanting (Fig. 1). The average total amount of N supplied on 59 cabbage crops in the Umlaas River Valley was 198 kg ha^{-1} (Table 1). The CV of total N was the lowest of all parameters studied in Table 1, and Fig. 1 showed 83 % of all crops received 150 - 250 kg N ha^{-1}. This shows that most farmers in the Umlaas River Valley apply ± 200 kg of N ha^{-1} for cabbages which is applied ¼ preplant and ¾ after transplanting. Correlations between total, preplant and postplant N and sample density were -0.12, -2.8 ($P \leq 0.05$) and 0.11 respectively. This shows that sample density or soil clay percentage were not factors determining amounts or ratios of N applied.

The application of P occurred mostly before planting (Table 1). An average of 73 kg P ha^{-1} was applied preplant and 4 kg postplant, giving an average of 77 kg P ha^{-1} in total (Table 1). Total P applied varied from 13 - 161 kg ha^{-1} showing differing practices with high or low soil P and sandy to clay soils. Many of the crops (49 %) received 50 - 100 kg P ha^{-1} in total and 27 % received > 100 kg ha^{-1}. This was excessive considering the high soil P levels (mean = 92 mg l^{-1}) in the Umlaas River Valley (§ 1).

The amount of K applied preplant varied from 0 - 380 kg ha^{-1} (Table 1) but the average was low at 79 kg ha^{-1} (Table 1). Very little K was applied postplant (average = 30 kg ha^{-1}, Table 1) with 108 kg K ha^{-1} being the mean total applied per crop (Table 1). Figure 3 corroborated these data showing that most crops (44 %) received 50 - 100 kg of K ha^{-1} preplant and 64 % got < 50 kg ha^{-1} postplant (Fig. 3). Figure 3 also shows that about half the crops in the Umlaas River Valley received an average of < 100 kg of K ha^{-1}. The other half received > 100 kg ha^{-1} on average, with most applied preplant (Table 1).

Many of the cabbage crops in the Umlaas River Valley (39 %) received < 50 kg of Ca ha^{-1} (Fig. 4). This was supplied as Superphosphate or a conventional N:P:K fertiliser such as 2:3:2:(30). Some crops (34 %) received < 50 - 100 kg of Ca ha^{-1} while 20 % of the crops were limed, thus getting 200 - 500 kg of Ca ha^{-1} (Fig. 4). The average amount of Ca (121 kg ha^{-1}) applied per crop in the Umlaas River Valley in Table 1 is misleading as indicated by the high SE (21.22) and CV (135 %). This average is not representative of the true Ca applications of all farmers because of the crops receiving lime (Fig. 4). Farmers who applied lime, supplied an average ≥ 200 kg of Ca ha^{-1} (Fig. 4) and sometimes as much as 968 kg ha^{-1} (Table 1).

Table 1 (average = 22 kg ha^{-1}) and Figure 4 show that little Mg was applied, with 92 % of crops receiving less than 50 kg of Mg ha^{-1}. § 3 shows cabbage nutrient removals for a 100 t ha^{-1} crop as 19 kg. Thus, the average Mg supplied ha^{-1} slightly exceeds the crop demand regardless of soil nutrient status.

Figure 4 showed that 61 % of cabbage crops received < 50 kg of S ha^{-1} with 46 % getting 50 - 200 kg ha^{-1}. The average amount of S supplied ha^{-1} was 67 kg (Table 1). Ca, Mg and S were mostly applied preplant.

Thirty nine percent of all cabbage crops monitored in the Umlaas River Valley from June 1991 to July 1993 were fertilised with a preplant application of 2:3:4(30) (Table 2). This was applied at an average rate of 696 kg ha^{-1}. 2:3:2(22) was applied on 16 % of monitored crops at a high average of 945 kg ha^{-1} (Table 2). Superphosphate (8.3) was applied at an average rate of 960 kg ha^{-1} on 10 % of all cabbage crops monitored (Table 2). The amounts of P applied ha^{-1} by these types of fertilisers were 70, 121 and 80 kg for 2:3:4(30), 2:3:2(22) and Superphosphate (8.3) respectively. Given an average soil P level of 92 mg l^{-1} for all cabbage crops monitored, these amounts of applied P were regarded as high.

Table 2 showed that 32 % of the cabbage monitor crops received either 5:1:5(36), AMP(16), MAP(33), KNO_3(50), ASN(27), KCl(50), LAN(28) or a 5:3:2(23) Agrofert mix. Most of the preplant fertilisation occurred in one form, e.g., 2:3:4(30), however, 7 % of crops received a mix of 2:3:2(22) and LAN(27), 4 % received Supers(8.3) and 2:3:4(30) and 4 % a mixture of AMP(16), ASN(27) and KCl(50).

The popularity of each fertiliser with each farmer exhibited a similar pattern to that shown in Table 2. Six farmers applied 2:3:4(30) as standard practice, with one of these mixing in Supers(8.3). Three farmers used 2:3:2(22)(one mixed in LAN(27)), three applied AMP(one mixing with ASN(27) and KCl(50)), another three used Supers(8.3)(one mixed with 2:3:4(30) and another with KNO_3(50)) while 5:1:5(36) was used by only two farmers.

Lime was only applied by three farmers on five crops, showing poor practises considering the acid soils of the Umlaas River Valley (§ 1). Only two farmers spread organic fertiliser on three cabbage crops. Application rates varied from 10 - 20 t ha^{-1} of chicken manure and 10 t ha^{-1} of pig manure. Furthermore only two farmers banded some of their preplant fertiliser. Of all the crops monitored 93 % of the fertiliser was broadcast before transplanting.

Table 3 shows 45 % of crops topdressed with LAN(28). LAN(28) was applied at an average rate of 372 kg ha^{-1} between weeks two and seven (Table 3). ASN(27) and 1:0:1(36) each supplied 23 % of cabbage crops with topdressed nutrients (Table 3). Average amounts applied ha^{-1} were 456 and 388 kg respectively and time of application varied from two to six weeks (Table 3). Only a small proportion of crops was topdressed with 5:1:5(36) (4 %), Agrofert (4 %) and 4:1:1(41) (1 %) but average amounts applied were high (430 - 600 kg ha^{-1}) (Table 3). This corroborates the high N levels observed in postplant applications in Table 1.

Most of the cabbage crops (62 %) were topdressed once only with one type of fertiliser (e.g., LAN(28)). However, 4 % of crops received split applications of LAN(28), 11 % received split applications of ASN(27) and 23 % received split applications of LAN(28) with ASN(27), 5:1:5(36) or 1:0:1(36). Most split applications were made at 2 - 3 weeks and 4 - 6 weeks respectively.

As seen with preplant fertiliser application, farmer fertiliser preference and use showed similar proportions to actual use in 59 cabbage crops (Table 3). 40 % of farmers used LAN(28), 25 % used ASN(27), 20 % used 1:0:1(36) and 5 % each used 5:1:5(36), Agrofert and 4:1:1(41). Five farmers topdressed with one fertiliser, once only. Two farmers supplied split applications of LAN(28), three used split applications of ASN(27) and three applied splits of LAN(28) with either ASN(27), 5:1:5(36) or 1:0:1(36).

Correlations analysis examined relationships between total nutrients supplied and soil nutrient status of that particular crop. This shows that most farmers gave little attention to soil nutrient status and applied a standard fertiliser programme. There was a low yet significant correlation ($P \leq 0.05$) between total applied N and soil pH ($R = -0.27^*$). This could show acidifying effects of NH_4 containing N fertilisers. Correlation between total applied P and soil P was very highly significant (R = -0.42***) indicating some grower attention to soil P levels. Total applied K had little correlation (R = - 0.03) to soil K levels, indicating a standard fertiliser programme regardless of soil K. It was notable that total applied K had an average yet very highly significant effect on soil Ca and Mg (R = -0.42*** and R = - 0.42***, respectively). This could indicate a soil response to applied K through Ca and Mg displacement from the clay particle. There was little correlation between total applied Ca and Mg and soil Ca and Mg (R = -0.16 and -0.11 respectively). There was also no correlation between total applied S and soil organic carbon, indicating little attention to soil and crop sulphur requirements. A very strong negative correlation, e.g., R = -0.80 would indicate fertilisation practises in keeping with soil nutrient levels. One or two farmers in the Umlaas River Valley follow strict soil analysis procedures and fertilise accordingly. However, most of the growers paid little attention to regular soil analysis and soil nutrient status and fertilised with a standard programme on all lands.

Multiple stepwise regression was conducted to determine possible effects of applied nutrients on yield. Total N applied was the only parameter fitting the chosen model with significant results and could account for 13 % (i.e., R^2 = 0.13) of the yield variation (t-value = - 2.30*). Total N was positively correlated to yield (R = 0.36***) with increasing yields at high levels of applied N.

Anova comparing yields with different types of preplant and topdressed fertilisers (e.g., 2:3:4(30)) showed no significant effects of fertiliser type on yield.

Discussion

This study generated some interesting facts regarding the fertilization of cabbages in the Umlaas River Valley. Most farmers supplied enough N to cabbage crops but used incorrect pre- and postplant proportions for top yields. For maximum yields, ⅔ of the total N should be applied preplant and ⅓ at 4 - 6 weeks (Smith & Hapelt, 1984). Topdressings of N should be applied once only and not split, as is common practise in the area. Application of P on cabbage crops was proportional to soil requirements but was generally excessive. Input costs could be decreased and high yields maintained if practices were based on soil analysis results.

Sufficient quantities of K were applied but scant attention was given to K, Ca and Mg requirements from soil analysis. Few farmers supplied lime to their soils in spite of soil acidity problems. This was partially because Cedara recommended lime when soil acid saturation was > 5 %. A soil with a pH of 4.3 (KCl) and saturation of 4 % would receive no liming recommendation. The lowering of minimum acid saturation at Cedara would help to improve liming practices in the Umlaas River Valley and the rest of KwaZulu-Natal. Improved grower knowledge about the relationship of S and soil organic carbon percentage could improve S applications. Most farmers used fertilizers containing more than half the N as NH_4, in preplant applications. This study recommends using more NO_3 based fertilisers to slow down acidification or at the least, corrective applications of lime. These observations show that some farmers in the Umlaas River Valley still do not perceive soil analysis results to be necessarily crucial for optimum yields, good soil fertility and lower input costs. This study also recommends the application of P and K as fertilizer, up to the critical value; and no P or K when critical values are exceeded.

The mean total N applied to 59 cabbage crops in the Umlaas River Valley was 198 kg ha^{-1} (Table 1). Thus, according to Greenwood *et al.* (1980 b), Anon. (1984), Smith & Hapelt (1984), Csizinszky & Schuster (1993) and Manson *et al.* (1993), most farmers supplied sufficient N to cabbages. Although farmers supplied enough N it was not in the correct preplant and postplant proportions. At present, most growers apply ¼ of total N preplant and ¾ as topdressing. This cannot be justified given only a few plots with sandier soils and hence quicker leaching (Tisdale *et al.*, 1990) and a low correlation between applied N and soil sample density. Richards, Smith & Bennett (1984) and Smith & Hapelt (1984) found lower yields when applying similar proportions of N. Highest yields also occurred when N was applied ½ preplant and ½ at four weeks (Richards *et al.*, 1984) while Smith & Hapelt (1984) showed higher yields with ⅔ N preplant and ⅓ at four weeks and no yield response above 200 kg N ha^{-1}.

The low, yet significant correlation ($R = 0.36^{***}$) between total N and yield was expected, with Richards *et al.* (1984) reporting a linear increase in yield up to 300 kg ha^{-1} of N and Zebarth *et al.* (1991) a yield response up to 500 kg. The maximum N applied ha^{-1} in the Umlaas River Valley was 304 kg and a response up to this level could well have been possible. However, this was somewhat contradicted by Smith & Hapelt (1984) who observed better yields with 200 kg ha^{-1} applied correctly rather than 300 kg applied incorrectly. Furthermore, percentage of plant recovery of N was lower for higher applications of N (Zebarth *et al.*, 1991). Therefore higher rates of N could easily approach luxury consumption levels with little economic return (Olson, Anderson, Frank, Grabouski, Rehm & Shapiro, 1987). A multiple regression model in § 8 using many variables affecting yield, showed a significant negative correlation between yield and total N. It was speculated that incorrect pre- and post-plant N proportions were responsible for this negative yield/total N correlation i.e., the farmers supplying more than 200 kg ha^{-1} of N were not applying the N in the ⅔, ⅓ ratio.

Most single topdressings occurred 4 - 5 weeks after transplanting and most split applications were applied at four and six weeks. Richards *et al.* (1984) and Smith & Hapelt (1984) found highest yields with one N topdressing no later than four weeks after transplanting. However, their seedlings were grown in 128 seedling trays whereas most of our farmers transplanted seedlings grown in 200 Seedling® trays. Field observations in the Umlaas River Valley found that seedlings grown in 200 size trays took longer to establish after transplanting and also reached heading later than seedlings from 128 size trays. Therefore topdressings from 4 - 6 weeks should coincide with the beginning of headform to ensure maximum yields (Richards *et al.*, 1984). Cabbage yields in the Umlaas River Valley could be improved if 200 kg N ha^{-1} were administered ⅔ preplant and ⅓ at 4 or 6 weeks postplant for seedlings grown in 128 and 200 seedling® trays, respectively.

Richards (1983) found no yield response beyond 60 ppm of soil P. Later work by Smith & Bennett (1984) showed that optimum cabbage yields occurred at 40 ppm of soil in KwaZulu-Natal. § 1 showed a yield response up to 88 mg l^{-1} of soil P. If most soils in the Umlaas River Valley had low P levels then the average P applied (i.e. 73 kg ha^{-1}, Table 1) on 59 cabbage crops in this study would have been acceptable. However, the mean soil P value was 92 mg l^{-1} (§ 1) making applications of 73 kg ha^{-1} excessive. Hochmuth *et al.* (1993) recommended no P when soil test values exceeded 30 mg kg^{-1}, therefore for a mean soil value of 92 mg l^{-1} and a critical value of 88 mg l^{-1} (identified in § 1) no P should be applied. High P applications were coupled with an average correlation ($R = -0.42^{***}$) between applied P and soil P. It was surmised that most farmers use soil analysis results to determine P requirements but, not knowing nutrient removals (§ 3) and acting conservatively, applied too much P. Communication with farmers shows that Cedara recommendations influence farmer fertilisation practices in this regard. Manson *et al.* (1993) recommended a minimum of 40 kg ha^{-1} with soil P from 50 - 120 mg l^{-1}. If the applied amount were reduced or made zero for soils with high P values, it could invoke a slow change in farmer practices.

Richards (1983), Smith & Bennett (1984) and Smith & Hapelt (1984) reported no yield differences when applying N or P as broadcast or banded. There is no evidence to suspect any different response to N and P applications in the Umlaas River Valley over the study period.

Cedara recommends that no K be applied at soil levels above the optimum, i.e., 200 mg l^{-1} (Manson *et al.*, 1993). However, § 1 showed that although there was sufficient available K at 200 mg l^{-1}, a yield response occurred up to 338 mg l^{-1}. Given an average soil K of 312 mg l^{-1} for the study crops (§ 1), a removal figure of 203 kg 100 t^{-1} crop (§ 3), sufficient available K at 200 mg l^{-1} and a yield response up to 338 mg l^{-1}, we surmise that an average total K application of 108 kg ha^{-1} (Table 1) would not constitute too much available K and could well increase yields. This is notwithstanding the fact that excellent yields could be attained at soil K of 200 - 248 mg l^{-1} (Manson *et al.*, 1993)(§ 1) and fertiliser costs could be reduced.

The study shows that farmers are supplying enough K to their soils for a cabbage crop. However, correlation analysis between applied K and soil K was very weak (R = -0.03). Applied K was not proportional to soil requirements, which shows little attention to K levels in soil analysis and indicates the use of a standard fertiliser programme, year after year.

For reasons stated in Results, the average total Ca applied was not representative of Ca applications by farmers. Figure 4 showed of all the crops limed, 73 % received < 100 kg ha^{-1} and 27 % > 100 kg ha^{-1} of Ca. Furthermore, only 20 % of all crops were limed, receiving > 200 kg Ca ha^{-1}. This was a cause for concern since 54 % of farmers grew cabbages in soils with pH < 4.5 and acid saturation > 2 % (§ 1). Effectively, only 30 %

of farmers needing lime on their soils were actually applying corrective liming procedures. This was corroborated by the poor correlation between applied Ca and soil Ca (R = -0.16). Similarly there was a poor correlation between applied Mg and soil Mg (R = -0.11) and average amounts applied barely exceeded Mg nutrient removals. The average soil Mg content over 59 cabbage crops was 273 mg l^{-1} which supplied enough Mg for crop requirements (Manson *et al.*, 1993). However, as with K, Ca and Mg (liming) requirements based on soil analysis results were not regarded as important enough to warrant farmer attention. Soil acidity and resultant Mn toxicity problems were detrimental to cabbage yields (§ 1 & 2). Smith, Demchak & Ferretti (1986) increased yields, lowered leaf Mn levels and showed better uptake of N with liming. Farmer education and lowering of Fertrec permissable acid saturation levels to 2 % (§ 1 & 2) would result in higher lime recommendations and increased yields in the Umlaas River Valley.

Tisdale *et al.* (1990) reported increases in available S with increasing soil organic carbon percentage. Our study showed no correlation between applied S and organic carbon. We speculate that most farmers are not aware of this relationship and therefore do not fertilise accordingly.

The most popular preplant fertiliser was 2:3:4(30) followed by even use of 2:3:2(22), AMP(16) and Supers 8.3). LAN(28), ASN(27), KCl(50), KNO_3(50) and 5:1:5(36) were incorporated in preplant applications with the four basic fertilisers. The most popular fertiliser for topdressing was LAN(28) followed by ASN(27) and 1:0:1(26). Very few farmers topdressed with Agrofert, 5:1:5(36) or 4:1:1(41). So long as basic nutrients were provided, different fertiliser types should not have affected yield response (Tisdale *et al.*, 1990). Indeed, Anova showed no significant yield differences (P = 0.05) with various fertiliser types applied pre- or postplant. However, most fertilisers except KNO_3(50) and LAN(28) had N in the NH_4 form. Even 2:3:2(22) and 2:3:4(30) were half MAP and half LAN (Hawksworth, pers. com.; Nitrochem, (PTY) LTD, Box 45, Howick, 3290) and possibly ¾ NH_4. KNO_3(50) had 100 % NO_3 and LAN(28) had half NH_4 and half NO_3. NH_4 has a stronger acidifying effect than NO_3 (Fey *et al.*, 1990; Tisdale *et al.*, 1990) and constant use of NH_4 containing fertilisers would increase soil acidity quicker than mixed or more use of NO_3 containing fertilisers. We believe that constant use of NH_4 containing fertilisers has enhanced soil acidity problems in the Umlaas River Valley. The rate of decreasing soil acidity, due to the use of nitrogenous fertilisers, could be reduced by using more NO_3 containing fertilisers. Obviously though, the acidity problems in the Umlaas River Valley would be rectified through corrective liming practices.

There are two important soil test interpretation philosophies in South Africa and USA (Miles pers. comm.; Olson, Frank, Grabouski & Rehm, 1982; Olson *et al.*, 1987; Kidder, 1993). The one, a build and maintenance approach, advocates replacing nutrients removed by the crop in addition to nutrients needed to bring the soil level up to a critical value. Once the critical value is reached, the soil is maintained at that level by supplying the amount of nutrient likely to be removed by the crop to be grown (Olson *et al.*, 1987). The other philosophy, the sufficiency approach, establishes critical values above which no fertiliser is recommended (Olson *et al.*, 1987) e.g., P and K recommendations of Hochmuth *et al.* (1993). The "sufficiency" concept achieves maximum yields for a reasonable cost while the "build up and maintain" approach produces maximum yields, but is more expensive, promotes luxury consumption and could cause more environmental contamination (Olson *et al.*, 1982; Olson *et al.*, 1987; Hochmuth *et al.*, 1993; Kidder, 1993). For cabbage growing in the Umlaas River Valley, this study recommends the use of the "sufficiency" approach for cabbage fertilization. For yields $\geq$ 100 t ha^{-1} soils should slowly be raised to the economic (cut-off) values identified in § 1 (Table 2) and no fertilizer recommended when the economic values are exceeded. Similarly, for maximum yields the critical (cut-off) values in § 1 (Table 3) could be used. Removals of the previous crop can be used to restore soils back to the cut-off values.

In conclusion this study has identified various problems relating to fertilization: - the amount used, time of application, little attention to soil analysis results and soil acidification effects. Each of these problems, with specified nutrients, were limiting factors in cabbage production in the Umlaas River Valley. Recommendations for improved yields were made.

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Table 1 Amounts of nutrients applied ha^{-1} of cabbage in the Umlaas River Valley, 1991 - 1993

	Average (kg ha^{-1})	Minimum (kg ha^{-1})	Maximum (kg ha^{-1})	SE	CV (%)
N preplant	61	0	161	4.89	62
N postplant	137	48	206	6.45	36
N total	198	107	304	6.55	25
P preplant	73	13	150	4.30	45
P postplant	4	0	35	1.30	264
P total	77	13	161	4.67	47
K preplant	79	0	380	7.34	72
K postplant	30	0	164	5.20	133
K total	108	0	380	8.90	63
Ca total	121	0	968	21.22	135
Mg total	22	0	196	4.09	146
S total	67	0	240	7.75	89

Table 2 Types and amounts of inorganic preplant fertiliser applied on 59 cabbage crops in the Umlaas River Valley, 1991 - 1993

Fertiliser	% of crops	Amounts of fertiliser applied (kg ha^{-1})	
		Average	Range
2:3:4(30)	39	696	500 - 1000
2:3:2(22)	16	945	500 - 1000
SUPERS(8.3)	7	960	650 - 1500
AMP(16)	7	620	360 - 1000
AGROFERT MIX 5:3:2(23)	6	1175	500 - 1400
5:1:5(36)	6	525	400 - 600
LAN(28)	6	355	350 - 360
MAP(33)	4	350	350
ASN(27)	3	458	427 - 489
KCl(50)	3	279	273 - 285
KNO_3(50)	1	1000	1000

Table 3 Types and amounts of inorganic fertiliser topdressed on 59 cabbage crops in the Umlaas River Valley, 1991 - 1993

	% of crops	Amount applied Average	Amount applied Range	Time of application Average	Time of application Range
		(kg ha^{-1})		(weeks)	
LAN(28)	45	372	100 - 500	3	2 - 7
ASN(27)	23	456	173 - 500	4	2 - 6
1:0:1(36)	23	388	300 - 400	5	2 - 6
5:1:5(36)	4	600	500 - 650	5	4 - 6
AGROFERT MIX					
5.3.2(23)	4	500	500	4	4
4:1:1(41)	1	430	430	5	5

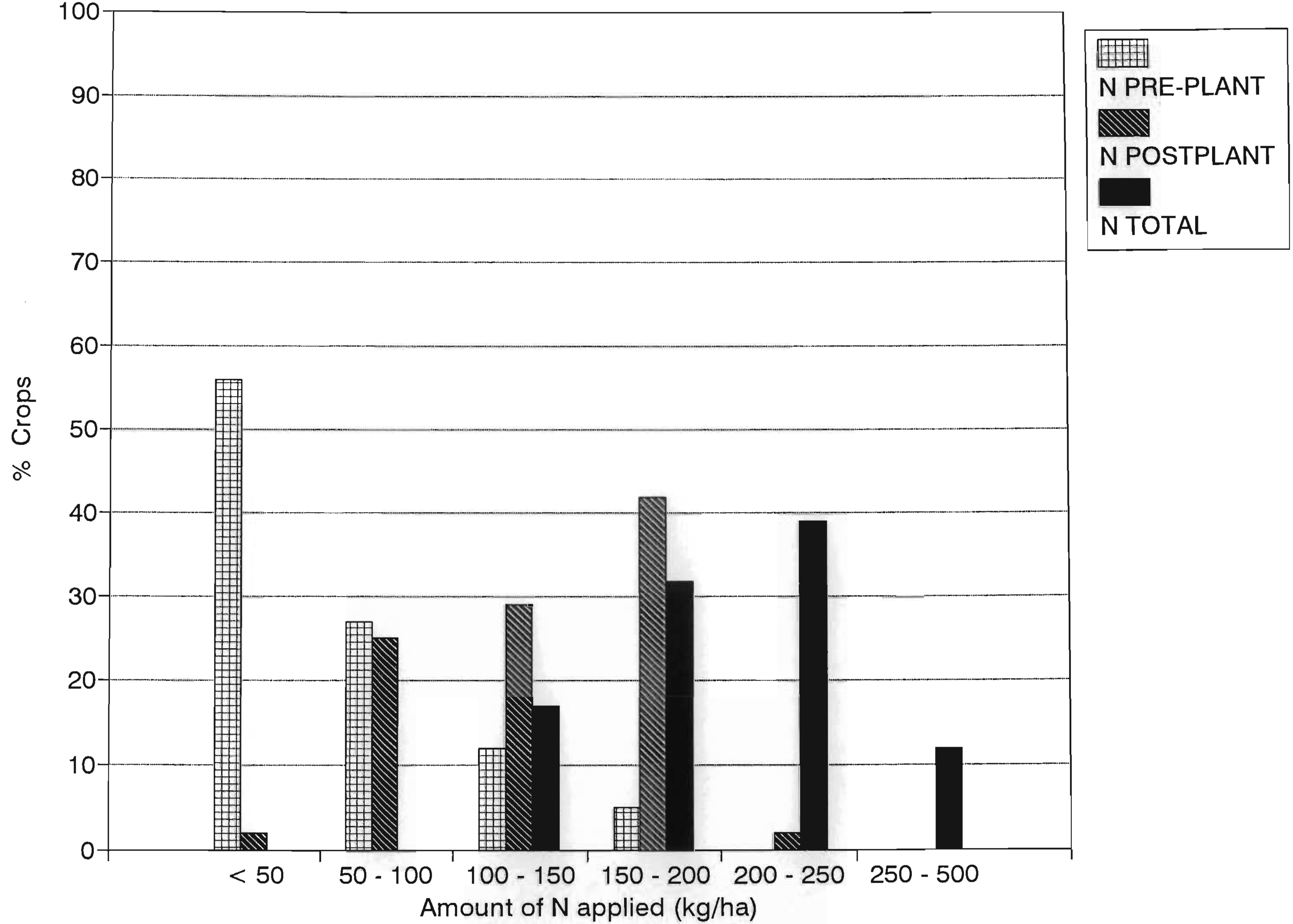

Figure 1 Percentage of 59 cabbage crops recieving "x" amount of N

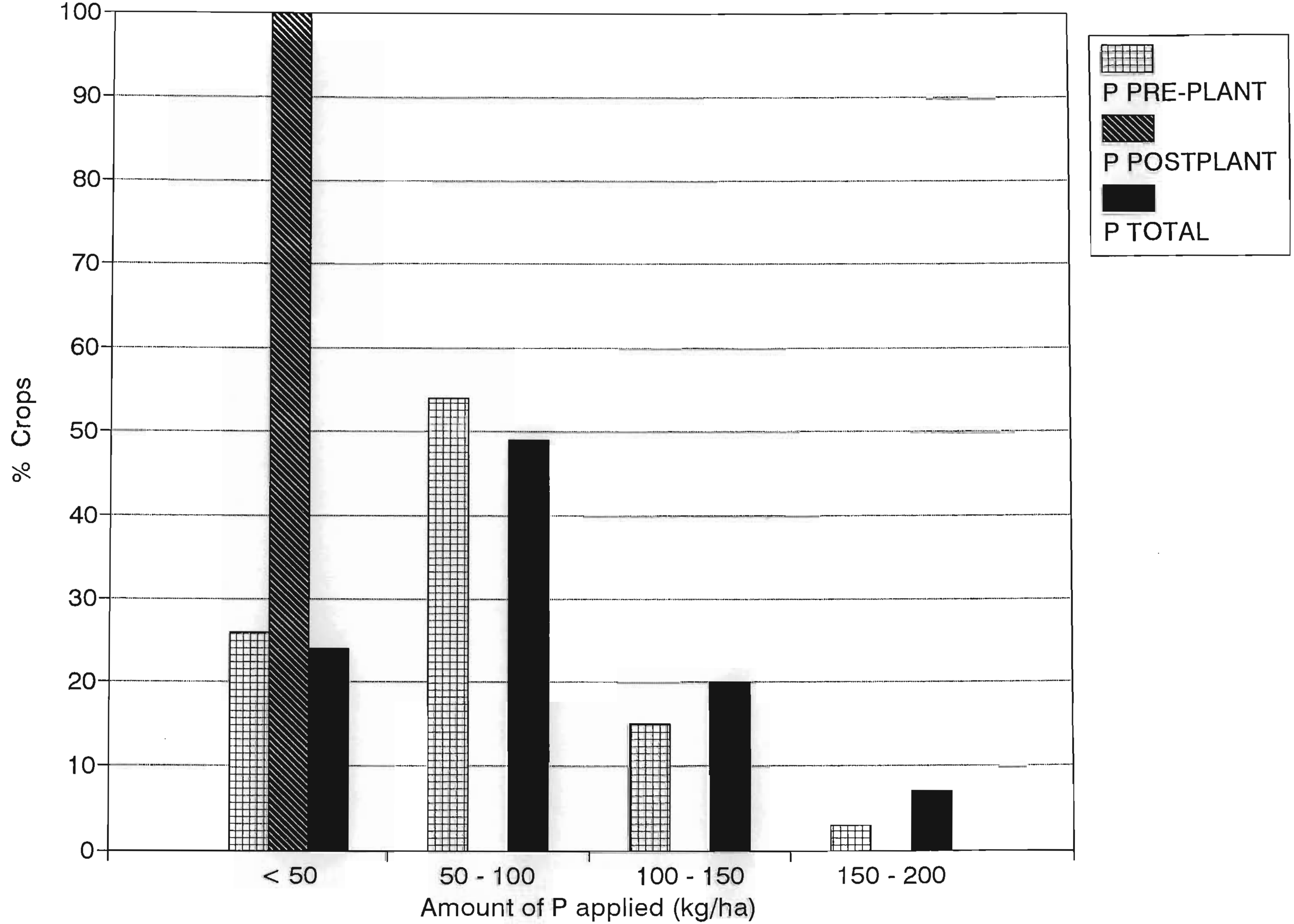

Figure 2 Percentage of 59 cabbage crops recieving "x" amount of P

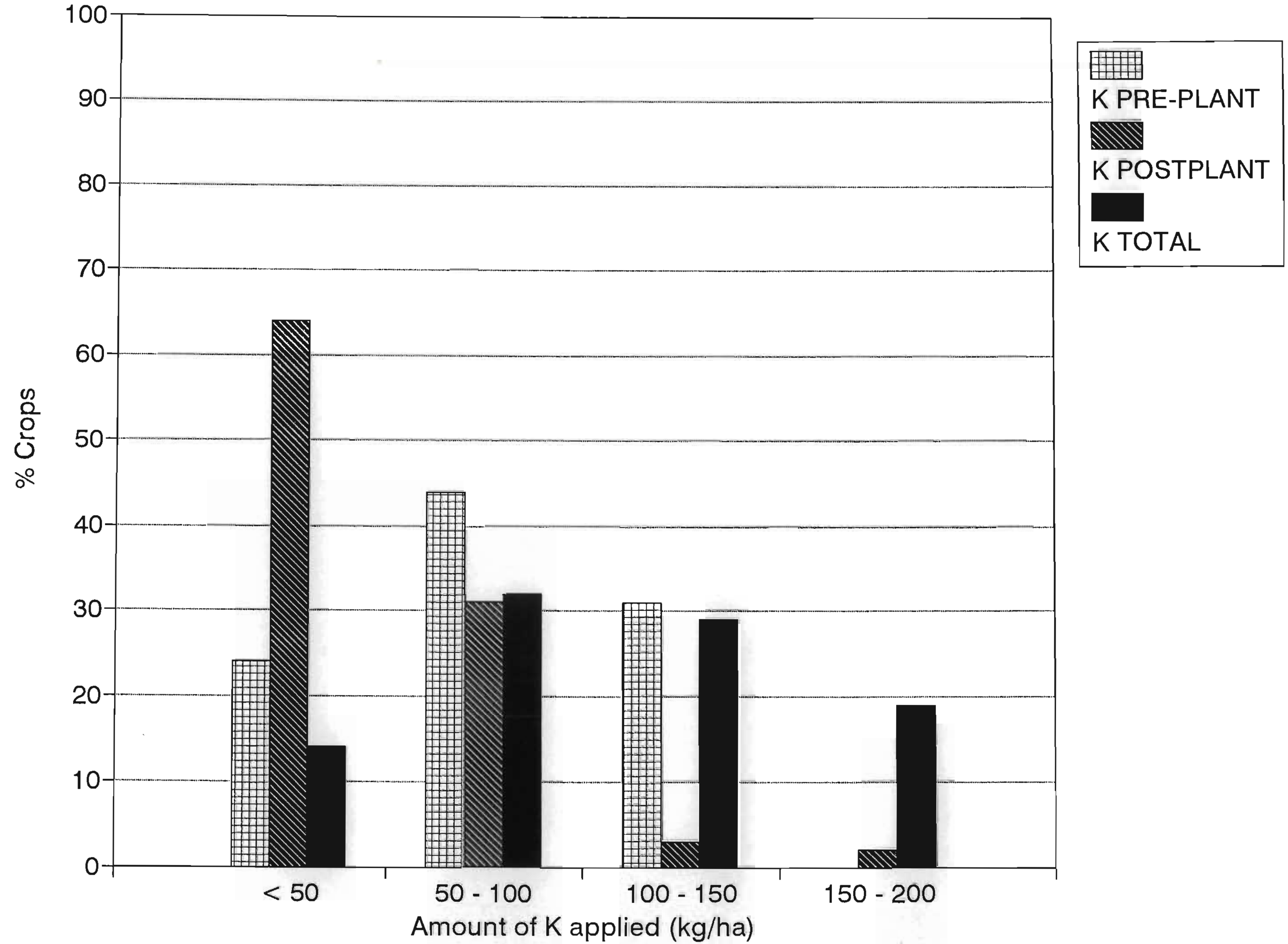

Figure 3 Percentage of 59 cabbage crops recieving "x" amount of K

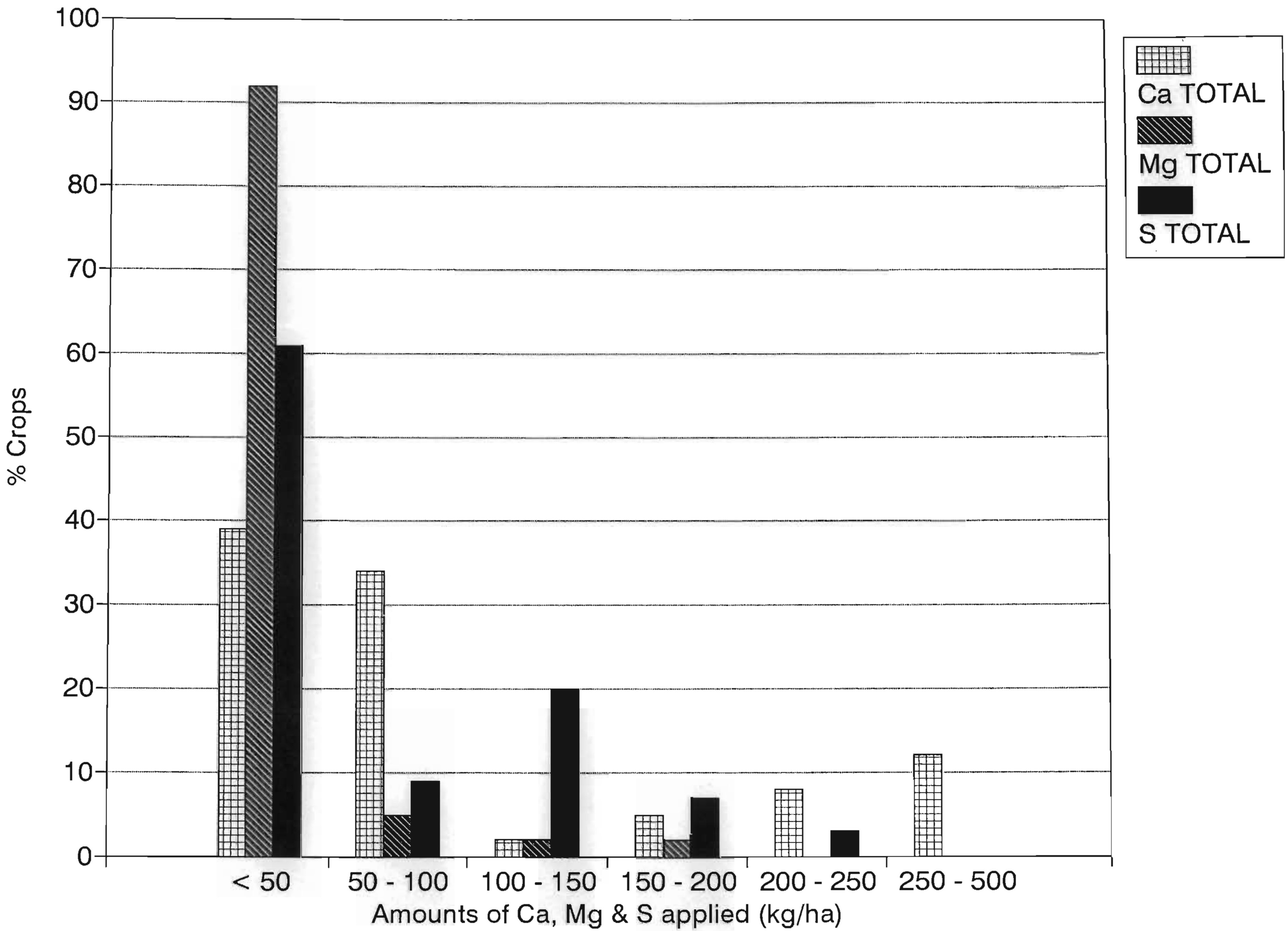

Figure 4 Percentage of 59 cabbage crops recieving "x" amount of Ca, Mg and S

5. DISEASES OF CABBAGE IN THE UMLAAS RIVER VALLEY : THEIR EFFECTS ON YIELD AND FACTORS RELATING TO DISEASE INCIDENCE

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Abstract

An extension and research exercise monitored diseases and many related factors on 59 cabbage crops in the Umlaas River Valley, KwaZulu-Natal. It identified optimum infection periods and maximum and minimum temperatures for infection by blackrot, clubroot, ringspot, damping-off, sclerotinia, downy mildew and alternaria leaf spot, and evaluated disease effects on yields. Clubroot, blackrot and damping-off significantly reduced cabbage yields. Clubroot incidence was generally associated with soil acidity problems, waterlogged lands, or sandy soils subjected to slight over-irrigation. Blackrot was reduced by adequate supply of N and K in fertilization, increased with higher concentrations of Mn in most recently mature leaves at headform (also associated with soil acidity) and always occurred with the warm, wet conditions of summer. Recommendations for better control and management of each disease were made.

Keywords: blackrot, clubroot, ringspot, damping-off, sclerotinia, downy mildew, alternaria leaf spot, pH, manganese, nitrogen, potassium, temperature

Introduction

Given appropriate conditions for successful disease cycles, diseases of cabbage (*Brassica oleracea* L. var. *capitata* Alef.) are endemic in intensive vegetable production areas (Walker, 1969; Agrios, 1988). Optimum environmental conditions vary according to pathogen which in turn are affected by management factors (Walker, 1969; Flint, 1987; Agrios, 1988).

A study of cabbage crops in the Umlaas River Valley, KwaZulu-Natal, from June 1991 - July 1993, monitored the incidence of prevalent diseases and factors relating to successful infections. The aim of this work was to evaluate the effects of disease on yield, to identify the most important pathogens in the area, optimum conditions for infection, factors increasing infection levels of each pathogen, and to make recommendations for improved disease control and therefore higher yields.

Procedures

Traditional methods used factorial experiments to evaluate interactions between, e.g., fertiliser, disease and yield. Furthermore, traditional experimentation usually involves a maximum of two diseases and a limited number of variables. As part of a research and extension programme, this study involved various cabbage cultivars grown in different soil types at different times of the year by 13 vegetable growers. The study also encompassed all prevalent diseases over the two-year study period. Many environmental and management factors affect plant diseases and their related yield response (Agrios, 1988). Therefore this study includes all quantifiable information relating to diseases of cabbage in the Umlaas River Valley over the period June 1991 - July 1993.

The crops and study method used as a basis for this work were the same as those of § 1, 2, 3 and 4. At maturity the plots were harvested and yields ha^{-1} estimated. Soil samples were taken (depth = 15 cm) at headform from within the monitor plot. Most recently mature (MRM) leaf samples (Hochmuth, Maynard, Vavrina & Hanlon, 1991) and a ⅛ headslice (Geraldson, Klacan & Lorenz, 1973) were taken at headform and harvest respectively. All soil and leaf samples were analyzed at the Soil Physics Laboratory at the Department of Agricultural Development Institute, Cedara (Analytical Methods Used in the Soil Science Laboratories at Cedara, 1986). Maximum and minimum thermometers, placed in a Stevenson screen in a CR 10 Data-logger, at a height of 1.2 m, recorded temperatures throughout the study.

A survey of farming practices of all participating growers determined the number of tillage operations prior to transplanting cabbage seedlings, crop rotations and waiting periods between successive crops. Type, amount and time of fertiliser application was recorded for each crop by the farmer. This was later retrieved by the researchers. The management scale of Burger (1971) was used to determine management aptitude of all participating farmers. This scale was well correlated to actual management observed on each farm and was therefore a good indicator of the level of management exercised on each monitor plot.

Monitor plots were subjected to all normal farming practices, e.g., weeding, spreading of fertiliser, chemical spraying, moving of irrigation pipes, etc.. Placement of tensiometers in monitor plots would have been too costly in terms of numbers required and damages incurred. Therefore, a "feel and appearance" technique (Mottram, 1982) and visual observations (wilted plants, soil around roots of weeds, etc.) were used during the weekly visits to ascertain available soil moisture. An assessment of crop water stress (based on weekly observations, knowledge of farm irrigation practices and prevailing water restrictions) was developed using a rating of 0 - 10. Estimated crop yield ha^{-1} was not considered in the determination of each crop water stress rating. The parameters for the different ratings were as follows:

0 - soil maintained at or near field capacity from transplant to maturity, consistent and adequate irrigation supplied to supplement rainfall.

2 - adequate available soil moisture throughout most of the crop, slight over-irrigation, inconsistency or insufficient irrigation water supplied to supplement rainfall.

4 - little available soil moisture, irrigation inconsistent and insufficient to supplement rainfall, dry soil observed $\pm$ three times, crops wilted once or twice.

6 - little available soil moisture, irrigation was often inconsistent and insufficient to supplement rainfall, dry soil observed $\pm$ five times, crops wilted $\geq$ three times and plants stunted.

8 - very poor soil moisture, irrigation $\pm$ three times, soil mostly dry and plants often wilted, little or no rain.

10 - irrigated once only after transplanting with no rain.

Literature regarding measurement of disease was inappropriate given the extensive nature of our study. Some diseases, e.g., damping-off (*Pythium* spp. or *Rhizoctonia solani* Kuhn) or sclerotinia rot (*Sclerotinia sclerotiorum* (Lib) de Bary), resulted in plant death or a nonmarketable product whenever prevalent (Flint, 1987). Other diseases, e.g., ringspot (*Mycosphaerella brassiciola* (Duby) Oud.) and downy mildew (*Peronospera parasitica* (Pers. ex Fr.) Fr.), reduced yields with increasing leaf area affected (Agrios, 1988). Therefore for most accurate results, both incidence and severity (slight, moderate and severe) of diseases of each crop was recorded on a weekly basis.

A disease severity index was developed to account for the effects of each disease on yield. The incidence (% plants infected) of disease within each category (slight, moderate or severe) over the whole cropping period was totalled. Each total was multiplied by its relevant factor (Table 2) and the products then added together for a final total, the severity index for a specific disease. Each severity index was then added together to give an overall disease index for that crop. Both Table 1 and 2 were developed from observations in the field.

Optimum temperatures for infection were determined by relating disease incidence to prevalent temperatures. Actual occurrence of disease during optimal conditions and basic statistics regarding disease incidence on infected cabbage crops were incorporated to give an idea of overall disease incidence in the Umlaas River Valley. Multiple stepwise regression was used to determine the effects of each disease on yield and identify the most important pathogens. Multiple stepwise regression also determined the following effects: soil nutrient levels, fertiliser applied, leaf nutrient levels at headform, management rating, water stress, number of land operations, soil factors, temperatures, plant population and time of planting on the severity index of each disease.

Black leg (*Leptosphaeria maculans* (Desm.) Ces. & de Not), a disease thought to be endemic in the Umlaas River Valley, was never observed during our study on monitor plots, or other crops at that time. Bacterial soft rot (*Erwinia carotovora* (Jones) Holland), a problem with summer grown cabbages, was only observed once ($\pm$ 2 % plants infected) on all our monitor plots. It was therefore excluded from analysis.

Results

The following diseases occurred in cabbage crops grown in the Umlaas River Valley from June 1991 - July 1993: sclerotinia rot, black rot (*Xanthomonas campestris* (Pammel) Dowson), ringspot, clubroot (*Plasmodiophora brassicae* Woron.), downy mildew, bacterial soft rot, damping-off and alternaria leaf spot (*Alternaria* spp.).

Optimal infection conditions

Black rot and clubroot were endemic during the warm summer period (Table 3) which coincided with the rainy season in the Umlaas River Valley . Clubroot was sometimes observed in the winter in shallow, well irrigated soils, when warm conditions prevailed. Damping-off was observed all year round but was more prevalent in the autumn and spring when mean minimum and maximum temperatures ranged from 7 - 15 and 20 - 27°C respectively and some precipitation occurred (Table 3). Downy mildew infections were observed from early autumn to spring, with most severe outbreaks recorded over the winter period with little or no rainfall but heavy dew (Table 3). Alternaria leaf spot preferred warmer conditions and occurred at mean minimum and maximum temperatures of 8 - 16 and 21 - 26°C respectively, favouring a warm winter through to late spring (Table 3). Infections by ringspot were more severe in warmer conditions with low levels of infection recorded over cold periods.

Occurrence of disease during optimum infection periods

Outbreaks of downy mildew were widespread when optimal conditions for infection were prevalent. Fifty-six percent of all crops grown from autumn to spring were infected by the pathogen (Table 4). However, the effects of downy mildew on yields were non-significant ($P \geq 0.05$, Table 3) with an average of 37 % of each cabbage crop or 21 % of all cabbages infected (Table 4). Similarly, ringspot infections were widespread (46 % of all crops or 16 % of all cabbages grown during optimum infection periods, Table 4) but had little effect on yield (Table 5) even with up to 100 % of a cabbage crop infected (Table 4).

Black rot occurred on 42 % of cabbage crops grown in early to late summer (Table 4). While infecting only an average of 20 % of each crop or 8 % of all cabbages, it was one of the more serious pathogens in the Umlaas River Valley and had a highly significant effect on yield (t-value = -3.68***, Table 5). Although clubroot infected only 21 % of all crops or 9 % of all cabbages grown through the summer period, it had the most significant effect on yields (t-value = -4.50***, Table 5). Both clubroot and black rot sometimes showed similar infection patterns, starting with one or two plants, and spreading to 75 - 100 % of the monitor plot (Table 4). At other times clubroot symptoms would appear uniformly over the whole plot.

Alternaria leaf spot was also quite prevalent from early winter to late spring. Table 4 shows that alternaria infected 34 % of all crops or 10 % of all cabbages grown during optimal disease conditions. Each crop infected with the pathogen had an average of 29 % plants infected (Table 4). However, alternaria had no significant effect on cabbage yields as shown in multiple regression results in Table 5.

Damping-off, caused by various soil-borne pathogens, did have a significant effect on yield (t-value = -2.4*)(Table 5), and infected 29 % of crops grown from early autumn to spring (Table 4). It only infected an average of six plants per monitor plot (i.e., 6 %) with a range of 1 - 20 % of plants per crop. Despite the low percentage of infection, it was a serious disease, killing the plant and thus affecting cabbage yields.

Sclerotinia rot, normally a dangerous disease, only infected 27 % of cabbage crops and 10 % of all cabbages, during the autumn and spring seasons (Table 4). The average percentage plants infected crop^{-1} was also low (3 %) and no significant effect on yield was seen (Table 5).

Regression analysis showing disease effects on yield

Table 5 shows the results of multiple stepwise regression relating disease indices to cabbage yields. Crops affected by water stress or soil acidity were excluded from analysis. Clubroot, black rot and damping-off were the most important cabbage diseases in the Umlaas

River Valley , having highly significant and significant effects on yield. Corporately, the diseases analyzed could account for 58 % of the variation in yield (R^2 = 0.58, t-value = 17.42***).

Factors affecting disease incidence

Stepwise multiple regression showed that total magnesium (Mg)(t-value = 4.35***) and sulphur (S)(t-value = -2.62*) applied in fertilisation influenced the incidence and severity of clubroot (R^2 = 0.29). Seventy-four percent (R^2 = 0.74) of infection by black rot was attributed to leaf manganese (Mn) levels at headform (t-value = 10.78***), favourable daily temperatures (t-value = 3.35**), acid saturation (t-value = -3.40**), total potassium (K) in fertiliser (t-value = -2.65*), soil acidity (t-value = 2.40*) and the amount of leaf nitrogen (N) at headform (t-value = -2.25*). No relationship could be found between damping-off and management and environmental factors.

Average daily temperatures accounted for most of the variation of downy mildew outbreaks (t-value = -3.96***) while soil acidity (t-value = 2.39*) and the time of year (t-value = -2.26*) had significant effects on severity. The severity and incidence of sclerotinia infections was significantly (t-value = -2.17*) correlated to the amount of phosphorus (P) in the fertiliser while ringspot had no significant association with any factors measured. Infection by alternaria was influenced by plant population (t-value = 4.70***) and soil Mg levels (t-value = -3.05**, R^2 = 0.34).

Discussion

Prior to this study, experience taught the Umlaas River Valley farmers when to expect specific diseases in their cabbage crops. Farmers were also aware of endemic diseases, factors accentuating disease and general effects on yield. However, substantiated facts were often lacking. This study provided a broad base of information on cabbage diseases, previously unsubstantiated and sometimes unknown to farmers. Maximum and minimum temperatures for infection by each pathogen, mean percentage crops infected, disease effects on yield and factors affecting disease incidence, were identified. As such, this information suggests new management tools for disease prediction and control which, if implemented, could reduce disease incidence and improve cabbage yields.

Clubroot

This study showed clubroot as the most important cabbage pathogen in the Umlaas River Valley. It normally infected cabbages in summer or occasionally in warm winter conditions in shallow, irrigated soils. This study recommends appropriate liming practices on low pH soils and avoidance of infected lands for cabbage production. If use of clubroot infected lands cannot be avoided, then only those with deeper soils should be used over winter.

Clubroot had a very highly significant effect ($P \leq 0.001$) on yield and infected 21 % of crops grown throughout the summer months. Serious losses due to clubroot are well documented in vegetable disease literature (Walker, 1969; Flint, 1987; Agrios, 1988). Buczacki, Ockendon & Freeman (1978) found that mean minimum soil temperatures of 19°C are essential for optimum disease infections by *P. brassicae*. Disease incidence of clubroot in the Umlaas River Valley agreed with their findings (Buczacki *et al.*, 1978) and occurred when mean minimum soil temperatures ranged from 19 to 22°C.

The incidence of clubroot was always observed concurrently with summer rainfall or warm winter conditions, irrigated lands and shallow soils. Despite the limited rainfall of summer 1993 and water restrictions from August 1992 until the end of the study, soil moisture was a vital factor affecting the disease cycle. Clubroot was more prevalent in low-lying, poorly drained soils or sandier areas with slight over-irrigation. Successful clubroot infection in waterlogged soils or those with sufficient free water, is well documented (Walker, 1969; Westcott, 1979; Agrios, 1988; Relihan, 1988). Hamilton & Crete (1978) showed that sandier soils needed a lower soil moisture level than heavier organic soils to induce a specific disease index of clubroot infection. Slight over-irrigation on sandier soils could raise soil moisture levels to infection requirements and explain the increased incidence of clubroot on sandier soils.

Yoshikawa & Buczacki (1978) experimented with clubroot on chinese cabbage. No clubs formed during periods of less than 11.5 hr day length and disease occurrence was affected by light intensity during the growing period. This could explain why clubroot was more prevalent in summer, but would also occur in winter (daylength can reach 11.5 hr in winter and 13 hr in summer).

Disease incidence and severity increased with high levels of Mg and decreased with high levels of S. It is well known that clubroot infections are greater on low pH soils and reduced on high pH soils (Agrios, 1988; Relihan, 1988). Lower pH soils and corrective liming practices, with resultant high amounts of applied Mg, could explain the correlation between clubroot and applied Mg. The application of sulphur is known to reduce the incidence of disease on some crops (Morris, Risdale & Platou, 1984) which could explain the relationship between applied sulphur and clubroot.

It would be best to avoid planting cabbages in lands with a clubroot history. However, given limited available land and farming practices in the Umlaas River Valley, it is unlikely that farmers can avoid the planting of cabbages in clubroot infected lands. Therefore we suggest using clubroot infested lands only for winter cabbage crops if infected land use is unavoidable. For winter use of infected lands, shallow soils should be avoided. Chances of waterlogging are decreased, minimum soil temperatures are lower, and light intensity and duration less than in summer months, therefore reducing chances of infection.

§ 1 and 2 identified a soil acidity complex as a large contributor to decreased cabbage yields in the Umlaas River Valley. Although soil pH, calcium (Ca) or Mg levels showed no correlation with clubroot in this study, other research (Campbell, Greathead, Myers & Boer, 1985) showed less clubroot with increased soil pH, Ca and Mg levels. Myers & Campbell (1985) also emphasized that balance of nutrients influenced host parasite development. Thus it appears that recommendations made in § 1 and 2 regarding soil nutrient balance and pH affect the development and spread of clubroot. Fertilization up to critical soil values (§ 1), liming practices to raise pH (§ 2), and regular soil tests, are recommended to reduce cabbage losses to clubroot. Practices that improve soil and conserve soil organic matter could also lower clubroot disease levels in the Umlaas River Valley (Dick, 1992).

Black rot

Black rot, endemic in the warm, moist season, is one of the most serious crucifer diseases, often causing losses of 40 - 50 % of the whole crop (Westcott, 1979). In our study black rot had a very highly significant effect ($P \leq 0.001$) on cabbage yields. It occurred over the summer period and infected almost half of the summer cabbage crops. Incidence was related to the soil acidity complex (§ 2), favourable temperatures, the amount of K applied in fertilisation and leaf nitrogen concentrations at headform.

Our work also identified a range of temperatures during which black rot infection occurred. Mean minimum and maximum air temperatures of 10 - 18 and 24 - 30°C respectively were synonymous with the appearance of black rot symptoms. Both Westcott (1979) and Agrios (1988) associated warm, wet seasons with black rot. In the Umlaas River Valley, black rot occurred over the summer season which coincided with warm wet conditions. Unfortunately the regression model did not take rainfall into account, but did include temperature which had a highly significant effect ($P \leq 0.01$) on the incidence of black rot.

High leaf concentrations of Mn at headform were related to an increase of black rot. Availability of soil Mn increases with low soil pH (Hewitt, 1953). § 2 show that acid soils caused high leaf concentrations of Mn, reduced yields and stunted plants in the Umlaas River Valley. All factors causing high Mn levels could be indirectly linked to black rot infection. Indeed, acid saturation and soil acidity had significant effects ($P \leq 0.01$ and 0.05, respectively) on black rot incidence. It is possible that high leaf concentrations of Mn stimulated black rot infections (Palti, 1981). Alternatively, the plant stress resulting from soil acidity problems and hence high concentrations of Mn produced low vigour crops. These low vigour crops were more susceptible to invasion by black rot, a facultative parasite (Palti, 1981; Van der Plank, 1984).

The significant effect of acid saturation on black rot incidence was unusual because disease incidence decreased as acid saturation increased. The opposite response, a positive correlation with leaf Mn at headform and soil acidity was expected. These acid saturation effects are contradictory to this and other research and cannot be explained.

A decrease in black rot disease incidence was observed with increasing leaf concentrations of N and higher K fertilization. It is possible that higher N concentrations reflected good plant vigour and made plants less susceptible to attack by black rot (Palti, 1981). § 4 showed that farmers supplied sufficient K to their cabbage crops. Palti (1981) said that an ample supply of K to crops reduces the severity of disease. This could explain lower black rot disease incidence with increasing K applied in fertilization.

This study has generated some management guidelines for the control of black rot in the Umlaas River Valley. Liming practices should be improved and soil pH raised to at least 4.5 (§ 1). Adequate N and K should be applied so that optimum plant vigour is achieved. Tolerant cultivars should be grown through the summer period. Black rot bacteria survive 2 - 3 years in infected lands (Agrios, 1988). Unless tolerant cultivars are used, cabbages should be excluded from crop rotations on infected lands in the summer. As black rot is a seedborne disease (Agrios, 1988), farmers should ensure that seed is purchased from a reputable company.

Damping-off

Damping-off caused by *Rhizoctonia* and *Pythium* species significantly affected cabbage yields in the Umlaas River Valley ($P \leq 0.05$). Infections were observed during cool, wet conditions, coincidental with spring and autumn seasons in the area. No factors affecting disease incidence could be identified.

Damping-off causes considerable damage before or after emergence of vegetable seed (Agrios, 1988). Of all the crops grown during optimal disease conditions, 29 % were infected with damping-off. In these infected crops, six out of every 100 plants were girdled by damping-off organisms. For a 100 t ha^{-1} crop, this represents a 6 t ha^{-1} loss. As expected from these figures, damping-off had a significant effect ($P \leq 0.05$) on cabbage yields.

Our study showed that damping-off occurred when mean minimum and maximum air temperatures were 7 - 15 and 20 - 27°C respectively. These temperatures were coincidental with a normal spring or autumn in the Umlaas River Valley . The temperatures were also associated with wet, cool conditions for a number of days. Most literature records damping-off in soils in cool, wet conditions (Westcott, 1979; Flint, 1987; Agrios, 1988). Agrios (1988) stated optimum infection temperatures for most races of *Rhizoctonia* as 15 - 18°C.

Agrios (1988) related infection to moderately wet rather than dry or waterlogged soils. He also said that slow growth due to adverse environmental conditions could influence disease severity. This study did not evaluate adverse environmental conditions *per se* but did include plant stress due to soil, management and water factors. No relationship could be found.

Many times damping-off occurs after transplanting, but is a direct result of infection in the nursery (Agrios, 1988). Many farmers in the Umlaas River Valley grow their own seedlings and could reduce damping-off losses with better tray and water sterilization techniques. Tray sterilization trials showed that copper based root-pruning agents gave significant disease control of cabbage plants (Laing, unpublished). More recently, 100 % tray sterilization was measured using steam (Laing & Paddy, 1992). The addition of Previcur® or Rhizolex® as a drench at sowing should reduce infection by damping-off pathogens in the growing medium (Nel, Krause, Hollings, Greyling & Dreyer, 1993). These nursery measures should be especially applied in the spring and autumn seasons.

Other non-significant diseases

Our study showed that sclerotinia occurred mostly in the spring and autumn seasons. Although it is a virulent pathogen it did not have a significant effect on cabbage yields in the Umlaas River Valley. Infections occurred before or after winter and were favoured by cool moist conditions. Although the percentage crops infected was similar to clubroot and damping-off, the actual average percentage of each crop affected was low (average = 3 %). This explains the non-significant effect on yield. Westcott (1979), Flint (1987) and Agrios (1988) state that sclerotinia infection is synonymous with cool moist conditions. High air humidity increases disease incidence (Agrios, 1988). Even though infection levels measured in this study were low, control practices should be maintained. Lower plant populations and good weed control to reduce microclimate humidity, and crop rotation are recommended (Agrios, 1988).

Downy mildew and alternaria leaf spot were observed from autumn to spring, with severe infections of downy mildew occurring in the winter. Temperatures had a very highly significant effect ($P \leq 0.001$) on downy mildew incidence. Optimum temperatures for epidemic development of downy mildew are 10 - 15°C (Dixon, 1981). This corresponds well to severe infections observed in winter. Optimum growth temperatures of alternaria species vary but greatest invasion occurs when liquid water is present on the leaf surface (Dixon, 1981). The dew experienced in the Umlaas River Valley during spring and autumn could provide sufficient leaf surface moisture and thus be related to more severe infections over this time.

Interestingly, infection of alternaria species was very highly significantly affected by plant population. It is possible that high RH, associated with plant microclimates at higher plant population densities, resulted in more moisture on the leaf surfaces for a longer time and hence more infections.

With optimum invasion temperatures for ringspot at 16 - 20°C (Dixon, 1981), infection in early spring and autumn were expected in the Umlaas River Valley.

Downy mildew has serious economic implications in cabbage seedlings (Agrios, 1988). Alternaria, ringspot and downy mildew can also cause serious damage to mature cabbage plants (Flint, 1987). However, in our study, none of these diseases had a significant effect on yield. We speculate that the weather was a major factor preventing epidemics of any of these three diseases. For example, for a complete life cycle, ringspot needs four consecutive days with RH at ≥ 100 % (Walker, 1969). It is unlikely that weather conditions in the Umlaas River Valley would have continuous RH ≥ 100 % for more than two days. The level of infection by downy mildew, alternaria and ringspot can be lowered by preventative and corrective treatments of various fungicides (Nel *et al.*, 1993).

In conclusion this study identified clubroot, black rot and damping-off as the most serious diseases of cabbages in the Umlaas River Valley. It also identified maximum and minimum daily temperatures at which infections of all prevalent diseases occurred. These temperature ranges could be used to predict appropriate conditions for disease infection. Soil acidity problems affected the incidence of clubroot, black rot and downy mildew. Improved liming practices could lower disease risk. Lands infected by particular soil-borne pathogens should be used in rotation with other nonsusceptible host plants or could be used for cabbage production when environmental conditions are unsuitable for successful infection.

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Table 1 Guidelines for severity assessments of various diseases of cabbage in the Umlaas River Valley, 1991 - 1993

	Assessments		
Disease	Slight	Moderate	Severe
Ringspot	< 2 lesions plant^{-1}	25 lesions plant^{-1}	> 5 lesions plant^{-1}
Downy mildew	5 % leaf area	25 % leaf area	50 % leaf area
Alternaria leaf spot	< 2 lesions plant^{-1}	25 lesions plant^{-1}	> 5 lesions plant^{-1}
Black rot	small tip lesion of leaf	lesion extends to ⅓ down on main leaf vein	lesion extends ⅔ main leaf vein
Clubroot	≤ 3 galls on roots	most roots have galls	no roots, solid mass of galls
Damping-off			stem girdled
Sclerotinia			white mycelia and/or sclerotia
Bacterial soft rot			any bacterial slime

Table 2 Multiplication factors used for disease severity indices of cabbages in the Umlaas River Valley, 1991 - 1993

Disease	Severity of disease		
	Slight	Moderate	Severe
Ringspot	0.01	0.05	0.2
Downy mildew	0.01	0.05	0.2
Alternaria leaf spot	0.1	0.3	0.7
Black rot	0.1	0.6	0.8
Clubroot	0.1	0.8	1
Damping-off	1	1	1
Sclerotinia	1	1	1
Bacterial soft rot	1	1	1

Table 3 Seasonal and temperature occurrence of various cabbage diseases in the Umlaas River Valley, 1991 - 1993

Disease	Daily temperature ranges Minimum °C	Maximum	Season
Damping-off	7-15	20-27	Early autumn to spring
Downy mildew	7-15	20-27	Early autumn to spring (worst over winter)
Sclerotinia rot	8-15	20-27	Autumn and spring
Alternaria leaf spot	8-16	21-26	Early winter to late spring
Ringspot	8-17	22-30	Early autumn and spring
Black rot	10-18	24-30	Early to late summer
Clubroot	12-18	23-30	Early to late summer

Table 4 Percentage crops infected during optimal disease conditions and infection figures within each cabbage crop in the Umlaas River Valley, 1991 - 1993

Disease	% crops infected	% plants infected/crop			Mean % of all cabbages infected
		Mean	Minimum	Maximum	
			%		
Downy mildew	56	37	1	100	21
Ringspot	46	35	5	100	16
Black rot	42	20	1	75	8
Alternaria leaf spot	34	29	1	100	10
Damping-off	29	6	1	20	2
Sclerotinia	27	3	1	20	1
Clubroot	21	43	1	100	9

Table 5 The effects of various diseases on cabbage yields in the Umlaas River Valley, 1991 - 1993

Disease	Coefficient	t-value[a]
Clubroot	-0.87	-4.50***
Black rot	-0.92	-3.68***
Damping-off	-1.78	-2.39*
Sclerotinia rot	-5.44	-1.78
Ringspot	6.32	1.06
Alternaria leaf spot	1.98	0.97
Downy mildew	-1.80	-0.74

[a] Numbers followed by * and *** are significant ($P \leq 0.05$) and very highly significant ($P \leq 0.001$) respectively

Variables	Coefficients	t-values
Clubroot	-0.870	-4.50***
Black rot	-0.920	-3.68***
Damping-off	-1.780	-2.39*

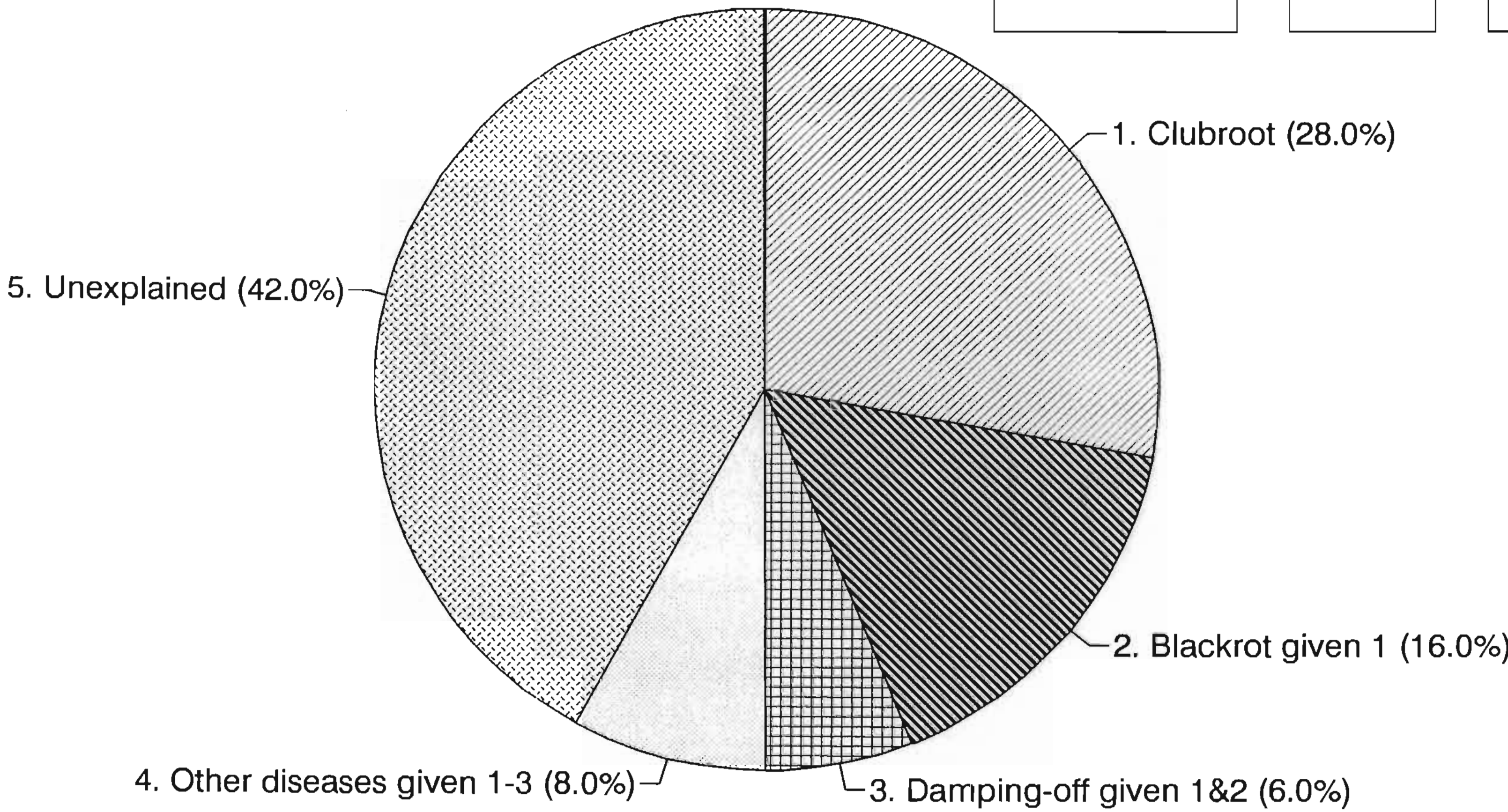

Figure 1 Effects of various diseases on yield of cabbages in the Umlaas River Valley, 1991 -1993

6. PESTS OF CABBAGES IN THE UMLAAS RIVER VALLEY : THEIR EFFECTS ON YIELD AND FACTORS RELATING TO PEST INCIDENCE

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Abstract

A research and extension programme examined cabbage pests in the Umlaas River Valley, their seasonal occurrence, effects on yield, and factors affecting pest incidence. Aphids and thrips occurred through the year, cutworm, bollworm, greater cabbage moth, leafminer and diamond-back moth mostly over the warmer season and webworm over the cooler period in autumn. Aphids, thrips and webworm were the most important cabbage pests, causing serious losses especially during the first six weeks after transplanting. Factors such as amounts of fertilizer applied, soil acidity problems, slope of the land, infiltration rate, soil nutrient status, water stress, leaf concentrations of each element, weeds and disease were all associated with the incidence of various pests. This study highlighted the importance of good management practices, which affect all these aspects of cabbage production, and therefore pest incidence. An awareness of these factors associated with pest incidence, and recommendations made in this study, could improve cabbage management practices in the Umlaas River Valley and therefore, reduce pest infestation.

Keywords: aphid, thrips, cabbage webworm, diamond-back moth, greater cabbage moth, bollworm, leafminer, cutworm, fertilizer, slope, acidity, management, irrigation, disease, weeds, temperature.

Introduction

Cabbage (*Brassica oleracea* L. var. *capitata* Alef.) pests in South Africa are numerous and varied. They include aphids, bagrada bugs, rootknot nematodes, various moths and caterpillars, cutworms, fly maggots, flea beetles, ladybirds, crickets, beetles, and mites

(Annecke & Moran, 1982; Bell, 1984; Myburgh, 1988). Some of these pests are not restricted to cabbage and can occur simultaneously on other crops, e.g., bollworm, spider mite and nematodes on tomato (Myburgh, 1988). If uncontrolled, most of these pests could inflict serious damage on cabbage crops.

No one factor causes pest problems in crops. Usually a combination of factors forms the basis for crop infection by a particular pest (Pimmental, 1985). Research on pests of agronomic crops such as wheat, has concentrated on causes of pest problems (Pimmental, 1985). Heitefuss (1989) reported increased aphid populations with increased levels of nitrogen (N) on wheat. Differences exist in how different pests respond to different nutrients at various levels on different crops (Heitefuss, 1989). Phosphorus (P) enhancement of root formation in wheat through fertilization, improved plant resistance to soil-borne pathogens (Heitefuss, 1989). Could the same P effects also be observed with pests? Monoculture and a lack of genetic diversity also contribute to sudden pest outbreaks (Pimmental, 1985). Closer plantings or more weeds could also result in fewer pests per unit area (Altieri, 1981; Pimmental, 1985). Although various factors affect crop infestation by pests, most cabbage (or vegetable) pest research has concentrated on effective control of pests rather than on understanding causes of pest infestations.

The purpose of this study was to identify the following: all pests infesting cabbage crops in the Umlaas River Valley area; their effects on yield; and temperatures at which infestation occurred. Furthermore, using multiple aggression analysis, the study evaluated factors related to pest incidence in order to formulate recommendations for cabbage pest control.

Procedures

As part of a research and extension programme this study involved 59 cabbage crops of various cabbage cultivars grown in different soil types at different times of the year by 13 vegetable growers. The study encompassed all prevalent pests over a two year study period and included all quantifiable information related to cabbage pests in the Umlaas River Valley.

The crops and study method used as a basis for this work were the same as those of § 1, 2, 3, 4 and 5. The same crops, methodology and parameters used in § 5 were used to study the effects of pests on yield and factors relating to pest infestation. As in § 5, a severity assessment (Table 1) and multiplication factors (Table 2) were developed to evaluate the severity of pest infestation. This resulted in a pest index (PI) for each pest on each crop and accumulative PI for each crop.

At maturity the plots were harvested and yields ha^{-1} estimated. Soil samples were taken (depth = 15 cm) at headform from within the monitor plot. Most recently mature (MRM) leaf samples (Hochmuth, Maynard, Vavrina & Hanlon, 1991) and a ⅛ headslice (Geraldson, Klacan & Lorenz, 1973) were taken at headform and harvest respectively . All soil and leaf samples were analyzed at the Soil Physics Laboratory at the Department of Agricultural Development Institute, Cedara (Analytical Methods Used in the Soil Science Laboratories at Cedara, 1986). Maximum and minimum thermometers, placed in a Stevenson screen in a CR 10 Data-logger, at a height of 1.2 m, recorded temperatures throughout the study.

A survey of farming practices of all participating growers determined the number of land operations prior to transplanting cabbage seedlings, crop rotations and waiting periods between successive crops. Type, amount and time of fertiliser application was recorded for each crop by the farmer. This was later retrieved by the researchers. The management scale of Burger (1971) was used to determine management aptitude of all participating farmers. This scale was well correlated to actual management observed on each farm and therefore a good indicator of the level of management exercised on each monitor plot.

Monitor plots were subjected to all normal farming practices, e.g., weeding, spreading of fertiliser, chemical spraying, moving of irrigation pipes, etc.. Placement of tensiometers in monitor plots would have been too costly in terms of numbers required and damages incurred. Therefore, a "feel and appearance" technique (Mottram, 1982) and visual observations (wilted plants, soil around roots of weeds, etc.) were used during the weekly visits to ascertain available soil moisture. An assessment of crop water stress based on weekly observations, knowledge of farm irrigation practices and prevailing water restrictions was developed using a rating of 0 - 10. Estimated crop yield ha^{-1} was not considered in the determination of the water stress rating in each crop. The parameters for the different ratings were as follows:

0 - soil maintained at or near field capacity from transplant to maturity, consistent and adequate irrigation supplied to supplement rainfall.

2 - adequate available soil moisture throughout most of the crop, slight over-irrigation, inconsistency or insufficient irrigation water supplied to supplement rainfall.

4 - little available soil moisture, irrigation inconsistent and insufficient to supplement rainfall, dry soil observed $\pm$ three times, crops wilted once or twice.

6 - little available soil moisture, irrigation was often inconsistent and insufficient to supplement rainfall, dry soil observed $\pm$ five times, crops wilted $\geq$ three times and plants stunted.

8 - very poor soil moisture, irrigation $\pm$ three times, soil mostly dry and plants often wilted, little or no rain.

10 - irrigated once only after transplanting with no rain.

A pest severity index (PI) was developed to account for the effects of each pest on yield (Table 1). The incidence (% plants infected) of pests within each category (slight, moderate or severe) over the whole cropping period was totalled. Each total was multiplied by its relevant factor (Table 2) and the products then added together for a final total, the severity index for a specific pest. Each severity index was then added together to give an overall PI for that crop. The multiplication factors (Table 2) and parameters for severity assessments (Table 1) were developed from field observations so that yield effects of each pest were comparable. Field observations found that, e.g., a severe infestation of diamond-back moth (*Plutella xylostella* L.) affected marketable yield the same as a moderate infestation of bollworm (*Heliothis armigera*, Hubner.), but not as much as a severe infestation of webworm (*Hellula undalis* F.)(Table 1 and 2). Damage varied according to pest, pest population per plant and the age of the plant. This was considered in the determination of pest severity indices. Stepwise multiple regression used individual pest indices to determine the effect of each pest on yield.

Optimum temperatures for infestation were determined by relating pest incidence to prevalent temperatures. Actual occurrence of pests during optimal conditions and basic statistics regarding pest incidence on infested cabbage crops were incorporated to give an idea of overall pest incidence in the Umlaas River Valley (Table 3).

Multiple stepwise regression was used to determine the effects of each pest on yield and identify the most important cabbage pests. Multiple stepwise regression also determined effects of soil nutrient levels, fertiliser applied, leaf nutrient levels at headform, management rating, water stress, number of land operations, soil factors, temperatures, plant population and time of planting on the severity index for each pest.

This study used five regression models to evaluate parameter effects on pest indices of the following cabbage pests: American bollworm, aphid (*Brevicoryne brassicae* L.), diamond-back moth, greater cabbage moth (*Crocidolomia binotalis*, Zella.), cabbage web worm, cutworm (*Agrostis* species), thrips (*Thrips tabaci* Lind. and *Frankliniella schultzei*) and leafminer (*Phthorimaea operculella* Zeller). Model 1 included all the parameters above (e.g., soil nutrient levels, fertilizer applied, etc.) except for overall DI to identify parameters affecting the overall and individual PI's of each crop. Model 2 included overall DI and Model 3 the DI for each disease on each crop. Ringspot (*Mycosphaerella brassiciola* (Duby) Oud.) often showed a strong association with overall and individual PI and was the most important factor in regressions, but had little effect on yield (§ 5) and was excluded from analysis in Model 4. Similarly sclerotinia (*Sclerotinia sclerotiorum* (Lib.) de Bary) showed strong correlation and very high significance to overall and individual PI but little effect on yield (§ 5) and was excluded from analysis in Model 5. Clubroot (*Plasmodiophora brassicae* Woron.) was often the most important factor in regressions of Model 5, and contributed to yield reductions in cabbage crops (§ 5). Therefore Model 5 was chosen as the last regression model.

Table 1 Parameters for severity assessments of cabbage pests in the Umlaas River Valley

Pest	Assessments		
	Slight	Moderate	Severe
Aphids	1-5 $plant^{-1}$	6-20 $plant^{-1}$	> 20 $plant^{-1}$
Cutworm	small bite out of stem (< ¼ of stem)	medium bite of stem (¼-½ of stem)	large bite out of stem (> ½ of stem)
Diamond-back moth	1 windowpane/eaten hole $plant^{-1}$	1-5 windowpane/ eaten holes $plant^{-1}$	>5 windowpanes/ eaten holes $plant^{-1}$
Greater cabbage moth	1 eaten hole $plant^{-1}$	1-5 eaten holes $plant^{-1}$	> 5 eaten holes $plant^{-1}$
Bollworm	1 hole $plant^{-1}$	1-3 holes or 1 worm $plant^{-1}$	> 3 holes or > 2 worms $plant^{-1}$
Thrips	< 5 $plant^{-1}$	5-20 $plant^{-1}$	> 20 $plant^{-1}$
Leafminer	≥ 1 tunnel $plant^{-1}$		
Cabbage webworm	1 worm outside the growing point (GP)	1 worm inside GP but GP not yet eaten	GP eaten

Table 2 Multiplication factors used for pest severity indices of cabbages in the Umlaas River Valley

Pest	Severity of pests		
	Slight	Moderate	Severe
Aphids	0.1	0.4	0.8
Cutworm	0.1	0.5	1
Diamond-back moth	0.1	0.4	0.6
Greater cabbage moth	0.1	0.6	0.8
Bollworm	0.1	0.6	0.8
Thrips	0.01	0.05	0.1
Leafminer	0.01		
Cabbage webworm	0.1	0.7	1

Results

The following pests were observed in cabbage crops grown in the Umlaas River Valley from June 1991 to July 1993: aphid, thrips, cutworm, greater cabbage moth, diamond-back moth, American bollworm, leafminer and cabbage webworm.

Seasonal and temperature occurrence

Aphids and thrips were observed all year round, with highest populations of aphid over summer and lowest populations over spring, and thrips from autumn to early summer (Table 3).

Table 3 Temperatures and seasons of cabbage infestation by various pests in the Umlaas River Valley, 1991-1993

Pest	Daily temperature ranges (°C)		Season
	Minimum	Maximum	
Aphids	8-18	20-29	All year round
Thrips	8-18	20-29	Can occur all year round, but mostly autumn to early summer
Cutworm	8-18	21-29	Spring to autumn
Greater cabbage moth	8-18	21-28	Spring to autumn
Bollworm	14-18	24-28	Late spring to early autumn
Diamond-back moth	14-18	24-28	Summer
Webworm	10-18	23-29	Late summer to early winter
Leafminer	9-18	22-28	Summer to winter

Lower thrips populations were seen over the summer rainfall period with apparent migrations of thrips from bush to irrigated cabbage lands over autumn and winter. This was attributed to the lack of rain over this period.

Most of the caterpillars and worms, namely cutworm, greater cabbage moth, diamond-back moths and bollworm, preferred the warm summer conditions and were seldom seen over winter. Leafminer appeared in summer and was still present until winter. It was not classified as a mid-summer pest because the mean minimum and maximum temperatures were lower than those of bollworm and diamond-back moth. Webworm preferred cooler conditions from late summer to early winter (10 - 18°C mean minimum, 23 - 29°C mean maximum, Table 3), but avoided the cold temperatures experienced over winter.

Pest infestation

Table 4 indicates the degree of infestation by each different cabbage pest in the 59 crops monitored.

Table 4 Percentage crops infested by each pest and infestation figures for each crop in the Umlaas River Valley, 1991-1993

Pest	% crops infected	% infestation crop^{-1}			Mean % of all cabbages infected
		Mean %	Minimum %	Maximum %	
Bollworm	90	12	1	40	11
Aphids	80	13	1	71	10
Diamond-back moth	68	14	1	63	10
Thrips	51	44	5	100	22
Greater-cabbage moth	34	8	1	45	3
Cabbage webworm	31	11	1	38	3
Leafminer	22	25	2	80	6
Cutworm	20	3	1	7	1

Of the 59 cabbage crops grown, 53 were infested with bollworm (i.e., 90 %, Table 4), but the mean percentage infestation $crop^{-1}$ was low (12 %). Aphids and diamond-back moth also infested the majority of crops grown but the mean percentage infestation $crop^{-1}$ was also low (13 and 14 %, respectively). Bollworm, aphids and diamond-back moths infested 10 - 11 % of cabbages grown from June 1991 - July 1993.

Thrips infested about half the cabbage crops grown over the study period with about half of each crop being infested by the pest. In terms of percentage total cabbage crop, thrips infested 22 % of all cabbages grown, and was thus the most prevalent pest.

Greater cabbage moth, webworm, leafminer and cutworm were found in 20 - 34 % of crops monitored and, except for leafminer (mean percentage infestation = 25 % $crop^{-1}$), infested a small portion of each crop. Table 4 also shows the resultant low infestation of these pests over the cabbage crop as a whole (1 - 6 %).

Pest effects on yield

Although Table 4 showed the percentage crops, plants $crop^{-1}$ and total crop infested by each pest, it was not possible to estimate the damage effected by each pest, except by use of the severity indices (Table 1 and 2). Stepwise multiple regression used individual pest indices (PI) to determine the effect of each pest on cabbage yields.

Some cabbage crops were affected by water stress and adverse soil conditions (low pH, high acid saturation). The exclusion of these crops in regression analysis showed that aphid and webworm had significant (t-value = -2.38*) and highly significant (t-value = -2.75**) effects on yield. The inclusion of crops affected by water stress and soil acidity problems showed that aphids and thrips had significant effects on cabbage yield (t-value = -2.58* and -2.45*, respectively), while webworm again had a highly significant effect on yield (t-value = -2.91**)(Figure 1).

Leafminer was found to have a highly significant association with yield (t-value = -3.52**) but was excluded from analysis because its effects on yield were regarded as negligible.

Field observations showed leafminer preference for stressed crops and therefore any yield association was attributed to the association with plant stress, not leafminer infestation.

Factors affecting PI

Multiple regression Model 1 (excluding DI) showed that weed leaf area index (LAI) infiltration rate and slope had significant effect on PI (t-value = 3.19**, -3.29** and 2.57*, respectively) but could only account for 29 % of the variation. Stepwise multiple regression Model 2 (Table 5, including DI), determined the effects of all factors on pest indices.

Table 5 Variables with significant association to pest indices (PI) of 59 cabbage crops in the Umlaas River Valley (Model 2)

Variable	Coefficient	t-value[a]
Management rating	-1.85	-2.35*
Leaf Mg at headform	-98.34	-2.18*
Land slope	5.78	2.45*
Disease index	0.68	4.9***

[a] Numbers followed by * and *** are significant at the $P \leq 0.05$ and 0.001 levels, respectively

It was found that management ratings, leaf magnesium (Mg) levels at headform, and slope all had significant ($P \leq 0.05$) effects on PI, while disease severity (disease index) had a very highly significant effect ($P \leq 0.001$) on PI (Table 5). Correlations (R) between PI and individual DI were explained with PI\DI correlations of 0.83 for ringspot, 0.77 for sclerotinia rot and 0.33 for clubroot which in turn explains the very highly significant association of the overall DI with PI. Model 2 had an R^2 value of 0.37.

Both management ratings and leaf Mg at headform had negative associations with PI, i.e., better management and higher leaf Mg levels were associated with low incidence and severity of pests.

Table 6 (Model 3) shows factors affecting PI and included the DI for each disease.

Table 6 Variables with significant association to pest indices (PI) of 59 cabbage crops in the Umlaas River Valley (Model 3)

Variable	Coefficient	t-value[a]
Weed index (LAI)	0.70	3.34**
Soil sample density	72.40	2.88**
Infiltration rate	-8.92	-2.58*
Land slope	3.32	2.34*
Ringspot index	16.34	10.84***

[a] Numbers followed by *, ** and *** are significant at the P ≤ 0.05, 0.01 and 0.001 levels, respectively

Ringspot could account for 69 % of the variation in PI. Soil infiltration rate and land slope had significant (P ≤ 0.05) effects, while weed (LAI) and soil sample density had highly significant (P ≤ 0.01) and ringspot very highly significant (P ≤ 0.001) effects on PI (Table 6). Model 3 could account for 80 % of the variation in PI. The positive coefficients in Table 6 showed that a higher weed index, sample density, slope and ringspot index were associated with increased incidence and severity of pest infestation. The negative coefficients of infiltration rate meant that higher infiltration rates (i.e., better infiltration) were associated with less pests or a low PI.

§ 5 showed ringspot had no significant effect on cabbage yields. Therefore, for a more accurate assessment of factors affecting PI, and thus yield, ringspot was excluded from the next analysis (Table 7, Model 4).

Table 7 Variables with significant association to pest indices (PI) of 59 cabbage crops grown in the Umlaas River Valley (Model 4)

Variable	Coefficient	t-value[a]
Applied P	0.17	2.69**
Applied S	-0.13	-3.38**
Leaf Zn at headform	0.34	3.61***
Mean daily temperature	3.96	4.15***
Effective rooting depth	-0.37	-6.44***
Land slope	2.85	2.22*
Sclerotinia index	10.72	13.42***

[a] Numbers followed by * , ** and *** are significant at the $P \leq 0.05$, 0.01 and 0.001 levels, respectively

In Model 4, sclerotinia accounted for 59 % of the variation in PI and, along with effective rooting depth, mean daily temperature and leaf Zn at headform, all had very highly significant ($P \leq 0.001$) effects on PI. The total P and S applied in fertilizer had highly significant ($P \leq 0.01$) effects on PI, while the association with land slope was significant ($P \leq 0.05$). Model 4 accounted for 83 % of the variation in PI.

The positive coefficients in Table 7 showed that high levels of applied P, leaf Zn at headform, mean daily temperatures, land slope and sclerotinia were associated with greater pest infestation. Conversely, the negative coefficients showed that higher applications of S and deeper effective rooting depths were associated with lower pest infestation. § 5 showed that sclerotinia had no significant effect on cabbage yields. Therefore sclerotinia was excluded from the next analysis in Table 8 (Model 5).

Table 8 Variables with significant association to pest indices (PI) of 59 cabbage crops grown in the Umlaas River Valley (Model 5)

Variable	Coefficient	t-value[a]
Weed index (LAI)	1.22	3.34**
Management rating	-2.48	-3.5**
Applied Mg	-0.41	-2.76**
Soil sample density	120.77	2.94**
Land slope	6.82	3.1**
Clubroot index	0.81	3.77***

[a] Numbers followed by ** and *** are significant at the $P \leq 0.01$ and 0.001 levels, respectively

In Model 5 (Table 8) clubroot accounted for 11 % of the variation in PI and had a very highly significant ($P \leq 0.001$) effect on PI. The weed index (LAI), management ratings, amount of Mg applied, soil sample density and land slope all had highly significant ($P \leq 0.01$) effects on PI. Model 5 could account for 47 % of the variation in PI.

The positive coefficients in Table 8 showed that higher weed LAI, soil sample density, clubroot index and greater slopes were associated with more pest infestation. Conversely, the negative coefficient showed that higher levels of management (i.e., better management) and the application of more Mg in fertilizer resulted in fewer pest problems.

Numerous variables were often associated with high pest indices in Models 2 to 5. Firstly, the overall amount of disease, expressed in the DI or as individual disease indices, was always responsible for much of the variation in PI. Steeper land always had at least significantly more pest problems than flatter land in all models, while management ratings, soil sample density, and weed indices had significant effects on PI in at least two models each. Infiltration rate and effective rooting depth could be linked to waterlogging effects of each respective soil, and were important factors in one model each. The amounts of applied P, S and Mg were factors in one model each, as were leaf Mg and Zn at headform. Mean daily temperature was an important factor in one model only. These facts indicate that the severity of pest infestation was strongly influenced by: the amount of disease and weeds; use of steep or poorly drained lands; applied P, S and Mg; and soil acidity problems with low Mg and high Zn uptake by the plant. All these factors could be related to management.

Aphids

Models 3 and 4 could explain the most variation in aphid indices of all cabbage crops grown in the Umlaas River Valley (R^2 = 0.81 and 0.83, respectively) (Table 9).

Table 9 Factors affecting aphid indices on cabbages grown in the Umlaas River Valley

Variable	t-values of each descriptive model[a]				
	Model 1 R^2=0.22	Model 2 R^2=0.40	Model 3 R^2=0.81	Model 4 R^2=0.83	Model 5 R^2=0.22
Leaf Mn at headform	3.40**		5.10***	5.65***	3.40**
Land slope	2.16*			3.86***	2.16*
Management rating		-2.54*			
Applied K		3.31**			
Applied Ca		-2.96			
Disease index		3.75***			
Soil sample density			3.27**	4.40***	
Soil Mg			2.218*		
Plant population			-2.48*		
Sclerotinia index			3.40**	12.61***	
Ringspot index			2.92**		
Applied P				2.90**	
Soil K				-2.15*	
Soil Zn				3.6**	

[a] Numbers followed by *. ** and *** are significantly different at the P ≤ 0.05, 0.01 and 0.001 levels, respectively

Leaf Mn, soil sample density and sclerotinia index had at least highly significant effects on aphid incidence and severity in both models, as had land slope in Model 4. Higher soil levels of Mg ($P \leq 0.05$), increased incidence of ringspot ($P \leq 0.01$) and lower plant populations ($P \leq 0.05$) were associated with higher aphid indices in Model 3. Model 4 showed increased aphid indices with higher applied P ($P \leq 0.01$) and soil Zn ($P \leq 0.01$) and lower soil K levels ($P \leq 0.05$).

Model 1 and Model 5 had the same results. Model 1 excluded all disease indices, while Model 5 excluded only ringspot and sclerotinia indices, thus showing only ringspot and sclerotinia to have significant effects on aphid indices. The exclusion of these two disease indices showed that leaf Mn at headform ($P \leq 0.01$) and land slope ($P \leq 0.05$) had significant effects on aphid indices. The effects of Mn at headform and slope were notable in Model 1, 3, 4 and 5 (leaf Mn, $P \leq 0.01$ and slope, $P \leq 0.05$).

Ringspot required little control and sclerotinia could not be controlled, therefore it is not surprising that management did not feature in Models 3 and 4. In contrast, the disease index included all diseases and was indicative of management ability. Therefore management featured in Model 2. Furthermore, aphids are an easy pest to control and only poor management allows populations to get out of control. Therefore management is a major factor associated with variation in aphid indices.

Thrips

Thrips had a significant effect on cabbage yields and accounted for 8 % of the variation in yield (Figure 1). Variables affecting thrips indices were the same for Models 1 and 2, and 3, 4 and 5. Therefore only results of Models 1 and 3 are shown in Table 14.

Table 14 Factors affecting thrips indices on cabbages grown in the Umlaas River Valley

Variable	t-values of each descriptive model[a]	
	Model 1	Model 3
	$R^2=0.53$	$R^2=0.53$
Soil acidity	2.64*	2.50*
Soil pH	5.24***	5.35***
Water stress	2.42*	2.51*
Mean daily temperature	-2.32*	-3.14**
Land slope	2.18*	2.21*
Infiltration rate		-2.34*
Damping-off		2.60*

[a] Numbers followed by *, ** and *** are significantly different at the $P \leq 0.05$, 0.01 and 0.001 levels, respectively.

The overall effects of disease had little effect on thrips incidence and infestation of cabbage crops as Model 2 was identical to Model 1. Higher soil acidity and pH, a lack of water and a greater slope were all associated with higher thrips indices in Models 1 and 2. Cooler temperatures were also associated with increased thrips indices. This agreed with observations in Table 3 with thrips present all year round, but more prevalent from autumn to early summer.

The inclusion of all individual DI in Model 3 showed only damping-off to have significant association with thrips damage. All other variables remained in the model and infiltration rate was also included. Heavier soils with a slow infiltration rate had more thrips damage to cabbages, than sandier soils with a high infiltration rate.

Cabbage webworm

Webworm was the most significant pest affecting cabbage yields and accounted for 9 % of the variation in yield (Figure 1). Variables affecting webworm indices in Models 4 and 5 were the same as in Model 3 and therefore not included in Table 13.

Table 13 Factors affecting webworm indices on cabbages grown in the Umlaas River Valley

Variable	t-values of each descriptive model[a]		
	Model 1	Model 2	Model 3
	R^2=0.12	R^2=0.12	R^2=0.38
Leaf Ca at headform	2.80**	2.80**	3.34**
Management rating			-2.34*
Damping off			4.25***

[a] Numbers followed by *, ** and *** are significantly different at the $P \leq 0.05$, 0.01 and 0.001 levels, respectively

There was a highly significant association between leaf Ca at headform and webworm severity in all models. Increased Ca levels in plants were always associated with more severe webworm infestation. Similarly, crops with more damping-off also had higher webworm indices. Webworm was a difficult pest to control, as shown by the negative association with management in Model 3. Better management resulted in less severe webworm damage.

Diamond-back moth

Diamond-back moth was infrequently observed in the field and had little effect on cabbage yields. None of the variables in Model 1 had any significant effect on the incidence and severity of diamond-back moth. The inclusion of DI into the variables in Model 2 show that only DI had a significant effect (R^2 = 0.11, t-value = 2.69**). Model 3 showed ringspot index as the only significant variable (R^2 = 0.40, t-value = 5.85***), while Model 4 showed sclerotinia and clubroot indices could explain 42 % of the variation in diamond-back moth index between them. In Model 5, only clubroot had a significant effect on diamond-back moth index, accounting for 13 % of the variation (R^2 = 0.13, t-value = 2.92**). It appears that plants infected by these diseases were more susceptible to infestation by diamond-back moth.

Greater cabbage moth

Greater cabbage moth was infrequently found in the field and had little effect on cabbage yields. No variables in Models 1 to 5 had any significant effect on the incidence and severity of greater cabbage moth. The highest correlation of any variable was R = 0.18, with leaf P levels at headform. The disease index in Model 2 and disease indices in Models 3, 4 and 5 showed no change to Model 1, with the order of correlated variables staying the same for all models.

American bollworm

Bollworm was often seen in cabbages monitored from June 1991 - July 1993, but did not have a significant effect on yield (Figure 1). Many variables had an effect on bollworm incidence and severity (Table 10).

Weed index (LAI) and soil wetness class were the most common factors associated with bollworm indices and had at least, significant effects ($P \leq 0.05$) in four out of five models. Applied N also played a significant role in Model 1 and 2.

Models 3, 4 and 5 accounted for the most variation in bollworm indices at R^2 values of 0.69, 0.68 and 0.52, respectively. Ringspot and soil wetness class had very highly significant ($P \leq 0.001$) associations with bollworm in Model 3. Similar effects were seen with sclerotinia ($P \leq 0.001$) in Model 4, and land class and alternaria ($P \leq 0.01$) in Model 5.

Higher levels of applied N and S, leaf Mn and soil CEC, better management and the increased incidence of blackrot, were all associated with lower infestation by bollworm. All the other variables in Table 10 were positively associated.

Table 10 Factors affecting bollworm indices on cabbages grown in the Umlaas River Valley

Variable	t-values of each descriptive model[a]				
	Model 1	Model 2	Model 3	Model 4	Model 5
	R^2=0.25	R^2=0.25	R^2=0.69	R^2=0.68	R^2=0.52
Weed index (LAI)	2.84**	2.84**	2.33*		3.5**
Applied N	-2.13*	-2.13*			
Wetness class	2.81**	2.81**	4.8***	2.38*	
Leaf Mn at headform			-3.34**		
Soil CEC			-2.5*		
Ringspot			8.9***		
Mean daily temp.				2.93**	3.27**
Land class				2.71**	3.53**
Sclerotinia				7.66***	
Alternaria				2.45*	4.15***
Management rating					-2.51*
Applied S					-2.32*
Blackrot					-2.50*

[a] Numbers followed by *, ** and *** are significantly different at the $P \leq 0.05$, 0.01 and 0.001 levels, respectively

Leafminer

Leafminer was found on 6 % of all cabbages grown over the study period (Table 4), but had no significant effect on cabbage yields (Figure 1). Model 1 showed that LAI of weeds ($P \leq 0.05$), N ($P \leq 0.01$), Ca ($P \leq 0.05$), Mn nutrient levels at headform ($P \leq 0.001$) and soil acidity ($P \leq 0.01$) had significant associations with leafminer PI (Table 11).

Table 11 Factors affecting leafminer indices on cabbages grown in the Umlaas River Valley

Variable	t-values of each descriptive model[a]				
	Model 1	Model 2	Model 3	Model 4	Model 5
	R^2=0.63	R^2=0.65	R^2=0.75	R^2=0.78	R^2=0.73
Weed index	2.49*	2.30*			
N at headform	-3.22**	-3.0**			
Ca at headform	2.31*				
Mn at headform	6.22***	5.31***			
Soil acidity	-3.29**	-3.97***	-3.85***	-3.97***	-4.14***
Disease index		3.8**			
Mg applied			2.54*	2.90**	
Blackrot			11.54***	12.6***	10.32***
Ringspot			4.83***		
Land class				2.30*	
Sclerotinia				5.56***	
Management rating					-2.15*
P at headform					-2.43*
Cu at headform					2.88**
Clubroot					2.46*

[a] Numbers followed by *, ** and *** are significantly different at the $P \leq 0.05$, 0.01 and 0.001 levels, respectively

Model 2 excluded Ca at headform and included disease index, but was otherwise similar to Model 1. The overall effects of all diseases (DI) was not as great as individual disease indices, as shown with Model 3.

Models 3, 4 and 5 showed that blackrot, ringspot, clubroot and sclerotinia had significant association ($P \leq 0.01$ and 0.001) with leafminer index. P ($P \leq 0.05$) and Cu ($P \leq 0.01$) leaf nutrient levels, applied Mg ($P \leq 0.05$ and 0.01), management ($P \leq 0.05$) and soil classification ($P \leq 0.05$) also influenced leafminer PI in Models 3, 4 and 5. Of note was the constant negative association of exchangeable soil acidity and leafminer index; an increase in exchangeable soil acidity was related to less leafminer infestation. Model 4 accounted for the most variation (78 %) in the leafminer index.

Cutworm

Only two variables could explain the variation observed in cutworm damage. Leaf P and Zn at headform explained 15 % of variation in cutworm indices for all models, 1 - 5 (Table 12).

Table 12 Factors affecting cutworm indices on cabbages grown in the Umlaas River Valley

Variable	t-values of each descriptive model[a]				
	Model 1	Model 2	Model 3	Model 4	Model 5
	R^2=0.15	R^2=0.15	R^2=0.15	R^2=0.15	R^2=0.15
P at headform	-2.8*	-2.8*	-2.8*	-2.8*	-2.8*
Zn at headform	2.33*	2.33*	2.33*	2.33*	2.33*

[a] Numbers followed by * are significantly different at the $P \leq 0.05$ level

Plants with higher levels of P and lower levels of Zn were less prone to attack from cutworm. The reliability of these data is questionable, as effects of good P uptake from the soil and excessive Mn uptake would only be observed about two weeks after transplanting. Plant destruction by cutworm would have taken place before the effects of applied P and excess Mn were expressed in the plant. Nevertheless this association was observed and should be noted.

Discussion

This study has recorded the actual occurrence of all pests in the Umlaas River Valley so that the overall infestation of cabbage crops by pests could be ascertained. It also identified temperatures and seasons suitable for the occurrence of various pests and evaluated individual pest effects on crop yield. This work identified factors related to infestation by specific pests, thereby generating guidelines for improved pest management of that particular pest. In general, PI were affected by factors all relating to farming/management practices and could be reduced by implementing the guidelines recommended in this study.

Aphids

Aphids are regarded as severe pests of cabbages in Natal (Annecke & Moran, 1982; Bell, 1984). Three species of aphid are found in South Africa; the cabbage aphid (*Brevicoryne brassicae*), the turnip aphid (*Lipaphis erysium*) and the green peach aphid (*Myzus persicae*) (Annecke & Moran, 1982). This study did not identify specific aphid types, but observed aphids all year round with higher populations over summer and lower populations in spring. Annecke & Moran (1982) reported good adaptability of the green peach aphid to summer and winter conditions, but found it was outnumbered by the turnip aphid in summer and the cabbage aphid in autumn and spring. Summer infestation of cabbage by the turnip aphid is generally known to be more severe than autumn or winter infestation by the cabbage aphid. Aphids are usually comparatively scarce in spring (Annecke & Moran, 1982). This is attributed to the cooler, wet conditions experienced in spring (Finch & Thompson, 1992).

Observations in this study showed that high populations of aphid caused severe stunting to cabbage seedlings (especially up to six weeks after transplanting), while infestation during the latter stages of plant growth detracted from the appearance of infested plants. Aphids, honeydew excreted by the pest, cast aphid skins and sooty mould growth on the honeydew, reduces marketability of cabbages (Annecke & Moran, 1982; Bell, 1984; Finch & Thompson, 1992).

Table 4 showed 10 % of all crops to be infested with aphids. This had a significant effect on cabbage yields (Figure 1). Finch & Thompson (1992), citing Theunissen (1984), suggested aphid population levels before applying insecticide, as 10 - 15 % infestation at two weeks after transplanting, 20 - 40 % at 6 - 10 weeks, 10 % at buttoning and 0 % four weeks before harvest of Brussels sprouts. The significant yield effects of 10 % aphid infestation in all cabbages in this study, suggest that spraying should be implemented at lower infestation percentages.

Based on the seasonal occurrence of aphid and its significant effect on cabbage yields in the Umlaas River Valley, we recommend preventative sprays of aphicides in summer, autumn and winter, with increasing frequency of spraying in summer. Scouting and corrective spraying is recommended for spring.

The most significant factors relating to aphid PI were leaf Mn levels, DI (esp., ringspot and sclerotinia), sandier soils and the slope of the land (Table 9). Other factors such as applied P and K and soil fertility levels had smaller, though significant roles (Table 9). The use of critical soil values in fertilizer recommendations (§ 1) would avoid low soil K and correct over-application of P. In examining the causes of high leaf Mn levels, other factors observed in Table 9 were found. Mn availability in the soil and plant uptake is increased with lower soil pH (Tisdale, Nelson & Beaton, 1990), therefore soil acidity problems could be associated with high Mn concentrations in the plant and more aphids. Applied K can reduce soil pH by displacement of Ca (Tisdale *et al.*, 1990), which could explain the positive correlation of applied K and aphid PI. Similarly, higher levels of applied Ca (Table 9) will raise soil pH, thus making Mn less available (Tisdale *et al.*, 1990), to the plants and less susceptible/attractive to aphids. Sandier soils are generally associated with lower soil pH (Tisdale *et al.*, 1990), therefore it was not surprising to find more aphids on soils with higher sample density (sandier soils) in Models 3 and 4 (Table 9). Corrective liming practices to raise soil pH would lower plant Mn concentrations and could result in lower aphid infestation.

Lewis (1969) documented the effects of slope on aphid infestation. Our study corroborated his findings, in that more aphids were deposited on sloping lands and tended to fly over flat lands, i.e., the steeper the slope of the land, the more aphids were found.

Overall it appears that management factors, and inherent soil factors (such as slope and soil sample density) played a major role in the degree of aphid infestation. The following guidelines are suggested for prevention and control of aphids on cabbage in the Umlaas River Valley:

1) Avoid the use of sloping lands for summer cabbage production. Sloping lands can be used in autumn and winter and into, but not through, spring.
2) Cognisance of prevailing winds and use of sheltered lands for cabbage production could also reduce aphid population levels.
3) Corrective aphicides should be sprayed in autumn, winter and spring and the frequency of corrective applications increased in the summer, especially in the first six weeks after transplanting. Scouting and the application of preventative aphicides should begin in late spring.
4) Avoid excessive amounts of K in fertilizer application (§ 1, 3 and 4) and excessive use of NH_4 containing fertilizers (§ 4)(both can reduce soil pH).
5) Avoid use of lands with soil pH < 4.5 (§ 1 and 2) or lime soils with pH ≥ 4.5.
6) Use the critical values in § 1 to maintain soil fertility levels.

Thrips

Thrips were a serious problem with cabbages grown in the Umlaas River Valley from 1991 to 1993. They infested 22 % of the total crop grown (Table 4) and had a significant effect (Figure 1) on cabbage yields. Literature does not regard thrips as notable pests of cabbages (Annecke & Moran, 1982; Bell, 1984; Myburgh, 1988; Finch & Thompson, 1992) but Annecke & Moran (1982) and Myburgh (1988) noted the appearance of the onion thrips on cruciferous plants.

As with aphids, this study observed that effects of thrips infestation were more serious in the seedling stage until about six weeks after transplanting. This study also observed thrips all year round, but with higher populations over the cooler period. Annecke & Moran (1982) and Myburgh (1988) associated thrips with damage to seedlings or young plants which are grown through the cooler season. Table 14 showed the highly significant effects ($P \leq 0.01$) of mean daily temperature on thrips incidence and severity. Higher temperatures were thus associated with lower thrips populations. Therefore, we recommend corrective spraying for thrips all year round, with increased frequency of spraying and corrective spraying from autumn to spring.

Higher thrips populations were observed during the cooler season on more neutral pH soils with a slow infiltration rate. A greater slope, increased water stress and higher soil exchangeable acidity were also associated with higher thrips populations (Table 14). Increased thrips PI with higher soil pH and higher exchangeable acidity was contradictory and cannot be explained. Guidelines for prevention and control of thrips in the Umlaas River Valley are as follows:

1) Spray correctively for thrips throughout the year with increased frequency over the cooler autumn to spring periods, especially in the first six weeks after transplanting. Scouting and corrective chemicals could be administered for crops grown through the winter.
2) Spraying and scouting is especially recommended for more neutral soils, heavier clay soils or lands with greater slope or compaction problems.
3) Crop stress due to lack of sufficient water, should be avoided. This study recommends improved irrigation practices, with use of tensiometers to monitor available soil moisture.

Cabbage webworm

Very little information is available on the cabbage webworm. Our study noted the appearance of webworm from late summer to early winter (Table 3). It infested only 3 % of all cabbages monitored (Table 4) but had a highly significant effect on yield (Fig. 1). One worm could easily eat out the growth point of one plant which resulted in a lack of head formation. Most of the time it was observed, webworm severity assessment was either moderate or severe. As with aphids and thrips, the most dangerous period was in the first six weeks after transplanting. Both Annecke & Moran (1982) and Myburgh (1988) noted the dangers of this pest on young cabbage plants. Field observations showed that regular spraying of registered chemicals applied at high pressure and a fine droplet size, could control these pests. However, control measures were less effective once the webworm had sprung its silken web and tied the young leaves together around the growth point. There are no chemicals registered specifically for webworm (Nel, Krause, Hollings, Greyling & Dreyer, 1993) but pesticides registered for other pests on cabbage gave good control if applied at high pressure in a fine droplet size.

This study showed webworm infestation of a particular cabbage crop to be highly associated with damping-off. All the models in Table 13 also showed a leaf Ca association with the pest. § 5 showed that leaf Ca had no significant effect on the incidence of damping-off, so the effects of these two factors on webworm indices appear to be separate but cumulative. High leaf Ca levels could be attributed to high soil Ca levels or too much available Ca from a recent application of lime. Poor crop management was also associated with more webworm damage.

Farmers should be aware of the possible webworm infestation from late summer to early winter, especially when damping-off is observed in the crop, soil Ca levels are high, or after the application of lime. Farmers with limited resources and therefore less effective crop management should be especially vigilant. Guidelines for prevention and control of webworm are as follows:

1) Scouting and preventative spraying with chemicals with a long residual action on the leaf surface, should begin at the end of summer.
2) Nozzles and spray pressure should be checked often but especially at the end of summer.
3) Corrective treatment should be applied regularly for the first six weeks after transplanting if infestation is noted.
4) To avoid excess uptake of Ca, lime must be applied at least one month before transplanting.

Diamond-back moth

Diamond-back moth are regarded as serious pests of cabbages in South Africa (Annecke & Moran, 1982; Bell, 1984). However, diamond-back moth did not have significant effects on yield in this study even though 10 % of all cabbages were infested (Table 4). Spraying procedures appeared to control diamond-back moth infestations, which in the Umlaas River

Valley were mostly a summer pest. In the Pretoria area, early and late summer plantings are subject to attack by diamond-back moth with populations decreasing in winter (Annecke & Moran, 1982).

Regression analysis to determine factors affecting PI of diamond-back moth showed only diseases, namely sclerotinia, ringspot and clubroot, to have significant effects on diamond-back moth PI. Since there were no other factors correlated with each disease, two possibilities could explain these associations. Firstly, diamond-back moth somehow recognised diseased plants. Alternatively, it is possible that diseased crops were neglected in terms of spraying and subsequently experienced more diamond-back moth infestation.

It appears that any reasonable pest control programme reduces diamond-back moth numbers and damage to such an extent that no serious economic damage is done; even 11.6 % caterpillars per plant fail to cause serious economic damage to the plants (Ullyett, 1947).

Greater cabbage moth

Greater cabbage moth (GCM) was also not a serious pest of cabbages in the Umlaas River Valley over the study period. Infestation was usually observed a little earlier than diamond-back moth, i.e., in spring. Annecke & Moran (1982) and Myburgh (1988) regarded the GCM as a minor cabbage pest which can be easily controlled by the same pesticides as for diamond-back moth (Bell, 1984; Nel *et al.*, 1993). Infestation figures in Table 4 showed only 3 % of all cabbages infested. With such a low percentage of infestation and most occurrences being only slight, it is not surprising that GCM had no significant effect on yield and also that no factors had any significant effect on GCM PI. As with diamond-back moth, any reasonable pest control programme should control GCM, with numerous chemicals controlling most pests (Nel *et al.*, 1993).

Bollworm

This study observed bollworm activity from late spring to early autumn, but bollworm was controlled by regular spraying of pesticides and had no significant effect on yield. Bollworm are well-known pests of cabbage crops (Bell, 1984; Myburgh, 1988) and cause serious damage if left unsprayed (Bell, 1984). Myburgh (1988) reported a drop in activity in midsummer, due to temperatures greater than 35°C, killing developing bollworm pupae. Chemicals controlling bollworm will also control diamond-back moth (Bell, 1984). Regular, effective treatments with registered pesticides will keep these pests under control, resulting in negligible crop damage. Management ability was only mentioned once in Table 10 as a factor affecting bollworm indices. Management effects were thought to be more indirect (e.g., wetness class) rather than direct, as in spraying, etc..

LAI of weeds and soil wetness class were the factors most commonly associated with bollworm indices. Most other researchers have observed decreased pest incidence with increasing weed populations (Altieri, 1981; Way & Cammell, 1981), especially with flying insects. Weeds lessen the contrast between young agronomic plants and the soil, and do not provide the crucial visual stimulus needed for the insect to recognise a crop in a field (Cromortie, 1975; Smith, 1976). This contrasted sharply with our work, where more weeds $plot^{-1}$ meant poorer weed management, and was related to higher bollworm indices. It seems more likely that bollworm problems were indirectly related to the management of each individual crop, as higher bollworm indices were observed on crops with soil of higher wetness class, i.e., very wet for most of the season. In other words, these were poorly drained soils, could be regarded as marginal lands, and therefore not managed as well as usual (less spraying, etc.). The fact remains, however, that more weeds and the use of soil prone to waterlogging was related to high bollworm infestations.

The possibility of some type of plant stress recognition by bollworm moths is mooted. Diseases such as ringspot, blackrot, sclerotinia and alternaria made very significant contributions to bollworm variation in their respective models (Table 10). Poorer levels of management, poor soils, insufficient N or S fertilizer were also correlated with higher bollworm indices. All these factors, disease, soils, management and insufficient fertilizer could result in plant stress which might be recognised by the bollworm moth when it lands on the leaf. Alternatively, after disease infection was observed, crops were neglected and pest infestation increased. The following management guidelines are recommended for prevention and control of bollworm on cabbages in the Umlaas River Valley:

1) Do not plant cabbage in poorly drained soils or marginal land, from spring to autumn, without adequate irrigation and pest control practices.
2) Ensure low LAI of weeds.
3) Scouting and preventative treatments can be used in early spring, with corrective treatments being applied after activity has been noted. Chemicals controlling bollworm will also control diamond-back moth and GCM.
4) Ensure adequate supply of N and S in fertilizer.
5) Bollworm infestation was associated with ringspot, sclerotinia and alternaria, therefore, be aware of possible infestation when these diseases are observed.

Leafminer

Leafminer is a non-significant minor pest of cabbages in the Umlaas River Valley area from summer to early winter. Weekly or bi-weekly insecticide sprays for the pest should keep leafminer under control, so that there is little chance of it becoming a severe pest. Leafminer is not mentioned as a pest of cabbages in South African literature (Annecke & Moran, 1982; Myburgh, 1988), but is recorded as a warm season pest of tomatoes. Myburgh (1988) reported that leafminer breed all year round, but extremely rapidly in summer, which accounts for their higher summer populations on tomatoes. High populations of leafminer are generally observed on the local tomato crop which is grown from spring to autumn. It is likely that adult moths seek alternate hosts with less rigorous spraying schedules on which to lay their eggs.

Contradictions observed in Table 11 are difficult to explain. In Models 1 and 2, the factors most significantly associated with the variation in leafminer indices were levels of Mn in the leaf at headform, and soil exchangeable acidity. Higher exchangeable acidity is generally correlated with lower pH and higher acid saturation. At lower soil pH, more Mn becomes available to the plant (Tisdale *et al.*, 1990). Our models contradict this, in that high soil acidity was related to lower PI of leafminer, and high leaf Mn resulted in high leafminer PI. Higher soil acidity should have resulted in higher leaf Mn and hence higher leafminer PI.

The application of NH_4-N in fertilizer causes acidification because of more available H^+ ions (Fey, Manson & Schutte, 1993). Higher leaf N at headform, had less leafminer infestation but could also be indicative of excessive N application. This could, in turn, be linked up with soil exchangeable acidity and explain lower leafminer PI with higher exchangeable acidity.

Models 3, 4 and 5 reveal important facts about leafminer associations with disease, namely blackrot, ringspot and sclerotinia. Leafminer also had a highly significant association with yield. It appears that diseased, stressed or poor crops appear more vulnerable or attractive to leafminer moths. Alternatively, these poorer crops are neglected and receive little pest control, facilitating infestation. Model 3 and 4 show the choice of higher potential land and better management to play a role in leafminer infestation.

In summary, leafminer is not an important pest of cabbages in the Umlaas River Valley and normal spray programmes for other pests should keep infestations at acceptable levels. However, farmers should use leafminer infestations as a gauge of crop health and management; infestations from summer to early winter show that cabbage crops are possibly neglected, diseased, poorly managed or in marginal lands.

Cutworm

Cutworms were observed from spring to autumn in cabbages in the Umlaas River Valley. Control measures were effective, with 1 % of all crop damaged by the worms, and no resultant significant yield effects. Cutworms are important pests of most vegetables and some agronomic crops, especially when transplanted seedlings are used (Bell, 1984; Myburgh, 1988). Cutworm normally overwinters as a slow-growing caterpillar. The first wave of infestation occurs in the spring, and two more generations occur before the next autumn. The occasional warm winters of the Umlaas River Valley could result in all-year-round infestation, or early infestation at the least, but farmers control by spraying or baiting for cutworm throughout the year. Clean cultivation and long waiting periods between crops, good crop rotations, poisonous baits and insecticides can be used for cutworm control (Bell, 1984; Myburgh, 1988).

Multiple regression in Table 12 showed cutworm preference for crops with lower leaf P and higher leaf Zn. These leaf readings were taken at about seven weeks after transplanting, so the results are more indicative of soil effects on the crop rather than seedling effects. It does point out, however, that better managed soils were observed to have adequate P and a reasonable pH (= lower leaf Zn levels, § 2), were probably better sprayed and had little cutworm problems.

In conclusion, webworm, aphids and thrips were the most serious pests of cabbages over the study period. Seasonal fluctuations of pest incidence were observed so that farmers could identify when to start spraying for specific pests. Most of the pests seem to occur over the warmer period from spring to autumn. The first six weeks after planting are the most crucial in terms of pest effects on cabbage yield. Webworm, aphids, thrips and cutworm can do great damage if not properly controlled during this period. Steeper slopes appear to be favoured by the smaller flying insects (aphid and thrips). This is probably because the larger moths (bollworm, diamond-backed moth, etc.) have more control when flying in the wind or in a gentle breeze. Therefore the smaller flying insects have more chance of being deposited on the slopes. The steeper the slope, the more aphids and thrips could be present. Generally there was a strong pest association with disease, soil class and condition, soil fertility and acidity, slope, weeds, fertilizers and plant health. All these factors were associated with farming practices and management choices. This study highlights the importance of management in pest control; better farming practices and good management choices resulted in less pests. Healthier plants on productive, fertile soils, experiencing good management and regular spraying, had little disease and lower levels of pest incidence.

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Variables	Coefficients	t-values
Webworm	-1.732	-2.91**
Aphids	-0.647	-2.58*
Thrips	-2.924	-2.45*

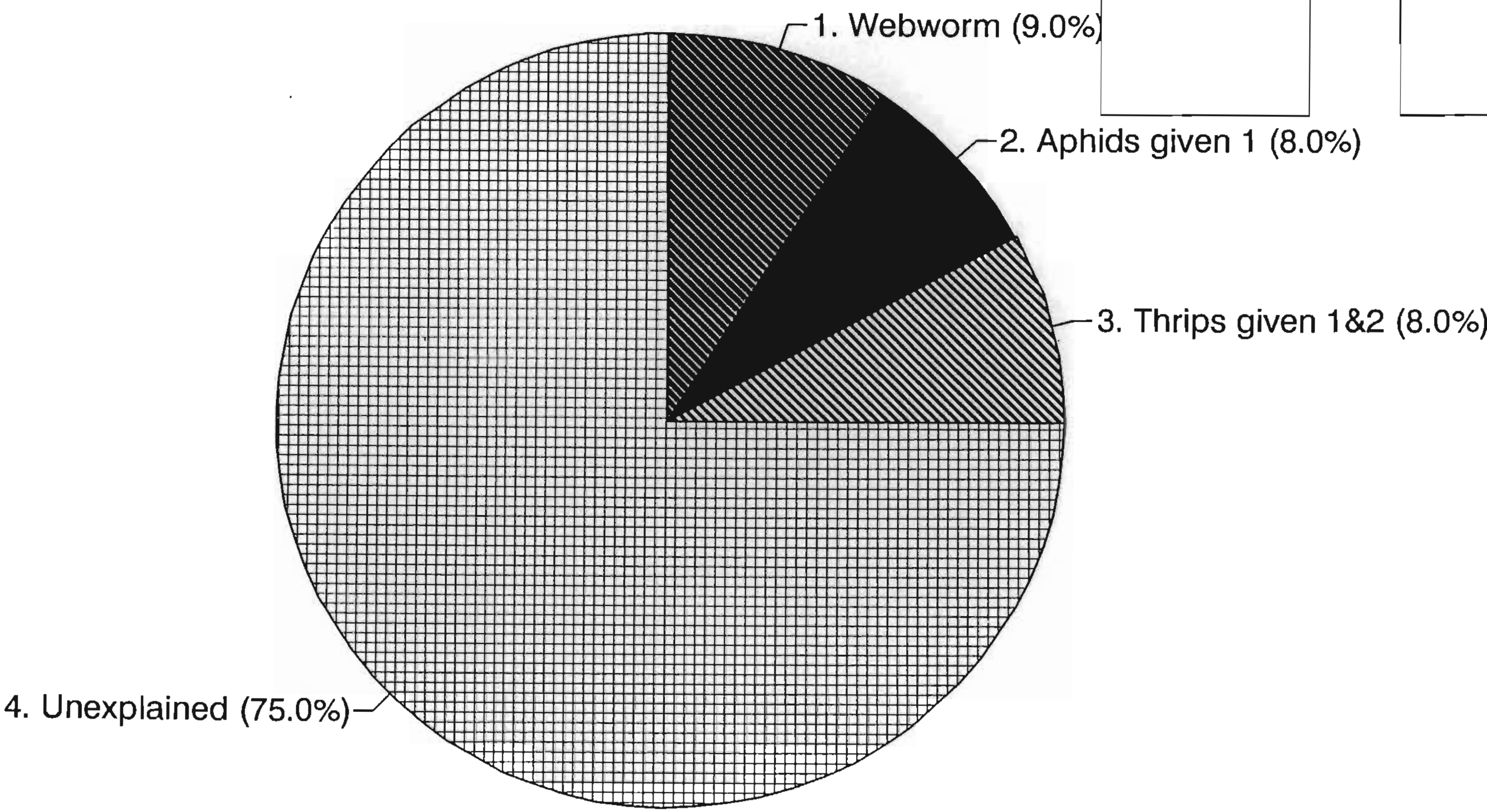

Figure 1 Pests affecting cabbage yields in the Umlaas River Valley, 1991 - 1993

7. INTERACTIONS BETWEEN WEATHER PATTERNS, HORMONE HERBICIDE SYMPTOMS ON PLANTS, PEST AND DISEASE INCIDENCE, AND PLANT HEALTH OF CABBAGE CROPS IN THE UMLAAS RIVER VALLEY, KWAZULU-NATAL, 1991-1993

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Abstract

Hot days with high temperatures > 30°C, high vapour pressure deficits (VPD) and high solar radiation, followed by a rapid drop in temperature, high relative humidity (RH) and low solar radiation (stress weather cycles) were characteristic of weather conditions with an approaching frontal low in the Umlaas River Valley. It would appear that an unknown factor (Factor X) occurred in conjunction with some of these weather cycles and caused hormone herbicide-like symptoms on some garden shrubs and trees and vegetable seedlings in the nursery. A Canary creeper (*Senecio tamoides* DC.), wild fig tree (*Ficus natalensis* Hochst.) and an indigenous Cape chestnut (*Calodendrum capense* (L.F.) Thunb.), showed symptoms of leaf bubbling, twisting, burn, deformities and leaf drop and served as indicator plants. Lettuce and cabbage seedlings were twisted, etiolated and suffered from downy mildew outbreaks. All trees, shrubs and nursery crops experienced these symptoms 1 - 4 days after the occurrence of stress weather cycles. It is possible that low levels of hormone herbicide (< 25 ng l^{-1}) deposited during dynamic fumigations (associated with an approaching frontal low), was the unknown factor. However, when examining simultaneous events on field cabbages and weather related factors, no clear relationship could be established between weather patterns, Factor X, cabbage plant health, deformities, and pest and disease incidence.

Keywords: stress, weather cycles, hormone herbicide, 2,4-D, cabbage, elevated inversions, deformities, pest, disease

Introduction

Findings of an intensive vegetable research programme into the causes of damage to vegetables in the Umlaas River Valley showed that many factors could be involved in the production of so-called hormone herbicide symptoms on crops (Van Niekerk, 1991; Holcroft, Smith & Dicks, 1991; Preston-Whyte & Laing, 1994). At this historic meeting, Preston-Whyte (1991 a & 1991 b) showed that hormone herbicide symptoms on lettuce (*Lactuca sativa* L.) were related to approaching frontal systems which caused lowering of the elevated inversion, contraction of the mixing depth and increased atmospheric temperatures. These factors associated with approaching frontal lows, resulted in deposition of pollutants (Preston-Whyte, 1990) which could have occurred through either thermal or dynamic fumigation in the Umlaas River Valley (Preston-Whyte & Tyson, 1988; Preston-Whyte, 1991 a). However, dates of hormone herbicide hits and lowering of elevated inversions were not related to hormone herbicide levels measured by the Plant Protection Research Institute (PPRI) in air and rain samples (Preston-Whyte, 1991 b). Smith (1991) examined the weather patterns and found that hormone herbicide symptoms on lettuce and adverse weather patterns were related. Days with high temperatures and VPD followed by cold fronts, were often associated with hormone herbicide symptoms on lettuce trials. Smith (1991) proposed that these environmental stress days caused ethylene release in the plant resulting in hormone herbicide-like symptoms. Alternately, it was thought that pollutant (e.g., acid rain) deposition during dynamic fumigations could account for the hormone herbicide symptoms on plants. However, analysis of air by Eskom showed low levels of pollutants, insufficient to cause damage to plants (Turner, 1991).

The monitoring of weather and hormone herbicides in rain was continued from 1991 - 1993. Damage attributed to hormone herbicide, was reported over this period. Unusual phenomena occurred on the farm of Mr M Wild. A Canary creeper (*Senecio tamoides* DC.), wild fig tree (*Ficus natalensis* Hochst.) and an indigenous Cape chestnut (*Calodendrum capense* (L.F.) Thunb.), situated in his garden showed visible symptoms of bubbling, twisting, leaf drop, deformities and leaf burn, etc.. Furthermore, symptoms on these plants were often associated with incidents in the nursery or in the field (e.g., downy mildew outbreak on lettuce and cabbage (*Brassica oleracea* L. var. *capitata* Alef.) seedlings, etiolated and twisted lettuce leaves, upright and etiolated cabbage seedlings, pest and disease outbreaks in the field). The farmer, Mr Wild, speculated that these related incidents were due to some form of hormone herbicide deposition. He especially noted simultaneous pest and disease outbreaks in field crops (esp., lettuce and carrot) which decreased his marketable yield. Other research has reported increased pest and disease activity after exposure to hormone herbicides. Oka & Pimental (1976) observed more corn leaf aphid and European corn borer, and southern corn leaf blight on maize exposed to 2,4-D than crops unexposed. Kessler (1980) reported high populations of canker worm on peach trees affected by 2,4-D drift, and Hodges (1980) reported increased incidence of *Drechlera sorokiniana*, on *Poa pratensis* after exposure to post-emergent herbicide combinations. Therefore it was possible that hormone herbicide deposition resulted in pest and disease outbreaks in nursery and field crops.

If hormone herbicides were involved, where were they coming from? No hormone herbicides > 25 ng l^{-1} were measured in rain samples from 1991 - 1993 and hormone herbicide drift from the immediate area was unlikely, as bans imposed in the area did not allow the spraying of any hormone herbicides. Pollutants in plumes from industrial stacks can be carried many kilometres in the elevated inversion, before wet or dry deposition occurs in other areas (Preston-Whyte & Tyson, 1988; Preston-Whyte, 1990). It was thought that hormone herbicide sprayed in unbanned areas, found its way into the Natal airshed, where it was present at levels below 25 ng l^{-1}. The hormone herbicides were then transported in the elevated inversion and deposited at the approach of a frontal low. However, the hormone herbicides were not measured in the rain samples because hormone herbicide levels were < 25 ng l^{-1}.

These reports and findings of the Working Group for Herbicide Damage from 1987 - 1991, lead to an examination of interactions between weather patterns, hormone herbicide symptoms on indicator plants, and pest and disease incidence in nursery and cabbage crops. The aim was to evaluate relationships between these factors, identify the cause of hormone herbicide-like symptoms on indicator plants and to determine if stress weather cycles and an unknown factor were responsible for any hormone herbicide symptoms or pest and disease outbreaks in cabbage crops grown in the Umlaas River Valley from 1991 - 1993.

Procedures

A canary creeper, indigenous Cape chestnut and a wild fig tree were designated as indicator plants on Ompad farm of Mr M. Wild from 1991 - 1993. The farmer reported to the author any hormone herbicide-like symptoms and related problems in nursery and field crops.

A Campbell Scientific CR10 Data Logger was set up by the Agrometerology Section of the Department of Agriculture, Cedara in July 1991. The station was placed on the crest of a hill in the centre of the study area. The following parameters were measured every 10 seconds and averaged over a 30-min period.

air temperature (°C)
soil temperature (°C)
saturated vapour pressure (kPa)
vapour pressure (kPa)
solar radiation (MJ day^{-1})
mean wind speed (ms^{-1})
mean wind vector magnitude (ms^{-1})
mean wind vector direction (0° - 360°)
rainfall (mm)
battery voltage (V)

Due to mechanical breakdown, some parameters were not measured for short periods during the study, but this did not affect overall accuracy of the data.

Monitor plots of 59 cabbage crops were visited weekly. Pests, diseases, weeds and general plant health were noted and soil analysis taken at headform (§ 1, 3, 4, 5 & 6). Crop water stress was also estimated with each visit (§ 5, 6 & 8).

Concurrently, all rain samples were collected by officials of the Department of Agriculture and tested at Umgeni Water for numerous hormone herbicides. Analysis could detect levels above 25 ng l^{-1} H_2O of the following active ingredients:

dicamba, MCPA, MCPB, 2,4,5-T, 2,4-D, 2,4-DB, trichlopyr and picloram.

In order to identify possible relationships, an analysis was made of the dates of hormone herbicide-like symptoms on indicator plants, data from the weather station and monitor plots and results of hormone herbicide analysis of rainwater.

Results

The observations of hormone herbicide-like symptoms on indicator plants and crops were recorded by the author. From when the data logger was set up in July 1991, 17 incidents were reported by Mr Wild. In relating these dates to weather patterns, it was observed that all 17 experienced a similar weather pattern, 1 - 4 days before the symptoms were observed. These patterns are illustrated in Fig. 1, 2 and 3. The conditions during these weather patterns were harsh and classified as stress weather cycles. Table 1 shows the ranges of temperature, VPD, RH and solar radiation changes induced by the change in weather on specific days of the year.

The first noticeable factor of these typical weather patterns was hot prevailing conditions which could last up to nine days (e.g., August 1991 for nine days at temperatures ≥ 25°C). These high temperatures (≥ 30°C except for June, July and August each year) would usually last for one to two days before being followed by a rapid drop in the maximum temperature (average = 12°C, Table 1), usually within a 24 hr period. The prevailing hot conditions were usually associated with winds from the east or south east, while the drop in temperature was associated with a change in wind to the south west or west, and an approaching cold front. The hot conditions were also associated with high VPD deficits, low RH and generally, high solar radiation. An approaching frontal system resulted in a drop in VPD and solar radiation and an increase in RH. The rapid changes with VPD, RH and radiation also took place mostly within 24 hr.

Figures 1, 2 and 3 illustrate this weather pattern. On 1 September 1991 (Day 244, Table 1), Mr Wild reported leaf drop on his fig tree and upright lettuce and cabbage seedlings in the nursery two days previously. A graphical examination of the weather parameters a few days prior to Day 244 in 1991 shows the weather cycle (Figures 1, 2, 3). On the 28th and 29th August (Days 240 and 241 respectively), maximum temperature rose to 30.6 and 31.5°C respectively. Minimum temperature for Day 240 was also very high at 15.8°C. The temperature plummeted over 24 hr after Day 240 to reach a maximum temperature of 14.6°C on Day 241 (Figure 1). Temperatures above 30°C are very high for August.

Correspondingly, the VPD for Days 239 and 240 were very high at 2.8 and 3.1 kPa respectively, whereafter they dropped off rapidly to 1.7 kPa on Day 241 and 0.6 kPa on Day 242 (Figure 2). As expected, the RH was low on the hot days (Days 239 - 240), and increased with the cooler conditions on Days 242 - 245 (Figure 2). Solar radiation was highest on Day 238 and declined steadily from 18.49 MJ day^{-1} on Day 238, to 4.06 MJ^{-1} on Day 242 (Figure 3). Thus Figures 1, 2 and 3 exhibit the stress weather cycle occurring with all reported hormone herbicide symptom dates.

Rain fell on 10 out of 17 symptom dates but no hormone herbicides were measured in the rain samples taken on these days. No hormone herbicides were measured in any of the rain samples taken from "Ompad" farm over the whole study period. This was somewhat strange, given high levels of hormone herbicides in rain samples measured by the Hormone Herbicide Working Group from 1987 - 1991. To check the validity of lab. analysis some water was spiked with various hormone herbicides. Water samples were taken over 24 hr at two hourly intervals at the normal site on "Ompad" farm. These samples were then analyzed at Umgeni Water. Although the results varied they were always showed the presence of each hormone herbicide at levels > 25 ng l^{-1}. This verified that no hormone herbicides at levels > 25 ng l^{-1} were recorded in any rain samples from June 1991 - 1993 July.

Thus no hormone herbicides could be found in the rain samples and every hit associated with adverse environmental conditions - apparently we had at last solved the problem. The hits were related to the stress weather cycles. However, in evaluating all the other weather data from July 1991 to June 1993, we observed 22 other occurrences with the same stress weather cycles. These were not symptom dates as recorded by Mr Wild, so the hits could not be ascribed to weather patterns alone. In fact, many of the non-symptomatic dates of the weather patterns had more harsh conditions than those of the actual symptom dates or hits themselves. Chi-squared analysis was used to test the assumption that all symptom dates were related to weather. X^2 (15.08) $\leq$ X^2 (p $\leq$ 0.05 for 18 df) meant the acceptance of the null hypothesis. Therefore, the observed symptom dates could be attributed to stress weather cycles but not every stress weather cycle was associated with symptoms on indicator plants.

Something occurred on the symptom dates which did not occur on the other non-symptom dates of the weather patterns. It was suspected that low levels of hormone herbicide (< 25 ng l^{-1}) which could not be detected by lab analysis, were deposited during the fumigations associated with approaching frontal lows. These low levels of hormone herbicide plus the adverse weather conditions could have resulted in downy mildew outbreaks in seedlings and the deformities observed in the indicated crops. Table 2 provides information on the dates and detail of any association between the symptom dates and pest, disease and deformity effects on the cabbage crops monitored.

Table 2 shows the symptoms observed in the monitor plots of cabbages, synchronised with the symptom dates: epinasty of cabbage leaves, deformities, stunted plants, aphid, diamond-back moth and webworm outbreaks, waxy and crinkled leaf appearance, but no disease. The pest outbreaks were all unexpected and severe. Of the 17 symptom dates reported by Mr. Wild, 13 occurred simultaneously with leaf symptoms and pest outbreaks on field cabbage crops. This can be misleading unless it is remembered that only cabbages $\leq$ six weeks in the field were regarded as susceptible to hormone herbicide (Meinhardt, 1989 citing Laing). Thus, only 13 out of a possible 64 (20 %) cabbage crops showed simultaneous symptoms. A Chi-squared test gave a X^2 value of 59.08 for the observed versus expected frequency of symptom dates and cabbage effects (Table 2). The observed X^2 $\geq$ X^2 (p $\leq$ 0.001 for 13 df) and therefore, the null hypothesis rejected. Symptom dates as reported by Mr Wild were not related to deformities and pest and disease outbreaks of cabbages in the field. Furthermore, some of the symptoms could have been linked to field and management problems e.g., low soil pH, water stress etc. (Table 2). Two of the affected cabbage crops had low soil pH and four were subjected to water stress. These factors could have played a role in the symptoms observed. The removal of these crops means that only seven out of a possible 64 (11 %) crops showed unexplained, though non-significant, correlation to the dates as recorded by the farmer. All these seven crops received adequate pest and disease control. No simultaneous disease outbreaks were observed in the field cabbages whatsoever although concurrent disease outbreaks were reported on other crops.

Discussion

Hormone herbicide symptoms on indicator plants were definitely associated with a characteristic weather pattern in the Umlaas River Valley. Hot days with high temperatures > 30°C, high VPD and high solar radiation followed by a rapid drop in temperature, high relative humidity and low solar radiation (conditions associated with an approaching frontal low) were always associated with symptoms observed by the farmer. However, this study has shown that the stress cycles alone were not responsible for the symptoms on indicator plants, because 22 other stress cycles occurred with no related symptoms. What then was the other factor, or factors, that coincided with the stress weather cycles to produce these symptoms on the indicator plants? Symptoms on the indicator plants were typical of hormone herbicide damage and no other factor related to the stress weather cycles could be identified. It is possible that hormone herbicides, present in the elevated inversion below 25 ng l^{-1}, and deposited during dynamic fumigations, were Factor X. However, without evidence of wet or dry deposition of hormone herbicides, hormone herbicides as Factor X in fumigations remains speculative. Regardless of the identity of Factor X, there was no significant association between stress weather cycles, Factor X, and pest and disease outbreaks, or morphological deformities of cabbage crops.

All hormone herbicide hit dates as reported by Mr. Wild occurred at the same time as stress weather cycles identified in this study. Preston-Whyte (1991 a & b) reported hit dates as supplied by a farmer to be correlated with suitable weather conditions for lowering of inversion layers and resultant fumigations. Some frontal systems showed no correlated hormone herbicide symptoms on the indicator plants. Smith (1991) observed the stress weather cycles to be associated with symptoms similar to those of 2,4-D. He postulated that the physiological stress caused by the harsh weather patterns, induced ethylene release in the plant, which caused deformities on lettuce. The production of stress ethylene in plants is induced by many environmental factors such as disease, waterlogging, low or high temperatures and water deficits (Hyodo, 1991). Smith (1991) also reported positive 2,4-D occurrences in the rain, accompanying these stress cycles in a summer lettuce trial. If weather-induced-stress alone was sufficient to cause hormone herbicide symptoms in this study, then all other 22 frontal lows would have caused the same thing. It appeared that some factor occurring concurrently with some frontal lows promoted ethylene production above plant threshold limits, thus causing hormone herbicide symptoms.

Deposition of pollutants during dynamic and thermal fumigations from elevated inversions are a source of concern in Natal (Preston-Whyte, 1990). Pollutants in plumes from industrial stacks can be carried many kilometres before wet or dry deposition occurs in other areas (Preston-Whyte & Tyson, 1988; Preston-Whyte, 1990). The presence of hormone herbicides in rain samples from 1987 - 1991 (Vogel, 1991) showed that hormone herbicides were present in the Natal airshed and transported by winds. Theoretically, therefore, dry deposition of hormone herbicides could also have occurred at any time when hormone herbicides were present in the airshed. As no hormone herbicides > 25 ng l^{-1} were recorded in rain samples during the study, it was speculated that wet and dry deposition of hormone herbicides ($\leq$ 25 ng l^{-1}) occurred during dynamic fumigations on the 17 reported hit dates. These low levels of hormone herbicide $\leq$ 25 ng l^{-1}, could have pushed ethylene above threshold levels in the indicator plants with the resultant hormone herbicide-like symptoms.

The evidence found could not establish a significant relationship between weather cycles, Factor X, pest and disease problems, and unusual plant symptoms of cabbages. Of the cabbage crops that had been in the field $\leq$ six weeks, a maximum of 20 % and a minimum of 11 % had symptoms that could be directly related to stress weather cycles and Factor X.

It is necessary to examine the symptoms observed in the cabbage crops to determine whether other factors or low levels of hormone herbicide could possibly have been causal agents.

Ethylene production induced by waterlogging causes leaf epinasty, leaf chlorosis, reduction in plant height, stem thickening, adventitious root formation and wilting (Kawase, 1974). These symptoms are very similar to MCPA treated cabbage plants (Way, 1963; Way, 1964;

Meinhardt, 1989). Although epinastic and stunted cabbage plants were observed, it must be remembered that this study was conducted over the drought period in KwaZulu-Natal and waterlogging as a result of overwatering was hardly ever observed. Therefore, waterlogging as a cause of the symptoms in the study, can be discounted.

Water deficits also cause ethylene production in the plant (Hyodo, 1991), but hormone herbicide-like symptoms resulting from a water deficit could not be found in literature. Plant exposure to air pollutants such as sulphur dioxide, ozone and mercury enhance the rate of ethylene production in the plant (Hyodo, 1991) and result in crop loss (Reinert, 1984). However, resultant plant deformities, though very possible, have not been documented. Turner (1991) found no evidence of acid rain in rain samples taken over the study area.

Some mineral disorders exhibit symptoms similar to those of hormone herbicides. Leaf cupping can be ascribed to molybdenum (Mo), sulphur (S) or zinc (Zn) deficiency, or manganese (Mn) toxicity (Scaife & Turner, 1983). Distortion of growing leaves may be due to calcium (Ca) deficiency (Scaife & Turner, 1983), or Mo toxicity (Bennet, 1991). Leaf discolouration may be due to iron (Fe), Mn, nitrogen (N), phosphorus (P) or S deficiencies while corky stem, stem cracking and multiple crowns could be due to boron (B) deficiency. Purpling of leaves could be induced by deficiencies of N or P (Scaife & Turner, 1983). Low pH soils and related Ca deficiency and Mn toxicity on one of the cabbage crops could have caused the cupping and deformities observed.

Way (1964) observed epinasty, cupped and leathery leaves, elongated internodes, parallel veins, staring centres, cracked stems and galling at soil levels on cabbages sprayed with 2,4-D. Way (1963) observed leaf chlorosis, delayed hearting, multiple heads, brittle stems and leaves as well as the symptoms of Way (1964), on cabbages sprayed with MCPA. Way (1963) also observed stem cracks and galls as the first symptoms sprayed with low doses of MCPA while leaf, root and apical effects were only observed at higher doses. The cabbages monitored in this study showed symptoms of epinasty and cupping but none of the other symptoms mentioned above. This seems to discount low levels of hormone herbicide as the unknown factor.

Apart from the discrepancies mentioned in Table 2, most of the cabbage crops showing symptoms correlated with hit dates were on soils which were within nutrient norms as laid out in § 1. They were not subjected to poor management, and only four did not receive enough water. However only 11 % of pest, disease and unusual symptoms of the cabbage crops could be directly related to the stress cycles and an unknown factor. Even less crops had a correlated pest outbreak. Therefore, we cannot rule out the fact that hormone herbicide-like symptoms or pest outbreaks on cabbages are caused by the weather cycles and Factor X, but this does not seem like a strong possibility. Furthermore, it seems that if hormone herbicide is Factor X, it should have produced more typical hormone herbicide symptoms (Way, 1963; Way, 1964). Cabbage diseases were not related to adverse weather conditions and an unknown factor. It was not surprising to find little relationship between these factors, as Meinhardt (1989) citing Lang, said that except during the seedling stage, cabbages are the most tolerant of all vegetables. Further analysis will examine these interactions on lettuce and tomato crops which are more susceptible to hormone herbicides.

In conclusion, an unknown factor coinciding with hot days, high VPD, high solar radiation, followed by a rapid decrease in temperatures, increase in relative humidity, and a decrease in radiation was responsible for strange symptoms on indicator plants and problems in nursery crops. Low levels of hormone herbicide deposited during fumigations could not be discounted as the unknown force in this relationship. However, a clear link between these weather cycles, Factor X, cabbage morphology, pest and disease outbreaks on crops of cabbages could not be established. Further research is necessary to validate these speculations.

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Table 1 Weather changes associated with reports of hormone herbicide damage in the Umlaas River Valley, 1991 - 1993

Day of year	Max temp (°C)		VPD (kPa)		RH (%)		Solar radiation (MJ day^{-1})	
	Range	Change	Range	Change	Range	Change	Range	Change
1991								
206	25-15	10	0.9-2.0	1.1	50-25	25	15-4.3	10.7
244	32-13	19	3.1-0.6	2.5	33-61	28	18-4	14
258	35-14	21	3.9-0.4	3.5	28-75	47	23-2	21
312*	35-25	10	2.6-0.9	1.7	52-69	17	29-2	9
330	32-20	12	2.3-0.6	1.7	51-70	19	31-11	20
1992								
8*	29-19	10	5.6-3.6	2	41-59	18	27-7	20
23*	24-18	11	5.7-3.7	2	46-82	36	30-6	24
38*	32-27	5	1.1-3.4	2.3	66-37	29	25-20	5
46*	32-20	12	2.5-0.5	2	44-76	32	30-10	20
48*	29-23	6	1.7-0.7	1	50-71	21	26-8	18
133	32-22	10	2.9-1.2	1.7	35-54	19	15-12	3
237*	31-17	14	2.9-0.7	2.2	30-58	28	18-4	14
348	32-18	14	2.4-0.3	2.1	44-87	43	26-6	20
1993								
3	30-19	11	2.0-0.4	1.6	46-80	34	23-3	19
56*	32-20	12	2.6-0.5	2.1	44-76	32	25-5	20
97*	32-16	16	2.6-0.3	2.3	41-84	43	20-4	16
196	28-18	10	1.9-0.5	1.4	47-73	26	14-12	2
Mean change		12		2.0		29		15

* indicates rainfall

Table 2 Relationships between symptom dates, number of cabbage crops under six weeks in the field, number of cabbage crops affected, symptoms and other factors

Symptom date	No. of cabbage crops		Symptoms and comments
	No. ≤ 6 wks	No. affected	
25/7/91	0	0	n/a
1/9/91	1	0	n/a
15/9/91	4	1	epinasty of leaves
8/11/91	8	2	leaf deformities and cupping (low soil pH)
26/11/91	4	0	n/a
8/1/92	0	0	n/a
23/1/92	3	2	leaf deformities (clubroot) and purpling (H_2O stress)
7/2/92	6	1	aphids, deformed, thick leaves and stunted plants (H_2O stress)
15/2/92	8	2	leaf purpling (low pH), aphids, deformed, thick leaves (H_2O stress)
17/2/92	8	2	"
12/5/92	3	1	crinkled leaves(H_2O stress)
24/8/92	2	1	leaf purpling
14/12/92	1	0	n/a
3/1/93	2	1	aphid, diamond-back moth, webworm
25/2/93	9	0	n/a
7/4/93	5	0	n/a
15/7/93	0	0	n/a
Total No.	64	13	

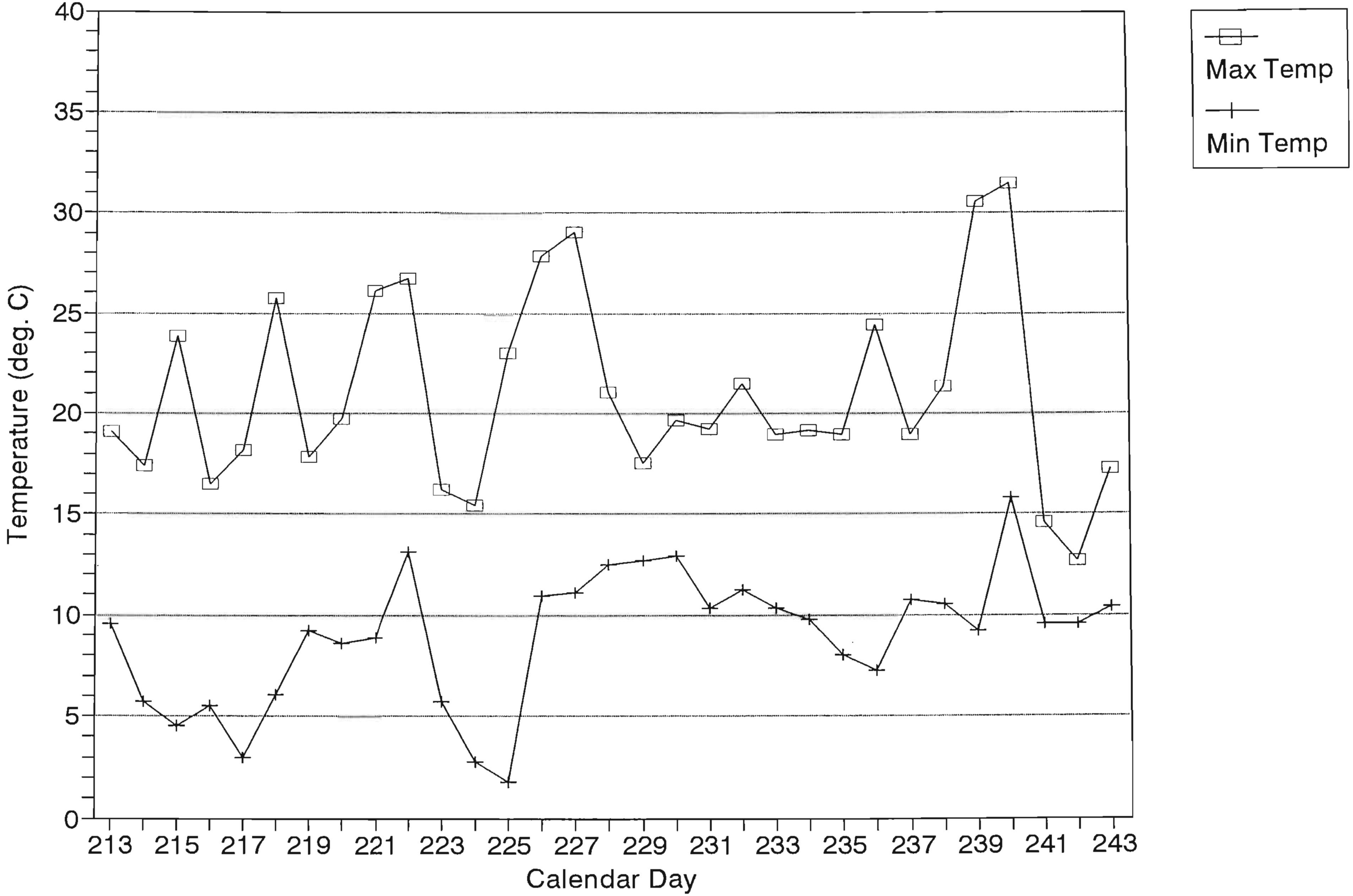

Figure 1 Daily max. and min. temperatures for the period 1 - 31 August 1991 (Calendar days 213 - 243)

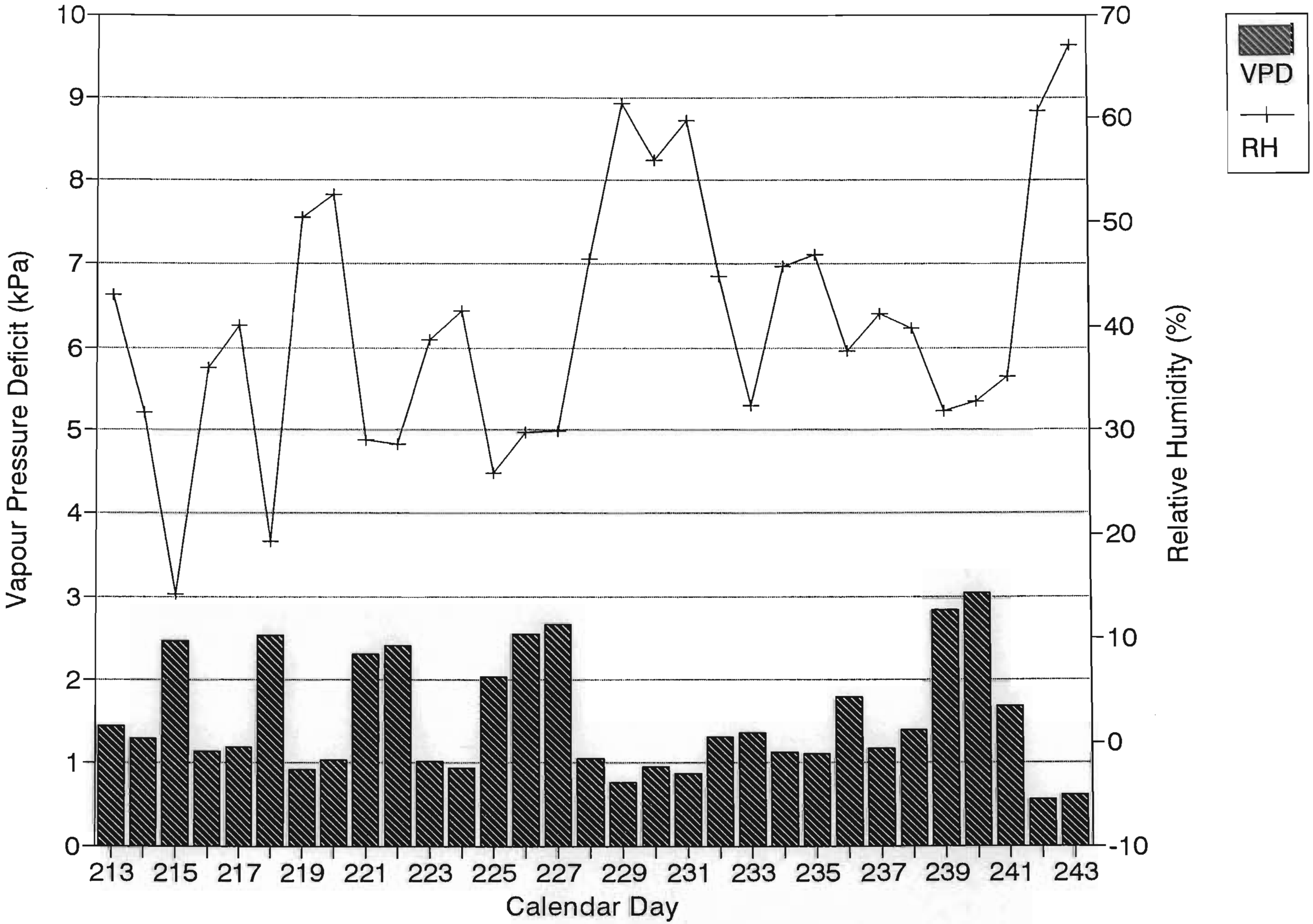

Figure 2 Vapour pressure deficits and relative humidity for the period 1 - 31 August 1991 (Calendar days 213 - 243)

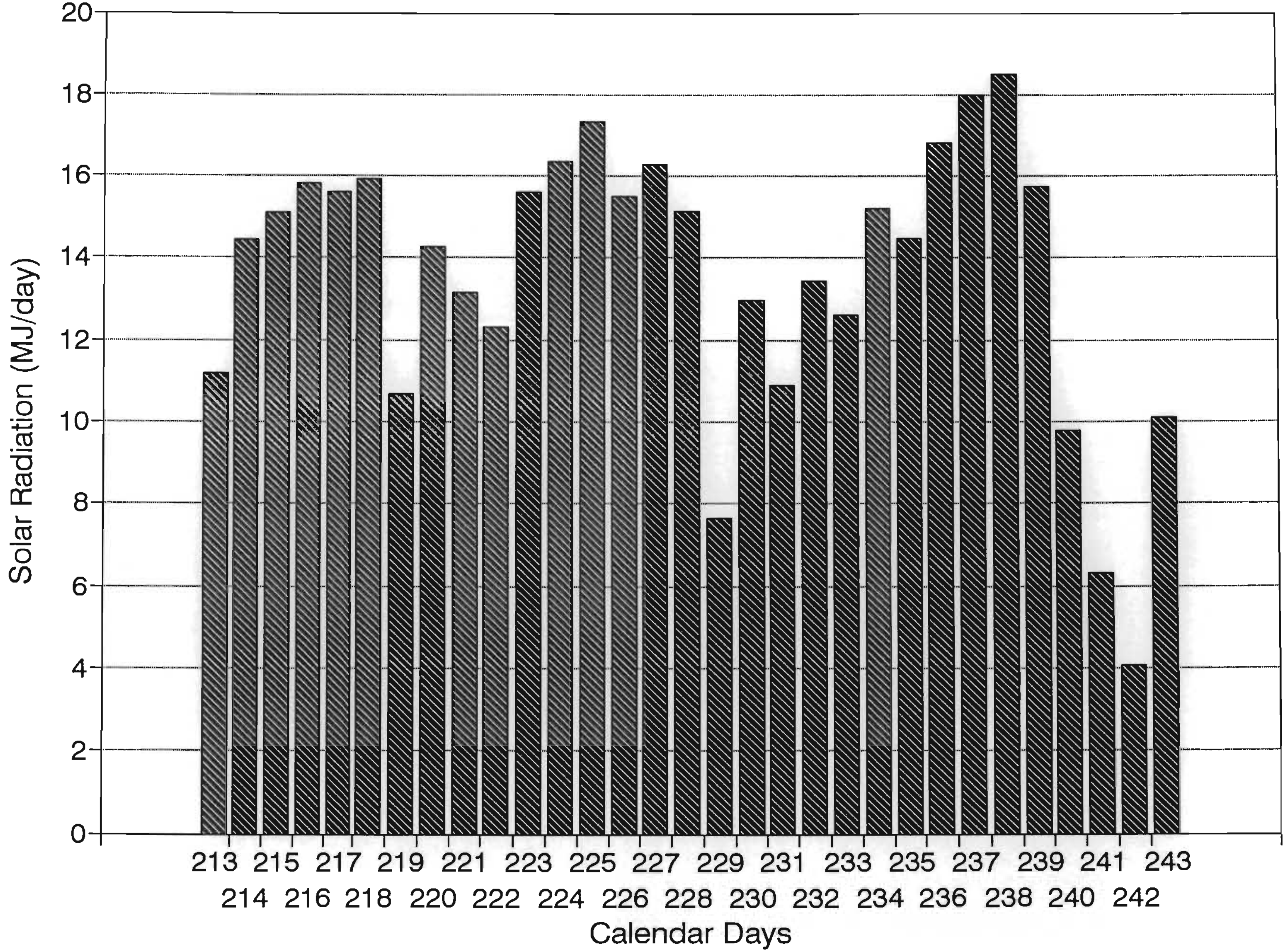

Figure 3 Daily solar radiation for the period 1 - 31 August 1991 (Calendar days 213 - 243)

8. OVERALL FACTORS AFFECTING CABBAGE YIELDS IN THE UMLAAS RIVER VALLEY, KWAZULU-NATAL, 1991-1993

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Abstract

A research and extension programme monitored 59 cabbage crops and many factors associated with cabbage production, in the Umlaas River Valley. These factors were included in regression models to determine effects on yield and included: soil analysis data, management and crop water stress ratings, total nutrients supplied; weed, pest and disease indices, tillage operations, soil characteristics, plant populations, percentage marketable yield and headmass. Poor water management, high incidence of weeds, pest and disease, excessive N and P applied as fertilizer and too many tillage operations were associated with low yields. Conversely, good water management, good liming and soil fertility practices, higher levels of soil K and better weed, pest and disease control, resulted in higher yields. A greater percentage of heads harvested was more important than head mass for higher cabbage yields. Recommendations were made to improve cabbage production in the Umlaas River Valley.

Keywords: cabbage, disease, pests, weeds, irrigation, water stress, fertilization, fertility, liming, management, scheduling.

Introduction

A research and extension project in the Umlaas River Valley, monitored many aspects of cabbage (*Brassica oleracea* L. var. *capitata* Alef.) production from June 1991 to July 1993. This research and extension exercise set out to identify:

1. the factors limiting cabbage production,
2. practices which maximized yield.

Previous work (§ 1, 2, 3, 4, 5, 6, and 7) examined specific factors affecting cabbage yields. § 1 identified critical soil values for cabbage production in the area, and noted the detrimental effects of soil nutrient levels above or below the identified norms. § 2 documented the effects of soil acidity on cabbage yield, and noted the association of acid saturation ≥ 5 %, manganese (Mn) toxicity and reduced yields. The importance of liming was emphasised. § 3 reported leaf nutrient norms and cabbage nutrient removals ha^{-1}. Cabbages with leaf nutrient levels above or below the adequate range showed reduced yields, and removals were used for fertilizer recommendations. § 4 evaluated cabbage fertilizer practices. Nitrogen (N) applications were too large and too late, and too much phosphorus (P) was also applied. Insufficient potassium (K) was incorporated and liming inadequately practised by most farmers. § 6 showed that webworm, aphid and thrips were the most important pests affecting cabbage yields, while § 5 showed clubroot, blackrot and damping-off to be the most important diseases. Both § 5 and § 6 discussed factors affecting disease and pest incidence on the cabbage crops; management factors played a large role. § 7 discussed the influence of stress weather cycles on cabbage crops. Crops affected by stress weather cycles within six weeks of transplanting showed little damage, while cabbage seedlings in the nursery were susceptible to the occurrence of a stress weather cycle combined with an unknown factor.

Many factors are known to affect cabbage yields; insufficient water (Sammis & Wu, 1989), pests (Annecke & Moran, 1989), disease (Agrios, 1988), liming (Smith & Bennet, 1984), poor fertilisation and soil fertility (Richards, 1983) all reduce yields. This study identifies and quantifies significant factors affecting yields and makes recommendations to improve cabbage production in the Umlaas River Valley. The study combines all quantifiable information generated by the cabbage research programme, for a more holistic view of important parameters affecting cabbage yields.

Procedures

Monitor plots of 100 plants were set up on 59 cabbage crops from July 1991 to June 1993 (§ 1). These plots were visited weekly and evaluated for pest (§ 6) and disease (§ 5) incidence and plant health (§ 7). Soil samples (§ 1 and 2) and the most recently mature leaf were taken at head-form (§ 3) for soil and leaf analysis. The plot was also harvested at maturity and a ⅛ headslice analyzed for removal figures (§ 3) and yields ha^{-1} were also estimated (§ 1, 2 and 3). Water stress was evaluated on each crop on a scale of 1 - 10 (§ 5 and 6). Management ability of each farmer was rated (§ 5 and 6) and soil factors were determined from the binomial soil classification. Total amounts of nutrients supplied to each crop were calculated from the data recorded (§ 4). The number of tillage operations per crop was calculated from a survey completed in early 1991. Date of transplanting was gleaned from monitor plot forms. The percentage marketable yields, and head mass were determined at harvest, and plant population determined from measurements taken after transplanting.

Stepwise multiple regression analysis was used to determine the effects of all the following parameters on yield: total N, P, K, calcium (Ca), Mg, and sulphur (S) applied as fertilizer; weed pest disease, water stress and management ratings; soil sample density, P, K, Ca, magnesium (Mg), zinc (Zn), soil acidity, pH and acid saturation; plant population; month of transplanting; and soil compaction, infiltration, wetness class, rooting depth, slope and land classification.

Soil form and cabbage cultivar type were not quantifiable and therefore not considered in regression analysis. However, the characteristics of each soil form were considered e.g., compaction and infiltration. Simple ANOVA showed no significant difference ($P \leq 0.05$) between soil forms and yield, and cultivars and yield. Observations in the Umlaas River Valley, showed that certain cultivars produced larger heads and higher yields and others were prone to bolting or splitting. Therefore, cultivar trials were conducted to identify the best cabbage cultivars for sowing, throughout the year. The written reports of the cultivar trials can be found in Appendix 12 a & b, but were not dealt with in the context of this study.

In Model 1 (Figure 1), all data from all plots was used regardless of pest, disease, soil, water or other problems. This incorporated all factors and gave a good overall idea of factors affecting yield. In Model 2 (Figure 2) all crops seriously affected by weed, pest, disease or water stress were excluded. Therefore, Model 2 examined the effects of all variables on healthy crops, highlighting soil fertility effects. Model 3 (Figure 3) was as per Model 2, with the exclusion of water stress, weed, pest and disease variables, so that soil fertility effects could be examined alone. In Model 4 (Figure 4), all factors were included except for crops damaged by drought or soil acidity. Model 4 effectively examined pest, weed and disease effects on crops with sufficient water and reasonable soil fertility. Model 5 (Figure 5) examined only head mass, weeks to harvest, percentage marketable heads and plant populations to determine which had the greatest effect on overall yield.

Results

In Model 1 (Figure 1), water stress and disease were the most significant factors affecting cabbage yields. Water stress could account for 52 % (R^2 value) of the variation in yield, while disease (given water stress) accounted for 25 % of the yield variation. A higher water stress rating meant that plants received little water which resulted in lower yields. Similarly, the increase of disease resulted in lower yields. Total N, number of tillage operations and soil K accounted for a small variation yield (3.2 % and 1 % respectively), but nevertheless had significant effects on yield. The application of higher amounts of N was associated with lower yields (t-value = -3.38**). Similarly farmers using an excessive number of tillage operations per crop had significantly lower yields. There was also a positive yield response to increased soil K.

In Model 2 (Figure 2) crops seriously affected by weed, pests and disease or water stress were excluded from analysis. Thus these were crops on any soil type with no serious weed, pest, disease or drought damage. In spite of this, water stress or insufficient water, and poor irrigation management again accounted for 64 % (R^2 value) of the yield variation. Pests and diseases also had significant effects on yield. Apart from some plots having low pH soils, these crops were in many respects, a normal cabbage crop. On these crops poor water management, and poor pest and disease control were the most significant factors causing yield variation.

In Model 3 (Figure 3), soil and fertilizer effects were mainly examined. Acid saturation had the most significant effect on yield ($P \leq 0.005$) and could account for 26 % (R^2 value) of the variation in yield. Higher acid saturation resulted in lower yields. As with Model 1 (Figure 1), total N and the number of tillage operations had significant effects on yield (P

$\leq$ 0.01 and 0.05 respectively). Once again high applications of N and an excessive number of tillage operations were correlated to lower yields.

Model 4 (Figure 4) included all fertilizers, soil, weed, pest disease factors, but excluded all crops damaged by water stress or soil acidity. Thus some of these crops suffered serious loss from pest and disease, weed and weed competition. Disease was again the most important factor affecting yields, and accounted for 60 % (R^2 value) of the yield variation ($P \leq 0.05$). Similarly, water stress accounted for 23 % (given disease) of yield variation and also had a highly significant effect on yield ($P \leq 0.005$) (Figure 4). Once again, poor disease control and irrigation management resulted in lower yields. Total P, soil K and weeds accounted for a small variation in yield (2 - 3 %) but nevertheless had significant effects on yield ($P \leq 0.05$). The excessive application of P was associated with lower cabbage yields (-t value = -2.25*). As observed in Figure 1, higher soil K levels showed a positive yield response. As expected, a high leaf area index for weeds resulted in lower yields.

Model 5 (Figure 5) examined parameters, each with an expected high correlation with yield. So far as yield was concerned, the number of weeks from transplant to harvest had little effect. The percentage marketable heads harvested had the highest correlation with yield and accounted for 62 % (R^2 value) of the variation in yield. Head mass was the next most important factor and accounted for 12 % (given percentage heads harvested) of the yield variation. This was followed by plant population, which could account for 16 % of yield variation (given percentage cut and head mass). Percentage heads harvested, head mass and plant population had highly significant ($P \leq 0.005$) effects on cabbage yields.

Discussion

This study has identified important factors affecting cabbage yields in the Umlaas River Valley. It has been proven that cabbage yields are improved by the following: better attention to water management; avoidance of plant stress; improved weed, pest and disease control; liming to lower soil acid saturation and raise pH; no excessive application of N and P in fertilization; and higher soil K.

Many farmers in the Umlaas River Valley do not pay enough attention to their cabbage water requirements. Infrequent or insufficient irrigation resulted in lower cabbage yields. Nortjé & Henrico (1988) and Sammis & Wu (1989) reported reduced yield with insufficient irrigation. A lack of available soil moisture results in a reduction of the water status of plant tissue (i.e., a low plant water potential). Low plant water potentials, especially during critical stages of a crop growth cycle, could have serious economic effects on yield (Green, 1985).

The exclusion of severe water stressed, weed, pest and disease ridden crops from analysis in Figure 2 meant that mostly healthy crops were examined, with some affected by soil acidity problems. Other factors such as soil pH, compaction, etc., were expected to predominate but water stress, pests and disease were the most important factors affecting yield. Likewise in Figure 4, the cabbages included in the analysis were not subjected to water stress, and yet water management (stress) could still explain 23 % (R^2 value) of the variation in yield.

Although farms were subjected to water restriction from August 1992, this only affected irrigation practises with a few cabbage crops. Most farms were on a water quota based on the area of registered arable land. Many simply reduced their normal planting area and maintained the same irrigation practises. Some farmers took a chance and did not reduce plantings, with the result that the yields of many different vegetable crops were reduced to zero. Cabbage crops so affected were excluded from analysis in Figures 2, 3 and 4. Therefore, the importance of water stress in Models 2, 3 and 4 are a reasonable estimation of the importance of irrigation management on cabbage crops as shown in Model 1.

A survey conducted at the beginning of the study showed that most farmers irrigated once a week at 25 mm water ha^{-1}. This recommendation of 25 mm water $week^{-1}$ is based on rough guidelines and is applied routinely, for most vegetable crops in Natal. It does not take into account the water holding capacity of each soil, rooting depth of the crop, or evapotranspiration (Green, 1985; Els, McSay & Kruse, 1993). Secondly, some farmers in this study could not accurately assess whether 25 mm was delivered, because different sets and lengths of irrigation piping were used, and pump power and water output varied on each part of the farm. No measurements to assess water output were ever taken. Thus the farmer was never sure whether he had delivered enough water to his cabbages and adopted a "touch and feel" approach.

Most farmers in the Umlaas River Valley need assistance in the regulation of irrigation for cabbages on different soil types. This study supports the use of an automatic weather station to schedule irrigation (R. Mottram, pers. com., Irrigation Scheduling Unit, Dept. of Agric. Meteorology, University of Orange Free State; Els *et al.*, 1993), irrigation scheduling from a Class A pan (Burgers, 1973: Green, 1985) or using tensiometers (Streutker, 1978) in the Umlaas River Valley. Furthermore a knowledge of cabbage water requirements at different growth stages, could be advantageous. Nelson & Hwang (1976) identified four growth stages for cabbages based on morphological development and water use. The first stage was from emergence to the start of headform, and was characterised by rapid plant growth. The second stage was short and accompanied by rapid increases in the weight of unfolded leaves, and the start of heading. The third phase is known as head-filling in South Africa, and was associated with the rapid expansion in size and weight of the head. The final stage was crop maturity and senescence. Dragland (1977) and Nortjé & Henrico (1988) agreed that moisture stress during the initial stages before head development (Nelson & Hwang, 1976), (stage 1), did not adversely affect yield, but that stress induced after the beginning of headform (stage 2 onwards) (Nelson & Hwang, 1976) was detrimental to yield. Cabbage water requirements as reflected by Green (1985) and Doreenbos & Kassam (1986) crop factors, agree with these findings. Nortjé & Henrico (1988) also counteracted adverse effects of water stress before headform by regular irrigation thereafter. Kolota (1970) recommended irrigation on reaching 35 % of soil moisture depletion level for plants prior to headform, and 25 % thereafter.

With the imposition of water restrictions, the knowledge of crop water requirements is even more useful. With little technical assistance farmers could adjust their irrigation practices according to cabbage crop need.

Crop loss to pest and disease factors has been well documented (Annecke & Moran, 1989; Agrios, 1988). The importance of the disease factor has really been highlighted in this study. Figures 1, 2 and 4, all showed disease to have a significant effect on cabbage yields.

Some farmers had little or no disease problems, while others experienced crop wipe-outs from clubroot, blackrot, etc. (§ 5). The effects of crop rotation in disrupting disease and arthropod cycles are well documented (Francis & Clegg, 1990). Therefore, crop rotation and other methods preventing pathogen spread are suggested for cabbage growers in the Umlaas River Valley, especially those free of diseases such as clubroot. Diseases significantly affecting yield were clubroot, blackrot and damping off (§ 5). Preventative methods for each disease are discussed in § 5. It must be remembered that every diseased or infected plant means one less head to harvest, or at least a smaller head. This reduces the percentage of marketable heads or head size, and will decrease cabbage yields.

Cabbage farmers should aim for the highest percentage of marketable heads and, secondly, large heads for highest yields. This is more quantifiable than aiming for a high yield alone, as higher percentage marketable heads and larger heads means higher yields for the farmer. After concentrating on factors such as soil fertility, nutrition, irrigation and plant population to produce the correct size and weight head, the farmer must concentrate on the control of pest and disease factors to maintain a high percentage cut.

The negative correlation of total applied N and yield showed that higher application of N was associated with lower yields. § 4 showed maximum N was 304 kg ha^{-1}. Smith & Hapelt (1984) found no yield response to N above 200 kg ha^{-1}, but found a better response with 200 kg applied at the right time than with 300 kg at the wrong time. § 4 showed that most farmers applied ¼ N preplant and ¾ postplant rather than ⅔ preplant and ⅓ topdressed. It is possible that farmers applying lower levels of N (e.g., $\pm$ 200 kg ha^{-1}) are applying the correct proportion observed by Smith & Hapelt (1984) i.e., ⅔ preplant and ⅓ topdressed. This could explain the negative correlation at higher N application levels.

The mean soil P value for all monitor plots was 92 mg l^{-1} (§ 1). The negative association of higher applied P with yield, indicated the detrimental effects of excessive applied P when soil P levels were high. § 4 observed P applications as proportional to soil test results, but generally excessive. It is possible that some soil interactions caused by excess soil P could limit other nutrients thus inducing some type of deficiency or stunting (Mengel & Kirkby, 1987; Tisdale, Nelson & Beaton, 1990).

An independent regression between soil K and yield showed a positive correlation in increasing yields with higher K (Askew, unpublished data). § 1 showed the upper limit for 50-90 tons ha^{-1} yields was 794 mg l^{-1} and for 100 tons ha^{-1} was 474 mg l^{-1}. Although the optimum was 353 mg l^{-1}, there seems to be an indication of a yield response to increased soil K.

The detrimental effects of acid saturation > 2 % have been presented in § 2. That farmers were unaware of their low pH problems is shown in § 2 and 4, which show that liming was not being done according to recommendations from Fertrec. These findings, illustrated in Figure 2, emphasise that farmers need to apply lime when necessary to improve cabbage yields. High acid saturation is generally associated with a low soil pH (Van Lierop, 1990), which in turn, causes Mn toxicity symptoms in cabbages and results in small stunted plants (Robinson, 1983; § 2). Therefore, the most probable immediate effect of liming, would be larger heads and thus higher yields.

Figure 1 and 4 show that an excessive number of tillage operations reduced cabbage yields. A preliminary survey carried out in 1991 showed that some farmers used up to seven tillage operations for a cabbage crop. Intensive vegetable cultivation and the use of so many land operations causes a decline in organic carbon and total N content of the soil, with an associated increase in soil/air space, aggregation and water holding capacity (Tate, 1987). This in turn will reduce root development (Tate, 1987) and could result in smaller heads, thus affecting yield. Soil amendments such as organic manures will maintain soil microbial activity, promoting better soil structure and plant health (Dick, 1992). Organic manures coupled with fewer tillage operations will in the long term result in larger heads and high yields. No-till is not recommended for cabbages as root growth is stunted, especially on soil previously used for intensive vegetable operations (Knavel & Herron, 1981).

In conclusion, the following guidelines are suggested for general cabbage growing in the Umlaas River Valley:

1. Use automatic weather stations, Class A pans or tensiometers for irrigation scheduling of cabbage crops.

2. Less water can be applied before headform, but thereafter, cabbage crop requirements increase. Any deficit from headform to maturity will reduce yields.
3. When limited water is available, reduce normal applications before headform but supply normal amounts after headform, ie., the crop can withstand water stress within about six weeks after transplanting, but thereafter will suffer economic loss if subjected to further water stress.
4. Use crop rotations with different types of crops, different rooting depths and alternate crops with high and low nutritional demands.
5. Farmers with clubroot-free soils should clean implements used on infected lands, and not allow vehicles belonging to hawkers, onto their lands. This will reduce the spread of infection from farm to farm, and field to field.
6. Scouting and good corrective and preventative spray programmes are essential, especially for pest control. Nozzles, spray pressure and droplet size should be checked regularly to ensure correct application and maximum disease and pest control.
7. Low pH soils should be limed to at least 4.5 (KCl) or an optimum of 5.5 (KCl). This could reduce disease and pest incidence, improve the soil cation balance, reduce Mn levels in the plant and promote soil fertility.
8. Apply 200 kg ha^{-1} of N, ⅔ preplant and ⅓ topdressed at 4 - 6 weeks after transplanting. This should result in higher yields. Avoid excessive applications of N.
9. Fertilizer recommendations should be based on the soil critical values identified in § 1, with the amount of available nutrients not exceeding these values.
10. Applications of P should be based on Cedara recommendations and the practice of applying extra for safety, should be avoided.
11. The number of tillage operations should be reduced as much as possible to reduce compaction and destruction of soil structure.
12. Chicken or pig manure should be incorporated at the rate of at least five t ha^{-1} an^{-1}. The application of more than 20 t ha^{-1} an^{-1} should be avoided. This will assist in the maintenance of soil structure and could reduce pest and disease incidence.
13. Farmers must aim for the highest percentage cut of large, heavy heads for the hawker market or highest percentage cut of medium heads for bagging.

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Variables	Coefficients	t-values
Water stress	-12.880	-11.35***
Disease	-0.717	-8.65***
Total N	-0.130	-3.38**
No. of land op.	-4.741	-2.27*
Soil K	0.027	2.09*

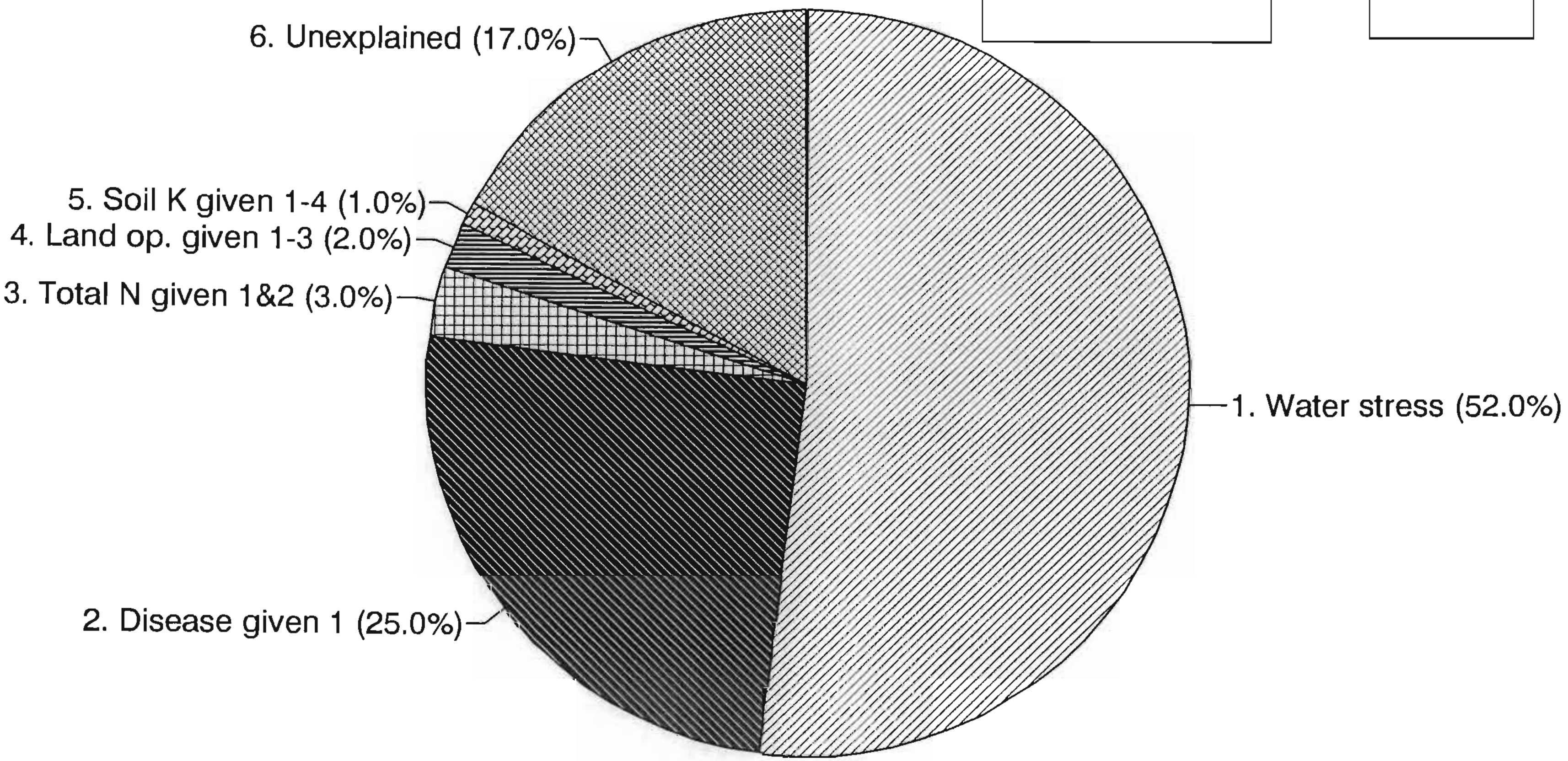

Figure 1 Factors affecting cabbage yields in the Umlaas River Valley (1991 -1993)

Variables	Coefficients	t-values
Water stress	-19.265	-8.30***
Pests	-0.205	-2.45*
Diseases	-0.527	-2.27*

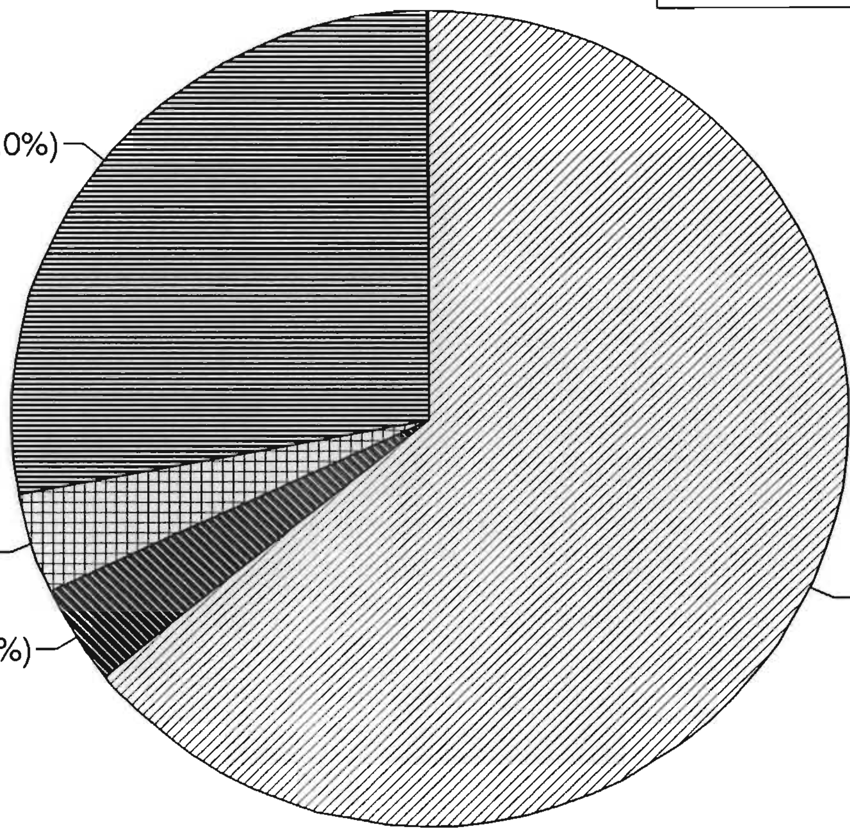

Figure 2 Factors affecting cabbage yields excluding crops seriously damaged by weeds, pests, diseases or drought

Variables	Coefficients	t-values
Acid saturation	-2.256	-3.68***
Total N	-0.183	-3.09**
No. of land op.	-7.553	-2.43*

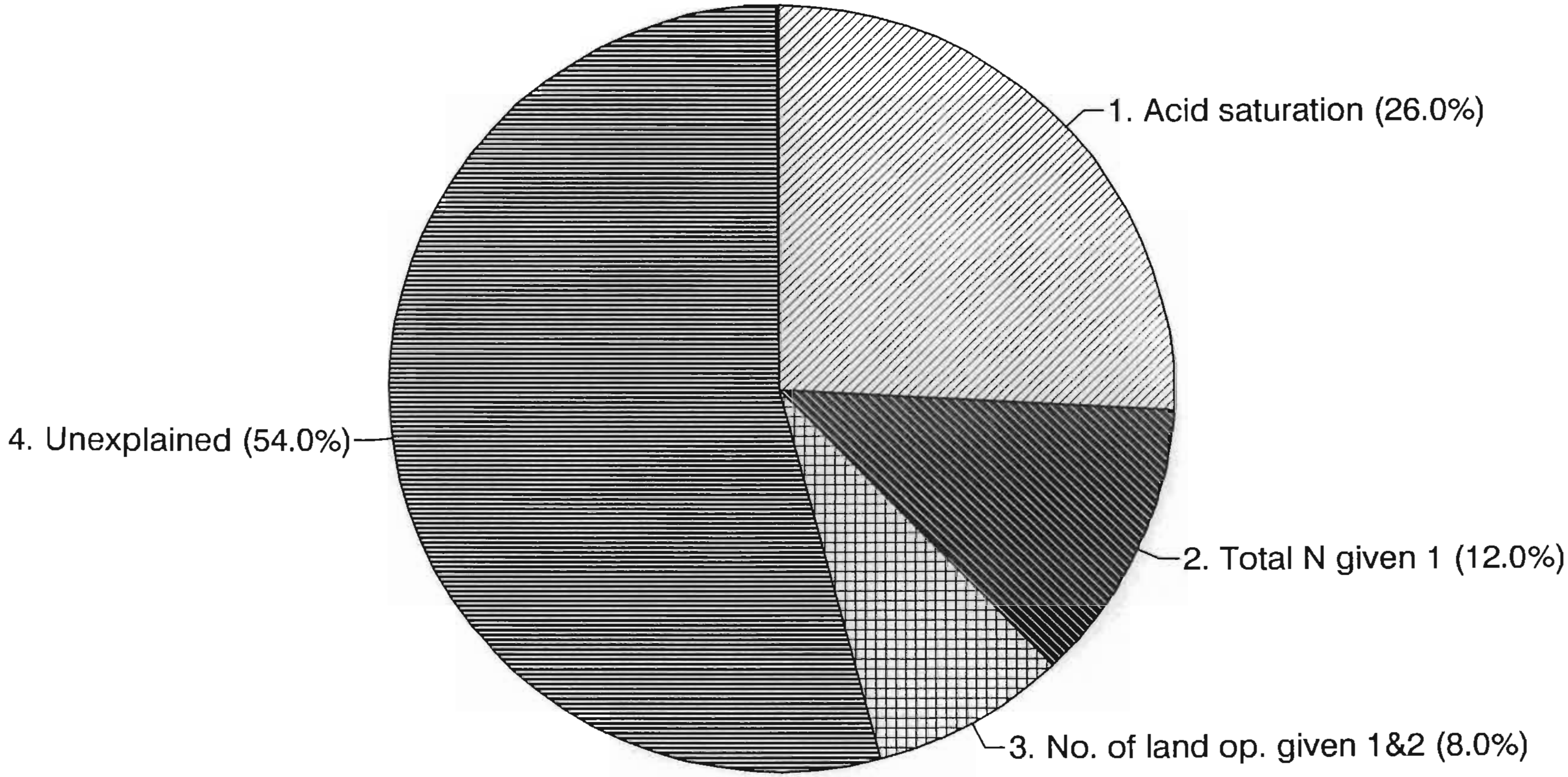

Figure 3 Factors affecting cabbage yields - water stress, weed, pest & disease variables excluded from analysis

Variables	Coefficients	t-values
Disease	-0.0782	-10.81***
Water stress	-13.400	-8.05***
Total P	-0.119	-2.25*
Soil K	0.030	2.58*
Weeds	-0.330	-2.18*

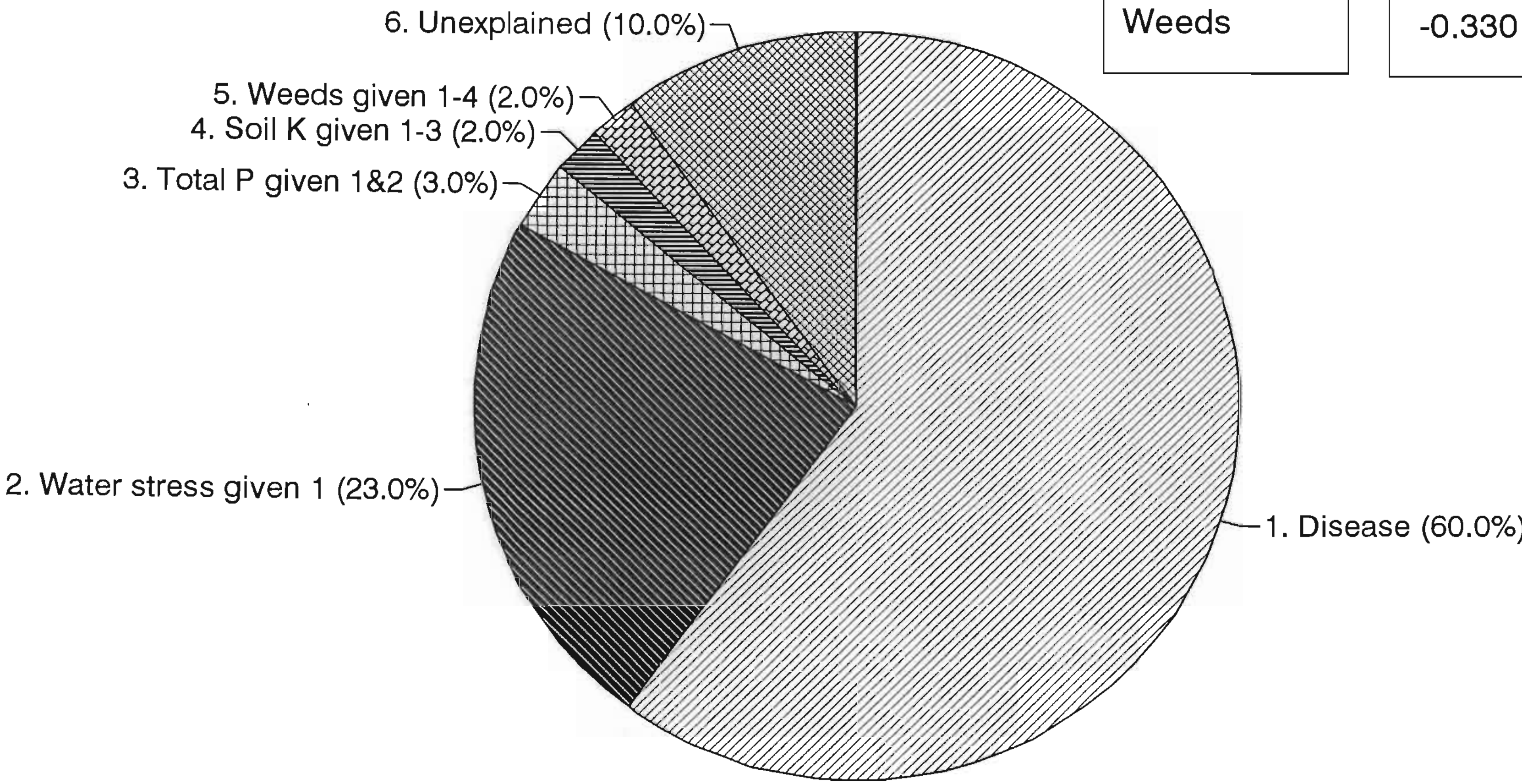

Figure 4 Factors affecting cabbage yields - excluding crops seriously damaged by soil acidity or drought

Variables	Coefficients	t-values
% cut	0.721	13.31***
Headmass	26.624	11.23***
Plant population	0.002	10.06***

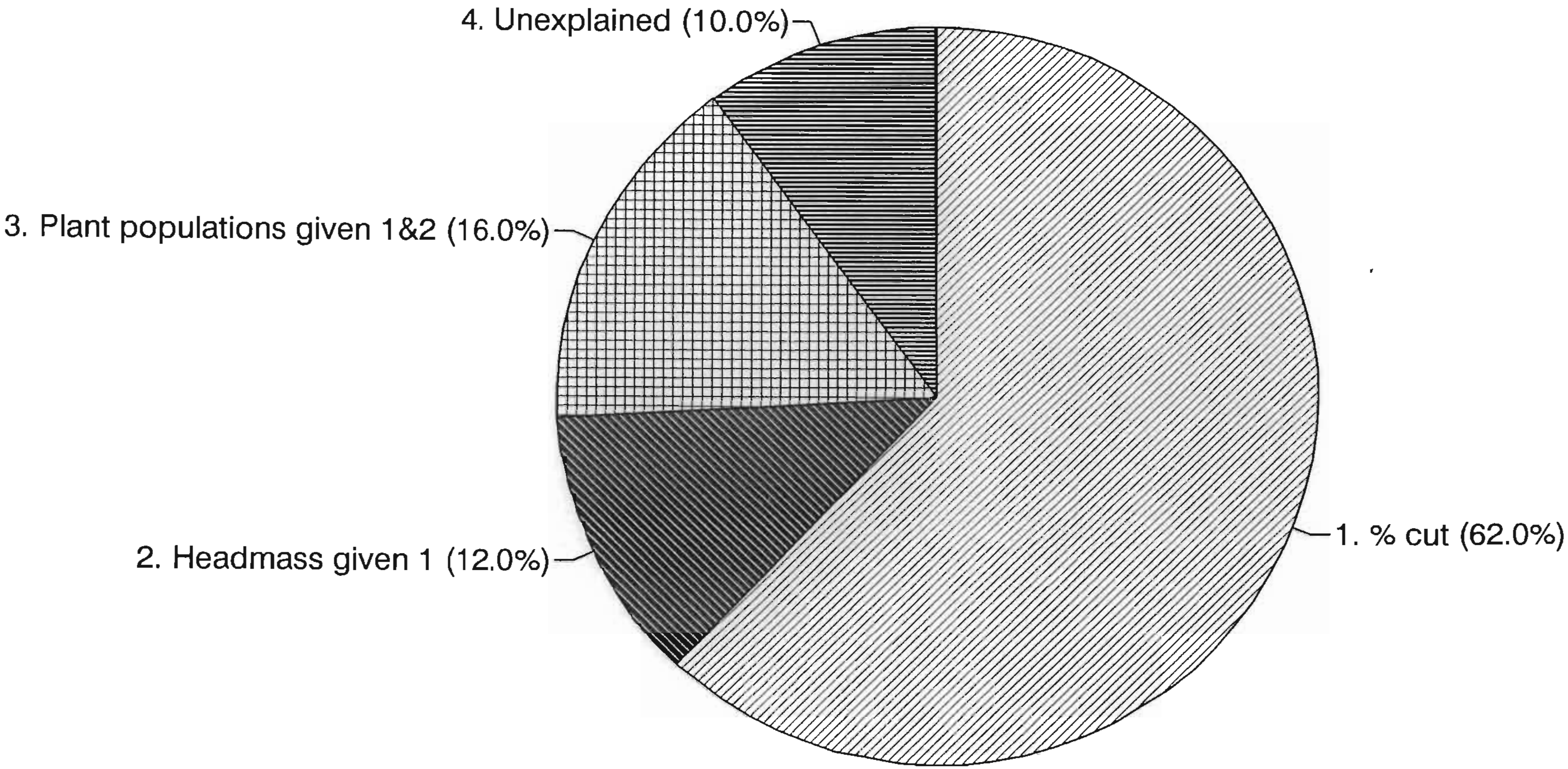

Figure 5 Effects of percentage cut, headmass and plant population on cabbage yields per hectare

DISCUSSION AND CONCLUSIONS

The original production problems experienced in the Umlaas River Valley were allegedly caused by hormone herbicides. The extensive research programme carried out by the Task Group for Hormone Herbicide Research found that hormone herbicides were not the only cause; poor yields and damage could be attributed to cumulative or individual effects of environment, managerial or hormone herbicide factors. The Umlaas River Valley Vegetable Project was instituted to monitor all factors affecting vegetable crop production in the area, identifying limiting factors and those which maximized yields, to be used as a basis for production guidelines. The project succeeded in its objectives, with soil and farming practice surveys completed, weather and crops monitored and all rain tested for hormone herbicides. This provided a large enough data base from which limiting and maximizing factors could be identified as a basis for production guidelines.

This study has concentrated on factors affecting cabbage production as related to cabbage monitor plots in the Umlaas River Valley. It has improved farmer knowledge of his own practices in comparison to those of other farmers, has highlighted problems, identified practices for optimal cabbage production, and has also exhibited the usefulness of the study method as a combined research and extension tool.

The study has generated many recommendations for cabbage growing in the Umlaas River Valley. Each section (§) identified limiting factors and those which maximized yields, and made appropriate recommendations to improve the former and implement the latter. The implementation of the recommendations generated by the study, could greatly improve cabbage production of vegetable farmers at given levels of management ability, in the Umlaas River Valley.

Very few aspects of cabbage production have been researched in South Africa. All work done since ± 1982 has been cited in this study and covers only aspects of fertilization, liming and irrigation. Much of this work has been supervised by the

Department of Horticultural Science at the University of Natal. This study has supplemented and added to previous fertilizer, liming and irrigation research, and will therefore contribute greatly to South African research. Furthermore, many of the findings in the study have covered new avenues of research and have cast new light on various aspects of cabbage production in South Africa. Most national and international research has focused efforts on one, or at the most three variables at a time, thereby limiting the study of interactions between the variables. This is understandable given limitations in experimental designs, logistics and statistical analysis of multi-factor studies. This study used a holistic, multi-factor approach and included all quantifiable variables in analysis. Through the methods used in this study, limitations of multi-factor experiments were dealt with to produce a statistically valid, cheap, and easily managed methodology. The holistic nature of this study has never been used for vegetable production in South Africa or the rest of the world, and as such, represents a first for South Africa.

The research and extension methodology used worked hand-in-hand, and was a unique facet of this study. The on-farm monitoring of all cabbage crops and collection of fertilizer and spray programmes encouraged good contact with the vegetable growers, as well as good grower participation. Regular study groups compared farming practices, viewed the latest developments in data accumulated, and encouraged co-operation with agri-business. This close contact with the growers, the weekly visits and monthly study groups, allowed for rapid feed-back of the latest developments or trends observed in monitored crops, and the quick transfer of the best available technology and expertise. Indeed, most of the findings reported in this study have already been conveyed to the growers in the Umlaas River Valley. In this way the Umlaas River Valley Vegetable Project, through this study, succeeded in providing an efficient extension service and followed up all work conducted by the Task Group for Hormone Herbicide Research.

Some of the findings of §1 regarding soil fertility are new and others raise old issues which have been overlooked in recent years. §1 observed highest yields at soil P levels of 88 mg l^{-1} at soil sample density 1.14 g ml^{-1}. This was almost twice the amount of

P recommended for the same sample density by Fertrec norms. The study also showed > 100 t ha^{-1} could be achieved at soil P levels of 47 mg l^{-1} (sample density = 1.12 g ml^{-1}). Even this was higher than Fertrec norms used in fertilizer recommendations from the Soils Physics Laboratory at Cedara. A yield response to higher soil P levels than indicated by previous research was apparent. This study also speculated that interactions between P and other soil nutrients could have been involved in this yield response to increased soil P. Further research, with different levels of residual P on different soils with varying sample density, K, Ca and Mg levels, should investigate cabbage response to the interaction between increased P and other soil nutrients.

Of note was the yield response to high soil K (248 mg l^{-1} for > 100 t ha^{-1} and 338 mg l^{-1} for maximum yields). Again this was higher than the recommended K for Natal, at 200 mg l^{-1}; and indicates the need for calibration trials, testing yield response to K - a response not documented in South African research. Low Ca and Mg levels have never been considered too important in fertilizer recommendations in Natal. Fertrec bases Ca requirements on acid saturation, while Mg requirements are determined by acid saturation and K:Mg ratios of < 4:1. The cation saturation approach, a method of fertilizer recommendation proposed in the 1960's and used much internationally in the 40's to the 80's, (but not regarded as accurate in many places and thus overlooked), used a 65:25:10 ratio for Ca:K:Mg. Research has shown there are merits in the cation ratio approach, especially in areas with low soil pH. This study suggests that Ca and Mg be should maintained at the critical values mentioned in § 1, and consideration be given to cation ratios in the determination of K, Ca and Mg soil requirements.

While other research has documented higher manganese concentrations in plant tissue in low pH soils, the approach and methodology of studying soil pH induced manganese toxicity of cabbage, is new. These findings highlight the importance of liming acid soils to improve cabbage production. The study also showed that liming recommendations should consider pH, and not just acid saturation. The model for achievable yields (§ 1) at specific maximum and minimum levels of each soil nutrient is useful for the illustration of the effects of low and high levels of each soil nutrient, or could be used for yield prediction. § 1, 2 & 3 provided new information for use in upgrading Fertrec recommendations for cabbage.

Associated with soil fertility, was the observation of fertilizer practices on all crops monitored. § 4 was an important part of this study in that it provided an accurate assessment of actual fertilization practices, and revealed the various shortcomings in the fertilization practices of farmers, which, if rectified, could improve cabbage yields. Growers should pay better attention to Fertrec recommendations from soil samples sent in for analysis. This would encourage the application of correct proportions of N, avoid excessive P and if maximum acid saturation was decreased to 1 %, would improve liming recommendations. The study highlights the need for farmer appreciation of Fertrec recommendations. Further research should examine the timing of N application on soils with different sample density (sandy to clay), and should also evaluate the acidifying effects of standard NH_4 and NO_3 containing fertilizers (e.g., 2:3:2 (30)). Answers to the latter problem would be especially applicable for subsistence agriculture in areas with acid soils, where lime application is problematic. Alternately, intensive vegetable producers in induced acid soil areas, such as the Umlaas River Valley, could also benefit from such research.

The study has contributed new facts concerning the occurrence and control of pests and diseases in the Umlaas River Valley. Findings concerning seasonal and temperature occurrence of pests and diseases in the area will enable better prediction and preventative control methods. Crop damage by pests and disease are well known but this study highlights the effects on yield, thus impressing on farmers the need for good control practices. As such, this paper demonstrates well the effective extension value of the study. Pest infestation and disease infection were rated in weekly visits to each cabbage crop (severity assessments). These severity assessments also showed the relative effects of each pest or disease on yield and could be useful in the determination of threshold limits and when to start spraying. The findings also showed which pests and disease had the most effect on yield. If growers sprayed routinely for less important pests and took extra measures for the more significant ones, the percentage marketable heads ha^{-1} and thus yields could be greatly increased. As stated in § 5 and

6, most other pest and disease research has concentrated on methods of control, and some on threshold limits. Therefore, although these reports of yield reduction by pest and disease are not new, the findings are specific for the Umlaas River Valley and form an integral part of management guidelines for cabbage farmers in the area.

International research of agronomic crops has mentioned the effects of e.g., fertilizer practices, on pest and disease incidence. Very little cabbage research has studied factors contributing to increased pest or disease incidence. The identification of factors associated with pest or disease effects are usually incidental. In this study clubroot, blackrot, damping-off, aphids, thrips and cabbage webworm significantly reduced cabbage yields. Various factors associated with disease corroborated other research, e.g., more clubroot on lower pH, water-logged soils. Other variables associated with higher pest and disease pressure were new, and some quite simple, e.g., higher incidence of deposition of smaller flying insects on the slope lands than on flat lands. Therefore, some recommendations for improved pest and disease control in the Umlaas River Valley are original, and will be of great use to the farmers in the Umlaas River Valley and possibly elsewhere. Further research should evaluate cultivar tolerance of acid soils. Tolerance of cultivars to acid soils could be synergistic with a tolerance to clubroot. Findings of this nature would be especially applicable in community gardens where low pH and clubroot are problematic, and lime difficult to apply.

This study also identified the occurrence of deformities on garden plants and vegetable seedlings which occurred concurrently with stress weather cycles and an unknown factor. These simultaneous events were not significantly related to deformities, pests or diseases on cabbage crops monitored in the field. Other research documented identical deformities and symptoms of the seedlings, and increased pest and disease incidence with applications of hormone herbicides. As no hormone herbicides above 25 ng l^{-1} were measured in rain samples over the study period, it is speculated that low levels of hormone herbicide (< 25 ng l^{-1}) could have been transported in the elevated inversion over Natal, and deposited during mixing of the elevated inversion at the approach of a frontal low. The resultant deposition of hormone herbicides could have caused these simultaneous effects on indigenous plants and vegetable seedlings in the nursery. This report indicates a source of plant stress to vegetables in the Umlaas River Valley. Cabbage seedlings are regarded as fairly tolerant to hormone herbicides after transplanting and therefore no significant association was expected between stress weather cycles and resultant mixing of elevated inversions, symptoms on indicator plants and field cabbages. However, the association of damage to indicator and nursery plants could add to the findings of the Task Group for Hormone Herbicide Research. Hot days, high temperatures, high vapour deficits, high solar radiation and low humidity were followed by rapid changes (associated with mixing of elevated inversions), with subsequent hormone herbicide-like symptoms on lettuce crops. Future research, coincidental with conditions suitable for elevated inversions, should apply low levels of hormone herbicide on indicator plants, nursery and field crops, and monitor plant health, pest and disease incidence, deformities and yields. As indicated by the Task Group for Hormone Herbicide Research, the cumulative stress effects of low levels of hormone herbicides, quick changes in temperature, vapour pressure deficits, solar radiation, relative humidity, management practices and waterlogging, could cause deformities and increase pest and disease incidence, especially on crops more susceptible to hormone herbicides or extreme weather conditions.

Findings regarding adequate soil moisture and cabbage yields are not new, but in the context of this study, are vital for improved yields. Most models that included water stress in § 8 showed very highly significant effects of water stress on cabbages. Old recommendations of 25 mm per week should be replaced by more accurate measures of determining soil moisture status, such as automatic water stations (AWS), tensiometers or Class A pans. Furthermore, water application should also be based on crop requirements which increase after headform ($\pm$ 7 weeks)(§ 8). Further research should demonstrate the effectiveness of AWS, tensiometers or class A pan scheduling as opposed to normal farming practices of 25 mm per week. Casual observations of different cabbage cultivars during the study, showed that some cultivars produced better yields than others, under conditions of water stress. Future cultivar trials, should consider different levels of available soil moisture to evaluate cultivar tolerance of water stress. The results of this type of trial would be especially applicable where water restrictions are enforced, (e.g., in Umlaas River Valley), in low rainfall areas or in subsistence agriculture.

Many of the factors affecting pest and disease incidence relate to sound management practices such as: good spraying; checking spray equipment and nozzles etc.; avoidance of poorly drained soils during the rainy season; careful use of marginal lands; appropriate liming practices and good irrigation practices, etc. While some of the findings w.r.t. management practices in this study, could be regarded as general knowledge, the effects of such practices by farmers, have never been researched or published in the scientific literature.

Intensive vegetable production and increasing the number of tillage operations for each crop reduces soil organic carbon and affects many other aspects of soil fertility and microflora. Therefore findings of reduced yields with more tillage operations in § 6 and 8 were not surprising and provide useful recommendations for cabbage growers in the Umlaas River Valley.

A critical review of the methodology used in this study, indicates that the reliability of the data could have been improved by increasing the number of monitor plots. This would have improved the accuracy of the means of a high yielding population, and provided more data points for each soil type or characteristic, for further analysis. Given many soil data points at all levels of soil fertility, this could facilitate critical values or norms for every soil type, sample density, etc.. In fact, future soil calibration studies should consider the advantages of this system to identify optimum soil nutrient values. Although more monitor plots would have been preferable in this study, 59 points were regarded as sufficient for reliable statistical analysis using this method. Furthermore, the accumulation of more data points was impossible, given the manpower, time constraints, and scope of the project.

The cabbages in this study were grown on 13 different soil forms (Appendix 4), the effects of which, were taken into account in § 5, 6 & 8, but not in § 1 & 2. Therefore, recommendations in § 1 & 2 must be seen for what they are i.e., an accurate report of findings with critical soil values as guidelines for maximized yields. Given the complexities of nutrient uptake, availability and interactions in different soils, are not the results of all calibration trials also guidelines for maximum yields? Pot trials or standard field calibration trials are recommended for verification of the critical soil values observed in this study. However, this would involve many years of research on all different soil forms. Verification of these results was not within the scope of the study and final values were only available at its conclusion.

Criticism could be directed at fertilization effects (esp. P & K) on the soil nutrient critical values generated by the single plot calibration studies in § 1. However, the use of different types and amounts of fertilizer and time applied did not greatly influence the results of soil analysis. All soil samples were taken after seven weeks and most P and K was applied preplant, thus giving the applied P and K sufficient time to be available in the soil and accurately recorded from soil analysis. Therefore different types and times of fertilizer application were not really regarded as a source of variation in this study.

The question must be asked, "Did this study cover all factors affecting cabbage yields"? Two factors, namely soils and cultivars warrant discussion. Although soil form/type was not included in analysis *per se*, the characteristics and land capability classification of each soil form were used in regression analysis in § 5, 6 & 8, and were significant factors affecting yield and pest incidence. The use of these soil characteristics from the Binomial Soil Classification of each farm, were if anything, more reliable than soil form alone. Furthermore, the soil characteristics were quantifiable, while soil form was not. Simple ANOVA and multiple range tests with different soil forms could not produce reliable statistical information. Overall, it was thought that the effects of different soils were adequately covered in this study.

Cultivars of all agronomic and horticultural crops are known to show different responses to various environmental and management factors e.g., fertilizer, soils, salinity, water deficits and climate. Cabbages are no exception, but were they a factor affecting yields and did their exclusion limit the reliability of this study? At the end of the day, the farmer wants the highest marketable yield for his targeted market, whether it be the hawker or bagging market. Given sound management practices, any cultivar having the correct characteristics and sown at the right time, should produce the desired result. Only seven cabbage cultivars were used by the farmers and these were planted at the correct time of the year. This reduced variation due to cultivar effects. Furthermore, simple ANOVA and multiple range tests, although not very reliable, found no significant yield differences between cultivars. Most importantly, it was not possible to quantify cultivars or their effects for inclusion in regression analysis. Only replicated trials on different soils, nutrient regimes, or more monitor plots would have enabled reliable analysis of cultivars and yield related effects. Problems with bolting, incorrect sowing times, and an influx of new untested cabbage cultivars were dealt with in cultivar trials. A sowing guide for trial-proven cultivars and reports of each trial in the Umlaas River Valley, can be found in Appendix 12 a, b & c. The cultivar trials were not related to the cabbage monitor plots as such, and therefore not included in the written study. In summary, cultivar effects were possible but not regarded as substantial, and could not be quantified in this study. Replicated trials on different sites or more monitor plots could test the validity of this statement. Therefore, I am of the opinion that the exclusion of cabbage cultivars in analysis, has not really detracted from the depth or reliability of this study.

§ 8 showed the effects of crop water stress on cabbage yields. In retrospect, it was unfortunate that more accurate measures of available soil moisture or amounts and frequency of irrigation were not obtained - the parameters used were somewhat subjective. However, the occurrence of crop water stress in cabbage production in the Umlaas River Valley was unknown at the time and it is my opinion that the parameters used were adequate in identifying water stress as a limiting factor, thereby achieving one of the goals of this study.

It must be pointed out, that this study was part of an investigation to pinpoint problems specific to a particular area and provide solutions proved in the field; cabbages on different soils, with different fertilizer and spraying programmes, experiencing different management practices, had to be monitored and compared. The study method used for the Umlaas River Valley Vegetable Project was the only way to accomplish the objectives of the project and has been highly successful in achieving its goals. A similar methodology is recommended for any area experiencing problems in vegetable production, in data accumulation or when actual practices need to be investigated.

In conclusion, a summary of the recommendations generated by this study, for cabbage production in the Umlaas River Valley, is presented:

1. Fertilizer recommendations should be based on the soil critical values identified in § 1, with the amounts of available nutrients not exceeding these values.
2. Soils with nutrient values exceeding the critical values (esp. P & K), should not receive any of that nutrient.
3. A fertilization strategy should be implemented to reduce excessively high soil nutrient levels and parameters, and raise excessively low soil nutrient levels and parameters.
4. Apply 200 kg ha^{-1} of N, ⅔ preplant and ⅓ topdressed at 4 - 6 weeks after transplanting. This should result in higher yields. Avoid excessive applications of N.
5. The practice of applying extra P for safety, should be avoided.
6. Ca, Mg and S requirements should also be considered in fertilizer recommendations.
7. Highest yields could be produced by maintenance of cation saturation ratios of 65:25:10 for Ca:Mg:K or maintenance of soil nutrient values for Ca, Mg and K as close as possible to the critical values (§ 1).
8. Liming recommendations should consider pH as well as acid saturation. Low pH soils should be limed to at least 4.5 (KCl) or an optimum of 5.5 (KCl). Maximum permissable acid saturation should not exceed 2 %. Attention to both factors could reduce disease and pest incidence, improve the soil cation balance, reduce Mn levels in the plant, and promote soil fertility.
9. Soil fertility problems on cabbage can be diagnosed by taking a soil sample in the problem area and leaf samples of a MRM leaf. The soil analysis can be compared to soil nutrient values in § 1 and leaf analysis to leaf norms in § 3.
10. Use crop removal figures in § 3 to estimate removals in fertilizer programmes.

11. Use crop rotations with different types of crops, different rooting depths and alternate crops with high and low nutritional demands.

12. Be aware of optimal infection or infestation periods of prevalent diseases and pests in the Umlaas River Valley as detailed in § 5 & 6.

13. Scouting and good corrective and preventative spray programmes are essential, especially for pest control. Nozzles, spray pressure and droplet size should be checked regularly to ensure correct application and maximum disease and pest control. Routine measures should control the less dangerous pests, but special efforts need to be made for thrips, aphid and webworm, esp. in the first six weeks after transplanting.

14. Where possible, avoid management factors that increase pest or disease incidence as stated in § 5 & 6.

15. Clubroot is a big problem in the Umlaas River Valley. Farmers with clubroot-free soils should clean implements used on infected lands and not allow vehicles belonging to hawkers, onto their lands. This will reduce the spread of infection from farm to farm, and field to field.

16. Growers producing their own cabbage seedlings in the Umlaas River Valley must be aware of possible downy mildew outbreaks, following stress weather cycles as mentioned in § 7.

17. Use automatic weather stations, Class A pans or tensiometers for irrigation scheduling of cabbage crops.

18. Less water can be applied before headform, but thereafter, cabbage crop requirements increase. Any deficit from headform to maturity will reduce yields.

19. When limited water is available, reduce normal applications before headform but supply normal amounts after headform, ie., the crop can withstand moderate water stress within about six weeks after transplanting, but thereafter will suffer economic loss if subjected to further water stress.

20. Growers should use the farm plans and Binomial Soil Classification produced by the Vegetable Project, to make management decisions on land use and irrigation requirements.

21. The number of tillage operations should be reduced as much as possible, or use of implements altered, to reduce compaction and deterioration of soil structure.

22. The use of green mealies or babala etc., in a rotation, and subsequent incorporation of plant residues into the soil would assist in the improvement of the soil structure.

23. Chicken or pig manure should be incorporated at the rate of at least five t ha^{-1} $year^{-1}$. The application of more than 20 t ha^{-1} $annum^{-1}$ should be avoided. This will assist in the maintenance of soil structure and could reduce pest and disease incidence. This should be applied at least one month before transplanting.

24. Farmers must aim for the highest percentage cut, of large, heavy heads for the hawker market or highest percentage cut of medium heads for bagging.

APPENDIX

TITLE	FILE NAME	DESCRIPTION & FILE TYPE
APPENDIX 1A	APPEND1A	Weather data - maximums, means, minimums (WORD PERFECT)
APPENDIX 1B	APPEND1B.WQ1	Weather data - wind direction graph (QUATTRO-PRO)
APPENDIX 2	APPEND2	Binomial soil classification (WORD PERFECT)
APPENDIX 3A	APPEND3A	Questionaire (WORD PERFECT)
APPENDIX 3B	APPEND3B.WQ1	Crucifer survey 1 - 9 (QUATTRO-PRO)
APPENDIX 4	APPEND4.WQ1	Soil analysis data (QUATTRO PRO)
APPENDIX 5	APPEND5.WQ1	Fertilizer (QUATTRO PRO)
APPENDIX 6	APPEND6.WQ1	Weeds, pests and diseases (QUATTRO-PRO)
APPENDIX 7	APPEND7.WQ1	Cabbage pests (QUATTRO-PRO)
APPENDIX 8	APPEND8.WQ1	Cabbage diseases (QUATTRO-PRO)
APPENDIX 9	APPEND9.WQ1	Elements at head formation (QUATTRO-PRO)
APPENDIX 10	APPEND10.WQ1	Elements at harvest (QUATTRO-PRO)
APPENDIX 11	APPEND11.WQ1	Plant population, water stress, management (QUATTRO-PRO)
APPENDIX 12A	APPEND12.WQ1	Cv sowing dates(QUATTRO-PRO)
APPENDIX 12B	APPEND12	Cultivar trials (WORD PERFECT)
APPENDIX 12C	APPEN12C.WQ1	Cultivar trial averages of all factors (QUATTRO-PRO)
APPENDIX 13	APPEND13	Production guidelines (WORD PERFECT)
APPENDIX 14	APPEND14	Hormone herbicide symptoms (WORD PERFECT)
APPENDIX 15	APPEND15.WQ1	Monitor plot form (QUATTRO-PRO)