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AGRONOMIC PERFORMANCE OF WILD MUSTARD IN AN INTERCROPPING WITH GREEN BEANS

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ABSTRACT

Wild mustard (*Brassica spp.*) is used as an edible wild leafy vegetable by indigenous people in South Africa. The potential of wild leafy vegetables in agriculture is not well understood, because there is generally no agronomic research on their production practices. The objective of this study was to examine the performance of three wild mustard species (herein referred to as I, K and M) over four cropping seasons in an intercropping system with green beans (*Phaseolus vulgaris* L. cv. Imbali). The crops were grown with and without organic fertiliser under dryland conditions at two sites (The University of KwaZulu-Natal Research Farm, Ukulinga and in a rural area of Umbumbulu, KwaZulu-Natal within the farmers' locality) during autumn, winter, spring and summer of 2004 to 2005. Plant development (leaf number, plant height and fresh biomass) during the first six weeks after sowing and seed yield were used to determine agronomic performance of each species. Nutrient status of the rhizosphere soil was determined at 42 days after sowing for each species to determine what effect growing the species would have on mineral availability. Wild mustard production significantly ($P < 0.01$) performed better at Ukulinga than Umbumbulu. Polyculture was beneficial for wild mustard leaf accumulation and green bean production as determined by land equivalent ratios greater than one for all species combinations, regardless of fertiliser application. Cool environmental conditions occurring in autumn and spring were more favourable ($P < 0.05$) for wild mustard and green bean biomass accumulation than summer and winter conditions. However, wild mustard seed yield was highest in winter compared with autumn and spring, and there was no measurable seed production in summer. Soil analysis results at 42 days after sowing showed an increase in P, K, Cu and Mg in the rhizosphere of wild mustard without organic fertiliser. Polyculture improved Zn, Cu, Mn and K in wild mustard leaf tissue. It is concluded that wild mustard can be grown as a leafy vegetable throughout the year, but it requires cool environmental conditions to enhance seed yield. Species M significantly yielded better biomass and seeds than species I and K during all the seasons. However, species K performed the least in all aspects.

DECLARATION

I, Nathan Phiri, hereby certify that the research work presented in this dissertation, unless otherwise, is my own original investigation and has not been submitted in part, or in whole to any other University. This research was carried out at University of KwaZulu-Natal, Pietermartzburg, South Africa.

Signature.....

November, 2005

Approved by

Signature:.....

Dr. Albert T. Modi (Advisor)

November, 2005

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CHAPTER 1. INTRODUCTION

1.1 Literature Review

Despite global food adequacy (~2900 calories per person per day by 2020), which according to the Food and Agriculture Organisation (FAO) has persisted since 1974, sub-Saharan Africa continues to suffer from food insecurity (~2300 calories per person per day by 2020) (Cohen, 2003). Limited availability of land for crop production, decreasing soil fertility, and declining yield for major food crops have raised major concerns about the ability of contemporary agriculture's ability to provide nourishment for the increasing human population (Sinclair and Gardner, 1998; Welch and Graham, 1999). Future focus on increasing agricultural production will have to be on sustainable use of natural, human and capital resources (Altieri, 1998).

In situations where arable land is limited (e.g. small-scale farming) diversification of crop species can be a viable option for increasing land productivity and economic returns (Tarafder *et al.,* 2003). It is acknowledged that Africa has a wide variety of vegetables that are underutilised and marginalised (Smartt and Haq, 1997). Intensifying production of underutilised crops could help to increase food security. Chrispeels and Sadava (1994) noted that many underutilised crops contain considerable amounts of vitamins, minerals and other nutrients, which could help millions of people who are suffering from deficiencies of these food components. Intercropping has a potential to diversify small-scale farmers' food choices, while it increases availability, the key elements to curbing

food insecurity. Undertaking to produce vegetables through out the year may also improve food availability and access for resource-poor farmers and also provide them with an income through sales of the vegetables to other consumers.

The vegetables consumed by people in developing countries can be classified into three categories: 1) Those that are gathered from the wild (e.g. *Bidens pilosa*), 2) those that are often gathered from the wild, but are also cultivated (e.g. amaranthus hybridus) and 3) conventional cultivated vegetables imported from the western countries (e.g. *Brassica oleracea*) (Rice et al., 1987). Little or no commercial cultivation of traditional and indigenous vegetables has occurred, mainly because of lack of technical production knowledge and economic incentives. It is also a general perception that small-scale farmers have not considered the cultivation of traditional wild vegetables because of the poor status of the crops in agriculture and commerce (Modi, 2003). However, wild vegetables have been shown to have a potential in combating hunger and malnutrition. This therefore calls for adequate attention given to the cultivation and use of these vegetables. This study undertakes to asses the agronomic potential of three species of wild mustard (Brassica species) as an alternative vegetable to organic farming system in an intercropping with green beans. Brassicas and other related cruciferous crops are widely cultivated through out the world as vegetable crops for human consumption, as condiments and spices for improved flavour of human diets. However, the larger fraction of these crops is cultivated for edible leafy vegetables and vegetable oil production.

Wild Mustard (Brassica spp.), is one of the wild type of vegetables in the rural south Africa. There is concern that anticipated demands for organic vegetables might not be

met by already existing conventional vegetables. Following the adoption of traditional Amadumbe, sweet potato and Irish potato as organic products, there is potential that wild mustard would adopted as an organic vegetable (Modi, A. 2003).Other than South Africa, preliminary research in Zambia showed that consumer preferences for Brassica carinata as a leafy vegetable was quite high (Msikita *et. al.*).

Many thousand-plant species have been used for several purposes by human. About 100 have been developed into important crops (Hill *et al.,* 1998) and only few of these crops have been intensively and widely used in the world's agriculture. This has lead to the shrinking or erosion of agricultural biodiversity and at the same time to an increasing level of vulnerability of food supply. These concerns have generated growing interest in the research on "underutilized"crops such as Vegetables which are important for human nutrition.

1.2 General description of polyculture cropping systems

In developing countries, it is common for farmers to grow crops in mixtures (polycultures or intercrops). This is a characteristic of traditional agriculture (Altieri, 1998). A variety of polyculture types exists, reflecting the wide range of crops and management practices that farmers use throughout the world. Polycultures may involve mixtures of annual crops with other annual crops, annuals with perennials, or perennials with perennials. Polycultures may be sown in spatial patterns ranging from simple mixtures of two crops in alternate rows to complex assemblies of more than two intermingled species.

Component crops may be planted at the same time or at different dates. Harvests may also be simultaneous or staggered. Descriptions of different polyculture systems have been published (Beets, 1982; Francis, 1986). Sullivan (2003) listed the following polyculture types depending on the spatial arrangement:

a) Row intercropping: growing two or more crops at the same time with at least one component crop grown in a row.
b) Strip intercropping: growing of two or more crops together in strips wide enough to permit separate crop production using machines, but close enough to allow component crops to interact.
c) Mixed intercropping: growing of two or more crops together in no distinct row arrangement.
d) Relay intercropping: planting a second crop in a standing crop at a time when the standing crop is at its reproductive stage, but before harvesting.

Until about 25 years ago, the characteristics of polyculture that make them desirable were generally ignored by agricultural researchers. However, polyculture research has increased in recent years and many of the potential benefits of polyculture are becoming evident. Machuka (2003) reported that intercropping has several advantages over sole cropping, including more efficient use of land resources, higher labour productivity, lower risk of crop failures and better weed management, among others.

1.3 Prevalence of polyculture in sub-Saharan Africa and the world

"Intercropping is the rule in Africa" stated Machuka (2003). Polycultures constitute at least 80% of the cultivated area of West Africa (Liebman, 1998). Machuka (2003) reported the following observations about sub-Saharan African cropping systems:

(a) In the humid forest zone of sub-Saharan Africa, the predominant cropping systems are cassava-based (~42% of agricultural land) rice-based (~ 16%), coffee-/cocoa-based (~21%), and banana-plantain-based (~9%). Yam and maize are also important. Farmers increasingly intercrop maize with cassava to meet specific food security needs provided early in the growing season.

(b) In the moist savannah zone, short-to-medium season crops, such as maize, cowpea, sorghum, millet and cotton in the drier areas, are predominant in addition to long-season annuals such as yam and semi-perennials such as cassava.

(c) In the mid- and high-altitude savannas and woodlands, maize is the predominant crop, and it is intercropped with cassava, sweet potato, cowpea, beans, bananas, soybeans and cucurbits.

(d) In the arid and semi-arid regions there are three dominant traditional farming systems: agro-silvicultural, agro-silvi-pastoral, and silvi-pastoral.

Most of the staple crop production in the Latin American tropics occurs in polycultures. More than 40% of the cassava, 60% of the maize and 80% of the beans in that region grow in mixtures with other crops (Leihner, 1983). In Asia, where upland rice, sorghum, millet, maize and wheat are the staples, polycultures are common (Jodha, 1981). In some

areas of south east Asia, where lowland (flooded) rice is grown as a sole crop, farmers build raised beds to produce dryland crops amid strips of rice (Beets, 1982).

Although it is a general perception that polycultures are practised in small-scale farming, where farmers lack capital or credit to purchase synthetic fertilisers, pesticides, herbicides and field machinery, the practice not restricted to such areas only. Liebman (1998) reported that polyculture can be practised on relatively large, highly mechanised, capital intensive farms. Examples cited by Liebman (1998) included forage grasses and legumes inter-seeded into a growing crop of maize, soybean, barley, oats, or wheat; soybean inter-seeded into a growing crop of wheat; field pea planted in a mixture with small grains for seed or forage production; soybean strip-cropped with maize or sunflower; grasses and legumes planted as understory vegetation in fruit and nut orchards and grass/legume mixtures for forage production.

1.4. Agronomic aspects of polyculture

The preceding discussion (1.2 and 1.3) has highlighted the general characteristics of polyculture and its prevalence as a cropping system in traditional agriculture of the developing world. It has also been highlighted that polycultures are important for specific crop management systems in the developing world. It is important to focus on the agronomic aspects of polyculture, as they pertain to traditional agriculture, while accepting that the system has limited use in large-scale, machinery-, synthetic input- and commodity-driven agriculture.

1.4.1 Farming system efficiency

Loomis and Connor (1996) stated that individual fields are the basic units for cropping system studies. A cropping system refers to a crop community, together with the management practices used in its production (Loomis and Connor 1996). At different levels of farming systems, the principal crops and different management practices are employed on any particular farm. According to Ruthenberg (1980) farms are the fundamental units for economic and sociological analysis, because they are organised to produce a net economic return. Productivity is the most important property of a farming system, although it is not the only important one. Productivity can be explicitly defined by the yield of a useful product per unit land area. Yield measure has the property of also measuring the efficiency of a crop relative to other inputs, such as labour, radiation, water and nutrients, which also occur per unit of land.

Land use efficiency is critically important in situations where land is a limiting resource. Research (Natarajan and Willey, 1980; Tsubo *et al*, 2003) illustrated that more yield can be harvested from a given area sown in polyculture than from an equivalent area sown in separate lands of monoculture. Natarajan and Willey (1980) showed that 0.94 ha of sorghum monoculture and 0.68 ha of pigeon pea monoculture were needed to produce the same quantities of sorghum and pigeon pea that were harvested from a 1-ha polyculture. Therefore, the land equivalent ratio (LER) of the polyculture was 1.62. See Loomis and Connor (1996) for a detailed treatment of the LER concept. The authors in this text reported that the yield of each crop in the mixture was reduced by competition from the associated crop, but the total yield of the polyculture, on a unit land area basis, was 62%

greater than that of the monocultures. Hence, a polyculture produces more combined yield in a given area than could be obtained from monocultures of the component crops whenever LER > 1. Values of LER reported from experiments with a variety of polyculture systems indicated that substantial increases in land use efficiency are possible: 1.26 for millet/groundnut (Reddy and Willey, 1981), 1.85 for barley and fava bean (Martin and Snaydon, 1982) and > 2.51 for cassava/maize/groundnut (Zuofa *et al.* 1992).

It has been argued that high LER values for mixtures of crops with different maturation times inflate the apparent efficiency of using polycultures, since several short-season crops might be grown sequentially over the same period of time as a polyculture (Altieri, 1998). These criticisms may not be fully justified since farmers often need to produce both short-season and long-season crops that can only grow at certain times of the year, even under irrigation Balasubramanian and Sekayange, (1990).

1.4.2. Farming system stability

In small scale agriculture, it is as important to reduce the risk of total crop failure as it is to increase potential nutritional and cash returns (Lynam *et al.* 1986). Yield variability of polyculture was shown to be less than that of the monocultures of the components (Rao and Willey, 1980). The stability of polycultures can be translated to economic stability at the farming system level. Trenbath (1999) showed that for a given land area, the probability of a family failing to produce enough calories for subsistence was lower when the area was sown to a sorghum/pigeon pea polyculture than when it was sown to monocultures of the same crops. Rao and Willey (1980), also working with sorghum and

pigeon pea, found that the probability of exceeding a specified disaster income level was greater for polycultures than for monocultures.

The reasons for the better yield stability in a polyculture system may be due to yield compensation occurring between polyculture component crops, such that a failure of one component due to environmental or biotic stress might be offset by increased yield of the other component(s). More research is needed to explain the stability of yield associated with polyculture and its mechanisms.

1.4.3 Resource use

The efficiency of polycultures in productivity is likely due to efficient capture and conversion of available light, water and nutrients to biomass or economic yield (Willey, 1990). Loomis and Connor (1996) described the improvement in resource use in polycultures as a reflection of niche differentiation. When two crops of differing species and clear physiological and (or) morphological characteristics that influence requirements for growth elements are grown in a polyculture, competition for resources between the two species is minimised, because of differences in potential niches of exploitation. Therefore, competition in mixtures will be more severe with similar plants (i.e. monoculture) than with plants differing in growth habit. Altieri (1998) explained the improvement in resource use in polycultures as a reflection of three phenomena:

(i) Complementarity: Crops differing in the way resources are used when grown in a monoculture complement each other when they are grown together in a

polyculture, and they make better combined use of resources. Hence, complementarity minimises niche overlap among associated species, and that way, resource competition is also minimised. Loomis and Connor (1998) presented a detailed explanation of the three types of complementarity: temporal (major demands on resources are made at different times), spatial (canopies or roots capture resources in different zones) and physiological (biochemical differences between crops cause differences in responses to environmental resources).

(ii) Interspecific facilitation: It occurs when crop species grown in polycultures have access to resources not available in monocultures or when they enjoy improvements in microhabitat that result in greater resource conversion efficiencies. For example, if one of the component species in a polyculture is a legume bearing nitrogen-fixing bacteria on its roots, atmospheric nitrogen may be transferred to associated non-legumes and increase their yield considerably.

(iii) Changes in resource partitioning: This phenomenon may occur in polycultures, such that greater percentages of total dry matter and nutrients are allocated to harvestable portions of crops when they are grown in mixtures than when grown separately. Where this occurs, each unit of materials acquired through photosynthesis or root uptake produces a greater benefit for the farmer in polycultures than monocultures.

1.4.4 Plant protection

Insect pests, plant pathogens and weeds have a significant negative effect on the ability of a crop to capture resources and convert them into harvestable portions. In commercial, large scale farming, these problems are effectively controlled by broad-spectrum pesticides and herbicides, because monoculture permits such an approach. The issue that frequently arises in discussions about polycultures is their effects on plant protection, i.e. from insect pests, pathogens and weeds.

1.4.4.1 Insect pests

Studies on the effects of polycultures on insect pests have shown that insect pests are less abundant in polycultures than in monocultures (Andow, 1991). In the review published by Andow (1991) in 209 field studies on 287 herbivorous arthropod species it was reported that 52% of the pest species were less abundant in polycultures, 15% were more abundant in polycultures, 13% showed no difference and 20% showed a variable response. The review (Andow, 1991) also reported that 53% of the predator and parasitoid species that act as natural enemies of insect pests were more abundant in polycultures than monocultures, 9% of the natural enemy species were less abundant, 13% showed no difference, and 26% showed a variable response in polycultures. The conclusion that can be drawn from the findings reported in the review (Andow, 1991) is that the use of polyculture production systems may increase the importance of predators and parasitoids as natural controls of populations of insect pests. This explanation for lower populations of insect pests in polycultures was termed by Root (1973) as the enemies hypothesis.

Roots (1973) provided a second explanation for the lower abundance of insect pests in polyculture as compared to monoculture and termed it "the resource concentration hypothesis". The resource concentration hypothesis was explained thus: insect pests, particularly species with a narrow host range, have greater difficulty in locating and remaining on host plants in small, dispersed patches as compared to large, dense, pure stands. The behavioural changes may result from increased chemical and visual interference with cues used in host plant location or modifications of microhabitat and host plant quality (Andow, 1991).

1.4.4.2 Plant pathogens

The review of literature conducted during this study showed that there is little research that has been done on the ecology and management of plant pathogens in polycultures. The few early studies available showed that in some cases the incidence of disease may be higher for crops grown in polycultures than monocultures, in other cases the reverse situation was reported (Sumner *et al.* 1981). Close examination of the conflicting reports indicated that the species composition in a polyculture may be important in influencing the incidence of pathogens. For example, Moreno (1979) found that the severity of cassava mildew was greater when cassava grew with maize, but lower when it grew with beans or sweet potato; angular leaf spot in beans was more severe in association with maize, but lower in association with cassava or sweet potato.

According to Altieri (1998), the following aspects of polycultures may be important for improving plant health:

(i) Planting susceptible plant species at lower densities in polycultures than in monocultures to allow the space between them to be occupied by the resistant or non-host plant species.

(ii) The "flypaper effect": resistant plants interspersed among susceptible can intercept disease inoculum spread by wind or water and prevent it from infecting the susceptible plants.

(iii) Spatial arrangements to promote a microclimate that is less favourable for disease development. For example, dense canopy coverage may increase humidity and reduce light penetration, favouring certain fungal and bacterial diseases.

(iv) Interplanting plant species that excrete substances that are toxic to root pathogens of other plants, even if the beneficial species is not a food plant [e.g. marigolds (*Tagetes spp.*) excrete substances that are toxic to nematodes].

No studies were found to indicate that decreased incidence of disease symptoms was responsible for higher yields in polycultures. Hence, more research is needed concerning the ecology and management of pathogens in polycultures.

1.4.4.3 Weeds

Weed control is one of the most labour intensive aspects of small-scale farming. In large scale, commercial farming, weed control is probably one of the most-chemical intensive operations. A review conducted by Liebman and Dyck (1993) showed that polyculture systems offer better options for weed control than monoculture systems. In examining the efficiency of polyculture in weed control Liebman and Dyck (1993) reported data on two

polyculture systems. In one system, the focus was on the yield of the main crop, and the second crop was intersown to smother weeds, so that its yield will be considered as additional to that of the main crop. In the other system, the focus was on both crops, and none of them was sown for the purpose of weed control. In the former system it was reported that weed growth in polyculture was lower in 47 cases and higher in 4 cases than the main crop grown alone. In the latter system, weed control in polyculture was lower than in all the component monocultures in 12 cases, intermediate between component monocultures in 10 cases, and higher than monocultures of all components in 2 cases. The findings of Liebman and Dyck (1993) were supported by Bauman *et al.* (2002).

Zuofa *et al.* (1992) reported that intercropping smother crops of groundnut, cowpea, or melon with a cassava/maize main crop showed superior weed control, higher yields and greater LER values than monocultures of the component crops. In another study (Zuofa and Tariah, 1992), maize intercropped with smother crops of sweet potato, cowpea, groundnut, or melon and hand-weeded once provided higher net income than monoculture maize hand-weeded three times or sprayed with herbicides. Ali (1988) reported that total seed yields of pigeon pea/mung bean intercrops without any hand-weeding were not significantly different from the yields obtained from weeded, monoculture pigeon pea. Interseeding green manure legumes into cereal and grain legume crops can provide increased weed control for the main crops, furnish ground cover for erosion control and improve soil fertility (Altieri, 1998).

Management practices such as crop density, choice of crop species, crop spatial arrangement and fertiliser regime have also been shown to affect weed control in polycultures (Ramert and Ekbom, 1996; Silwana and Lucas, 2002; Wahua, 1985). In general, increases in crop density result in increased suppression of weed growth (Mohler and Liebman, 1987). Polycultures that include species and cultivars with rapid, early growth and dense, vigorous canopy formation over the ground surface are particularly effective in reducing weed growth (Samson *et al.* 1990). Arvind *et al.* (1998) reported less weed growth in pigeon pea/sorghum polycultures when pigeon pea was sown in paired, rather than evenly spaced rows. This finding showed that the effects of crop spatial arrangement on weed control in polycultures may vary with the arrangement. An early study by Bantilan *et al.* (1974) showed that nitrogen fertiliser increased competitive suppression of weeds by maize/mung bean polyculture, but it either decreased or had no significant effect on weed suppression by maize/groundnut and maize/sweet potato polycultures. Davis and Liebman (2001) reported that the source of nitrogen has an important effect on crop/weed interactions in polyculture. The response of component species to fertiliser regime would clearly be an important consideration in studies of polyculture/ weed interactions focusing on fertiliser regimes.

1.5. Conclusion and study objectives

The role of polycultures in the agriculture of developing countries or resource-poor farmers will probably expand as there is increased understanding of the economic and environmental costs of heavy reliance on agricultural chemicals. Polyculture can offer

farmers potentially useful options for decreasing dependence on purchased external inputs, minimising exposure to agrichemicals, reducing economic risk and nutritional vulnerability, and protecting the natural resource base necessary for agricultural sustainability. The task of polyculture researchers and farmers is to better understand the complexities of polycultures, predict their benefits so that these systems may be refined, transferred and adapted.

The present study investigated the effect of three wild mustard species (brascica species) and green bean (*Phaseolus vulgaris*) polyculture on plant development and yield of the component crops under field conditions at two sites during the four normal seasons of the year (Autumn, winter, spring and summer).

The objectives of the study were:

(i) To examine the effect of wild mustard/green bean polyculture on crop development and LER,

(ii) To investigate the influence of cropping season on wild mustard production in polyculture,

(iii) To investigate the response of wild mustard and green bean to organic fertiliser application and

(iv) To examine the effect of wild mustard and green bean on changes of selected mineral nutrients in the root zone.

It was hypothesised that the wild mustard/green bean intercrop would supply a higher and diverse yield and nutritional value from the same area of land compared with the

monocultures of each component crop. Wild mustard is an edible wild plant with a potential for cultivation as a leafy vegetable. Agronomic practices for its production had not been published prior to this study in South Africa. Organic farmers from Umbumbulu, KwaZulu-Natal, wanted to produce wild mustard, which occurred in their location as an edible weed in a polyculture with green beans, which they produced for an organic market. The study would identify the suitable time of the year to grow wild mustard, and investigate whether growing green beans with wild mustard would have a beneficial effect on each or one of the crops, with respect to yield.

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Chapter 2. DETERMINATION OF THE GROWING SEASON FOR WILD MUSTARD IN AN INTERCROPPING WITH GREENBEANS

2.1. Introduction

Polyculture systems are associated with the efficient use of production resources, such as land, water, nutrients and solar radiation (Jeranyama, 2000; Tsubo and Walker, 2004; Francis, 1989). Increased yield and income per unit of land may be the most important objectives for small scale farmers with small land areas and limited production resources. Intercropping often results in better land use efficiency than sole cropping, which is usually associated with high yields. Innis (1997) reported that intercropping produces more biomass than a pure crop stand. However, yields might be affected by either shading effect or competition for nutrients as the plants grow (Tsubo and Walker, 2004). Studies on vegetable and legume intercropping are scarce in the published literature, although intercropping of leafy vegetables and legumes may have been practised by small-scale farmers over many decades. Hence, the performance of leafy vegetables and legumes under intercropping requires an investigation. It has been reported that overall vegetable yield is determined by several yield components that include leaf number and plant height (Fukai and Trenbath, 1993). These components are normally affected by environmental conditions such as light, temperature, rainfall and humidity from sowing to crop maturity (Lesoing and Francis, 1999). Other stress factors that may affect crop performance in an intercropping are diseases and pests. Most brassica species to which wild mustard belongs are annual herbs and grows best under cool seasons. Wild mustard can also be grown in a short season. This possibility makes draws the anxiety to try to

produce wild mustard through out the year. Therefore, the objectives of this study were to determine the effect of intercropping wild mustard with green beans on plant development, fresh biomass accumulation and economic yield in order to determine the best growing season of both in the mustard-green beans system

2.2 Materials and methods

2.2.1 Site description

Field experiments were conducted at two locations in Kwazulu-Natal: on-station in Pietermaritzburg at The University of KwaZulu-Natal's Research Farm, Ukulinga and on-farm at Umbumbulu. The two locations are located about 65 km apart, with the Umbumbulu site situated 60 km from the coastal town of Durban (see map on Appendix 2.2). The two locations have minor differences in weather patterns although temperatures and rainfall patterns for Pietermaritzburg and Umbumbulu are more comparable (Tables 2.1 and 2.2) The soil characteristics at each site were determined by digging pits in the fields where field experiments were planted. The soils were classified to belong to Avalon Mafikeng family and Magwa Ntsubane family at Ukulinga and Umbumbulu, respectively according to the soil classification working group (1991) (Figure 2.1.).

Table 2.1. Long-term climatic data (rainfall, temperature, sunshine) averages at Ukulinga from January to December.

	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall													
Median rainfall (mm)		116	94	89	39	16	4	6	15	38	64	88	100
Mean rainfall (mm)	738	116	98	92	48	27	10	10	30	51	67	90	99
Temperature													
Mean (degrees C)	18.1	21.9	21.9	21.1	18.7	16.0	13.4	13.4	15.2	17.1	18.3	19.5	21.2
Maximum (degrees C)	24.3	27.1	27.2	26.6	24.9	22.9	20.8	20.9	22.2	23.6	24.2	25.0	26.8
Minimum (degrees C)	12.0	16.6	16.7	15.6	12.6	9.2	6.1	6.0	8.2	10.7	12.4	14.0	15.7
Heat units (base 10.0 C)		367	337	344	262	187	102	106	160	214	257	284	348
Heat units (base 4.4 C)		541	495	517	430	360	270	280	333	382	431	452	522
Heat units (base 5 C)		522	478	499	412	342	252	261	315	364	412	434	503
Utah-7 chill units		0	0	0	0	0	75	77	0	0	0	0	0
Positive Utah chill units		0	0	0	0	0	75	78	0	0	0	0	0
Evaporation													
A pan	1697	180	158	149	123	106	94	104	129	147	158	163	186
Sunshine													
Hours/day (Oct-Mar)	6.8												
Mean annual (hours)	7.2												

Frost hazard: Light

Climatic capability rating: C5 (Climatic limitations to production are moderate)

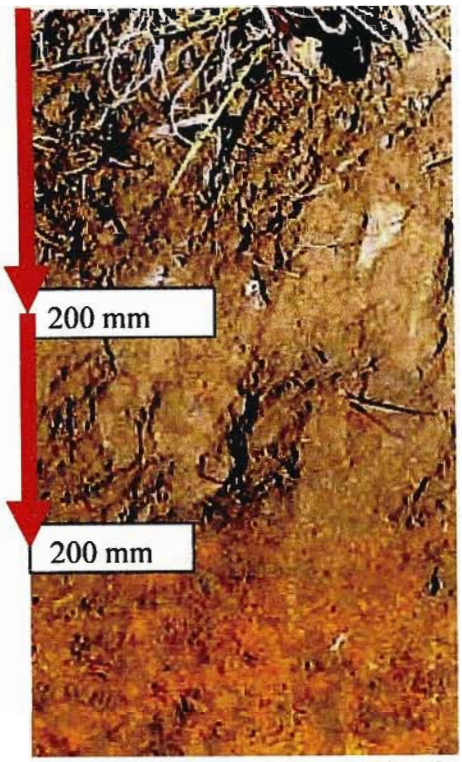
Table 2.2. Long-term climatic data (rainfall, temperature, sunshine) averages at Umbumbulu from January to December.

	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall													
Median rainfall (mm)		125	109	108	51	22	11	12	25	54	84	109	111
Mean rainfall (mm)	956	138	121	127	59	40	27	24	33	61	94	119	113
Temperature													
Mean (degrees C)	18.6	21.9	22.1	21.4	19.4	17.2	14.9	14.7	15.7	17.3	18.4	19.5	21.2
Maximum (degrees C)	24.0	26.4	26.7	26.2	24.6	22.9	21.0	21.0	21.9	22.9	23.5	24.3	26.0
Minimum (degrees C)	13.4	17.4	17.6	16.7	14.2	11.4	8.8	8.6	9.6	11.9	13.3	14.8	16.5
Heat units (base 10.0 C)		369	342	354	281	222	146	147	178	220	260	286	348
Heat units (base 4.4 C)		542	500	528	449	396	314	320	351	388	433	454	522
Heat units (base 5 C)		524	483	509	431	377	296	302	333	370	415	436	503
Utah-7 chill units		0	0	0	0	0	0	0	0	0	0	0	0
Positive Utah chill units		0	0	0	0	0	0	8	0	0	0	0	0
Evaporation													
A pan	1623	165	153	144	119	105	92	101	118	135	155	158	178
Sunshine													
Hours/day (Oct-Mar)	6.0												
Mean annual (hours)	6.4												

Frost hazard: None

Climatic capability rating: C2 (Climatic limitations to production are slight)

(a) Ukulinga – Avalon Mafikeng

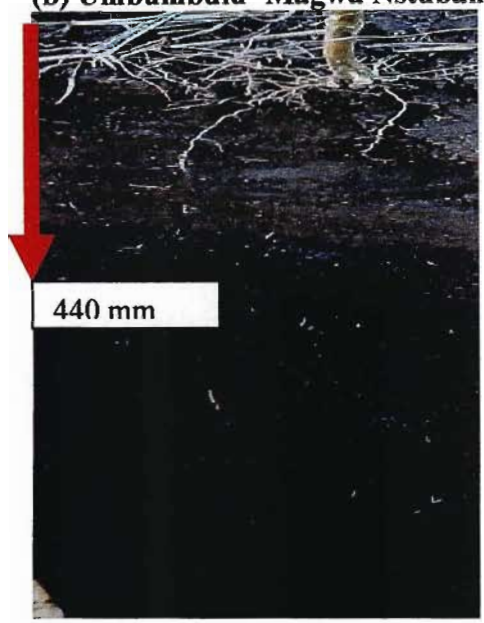


A – horizon: Orthic
Very dark greyish brown with blocky structure. Many fine to medium roots, self mulching properties with friable consistence

B1 – horizon: Yellow brown apedal
Very greyish brown soil colour containing very few fine roots with hard consistence. Has more clay content than B and has few yellowish and brownish congruent. The transition from A to B1 is not abrupt

B2 – horizon : Soft plinthic
Dark brown soil colour. The transition from B1 to B2 is not abrupt..

(b) Umbumbulu- Magwa Nstubane



A – horizon : melanic
Very dark brown soil with many fine and medium size roots and friable consistence and has a weak massive structure

B – horizon: Yellow brown apedal
Friable Massive structure with very fine and medium size roots. More clay content than A horizon. Well drained consistence.

Figure 2.1 Characteristics of soils at Ukulinga and Umbumbulu.

2.2.2 Plant material

Fresh seeds of three wild mustard species were collected in September 2003 by Dr Albert Modi (University of KwaZulu-Natal, Pietermaritzburg) from fallow crop fields and veld in KwaZulu-Natal and Western Cape provinces of South Africa, respectively. Species I (*Sisymbrium capense*) seeds were collected from the veld near Saldanah Bay, Western Cape. Species M (*Sisymbrium thellungii*) and K (*Brassica kalba*) were collected from crop fields at Msinga, near Tugela Ferry, KwaZulu-Natal. The species have similar seeds interms of shape (Figure 2.2), but plant morphologies differed during the vegetative stages of development (Figure 2.3). However, the inflorescences, flower colour (yellow) and flower parts (four petals) were identical for all the species. At a close examination, the seeds of species K contain a greater proportion of darker seeds compared with the seeds of species I and M, which are not differentiable (Figure 2.2). The green beans seeds of cultivar Imbali, produced in 2003, were purchased from a local seed company (Pro-seed).

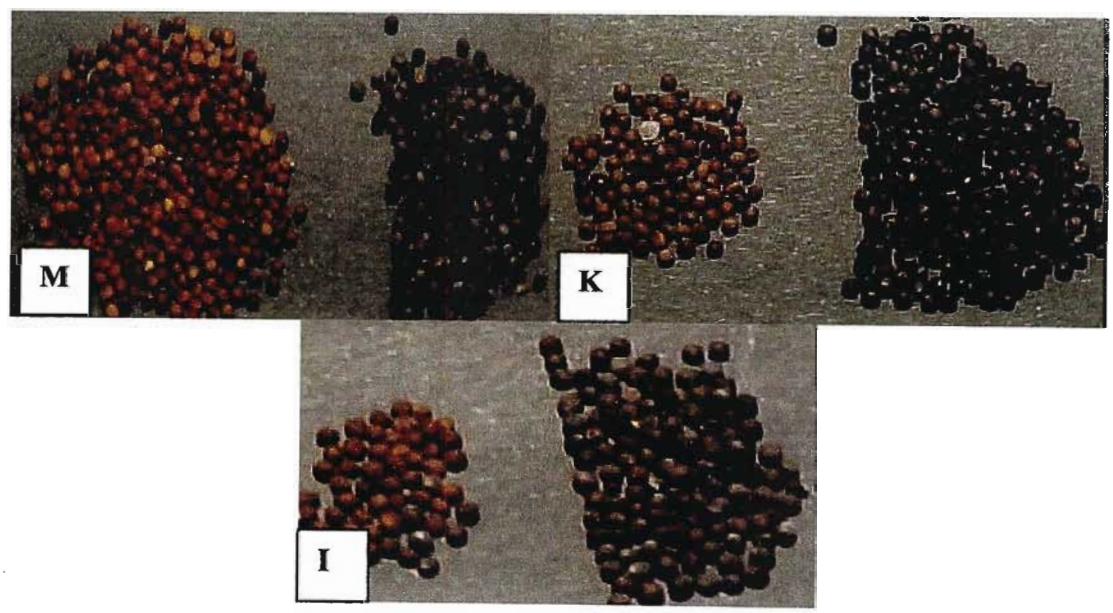


Figure 2.2 Seeds of the three wild mustard species of species M, species K and species I

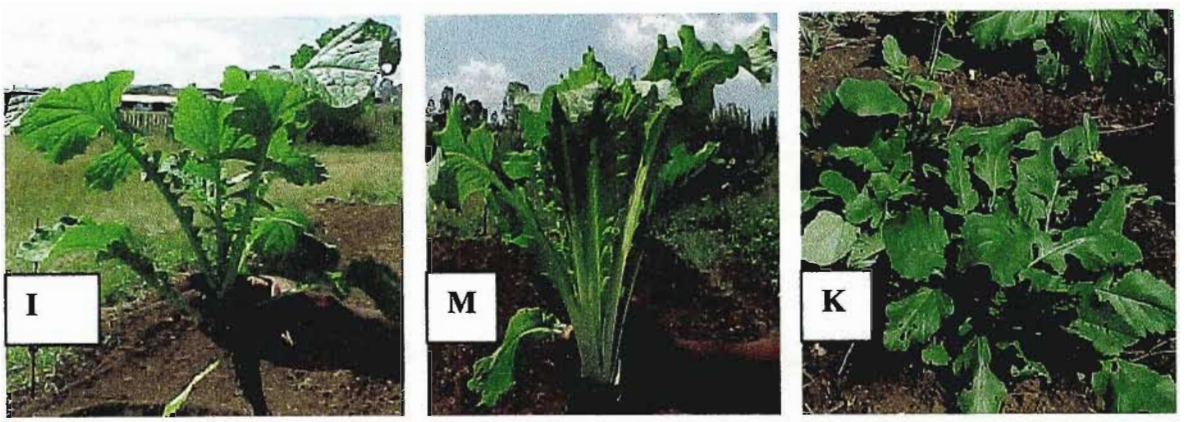


Figure 2.3. Morphological appearance of the three wild mustard species (I, M and K) at the vegetative stage of development approximately four weeks after emergence.

2.2.3 Experimental design

At each site, field experiments were constituted by one organically fertilised, (1.75 kg m^{-2} Neutrog® containing: N = 30 g kg^{-1}, P = 11 g kg^{-1}, P_2O_5 = 25 g kg^{-1}, K = 10 g kg^{-1}, K_2O = 12 g kg^{-1}, Ca = 25 g kg^{-1}, S = 6 g kg^{-1}, Mg = 8 g kg^{-1}, Zn = 443 mg kg^{-1}, Organic matter = 650 g kg^{-1}, moisture = 120 g $kg^{-1}$and the product density = 655 kg m^{-2}) block and a non-fertilised block. The fertilised block was always purposely located below the non-fertilised one down a slope gradient to avoid a possible movement of fertiliser to the non-fertilised block. In each block, 1.2 m^2 plots were laid in a randomized complete block design and the wild mustard and green beans were planted using the following treatments (T): T 1 = sole green beans; T 2 = sole species I; T 3 = sole species M; T 4 = sole species K; T 5 = species I + green beans; T 6 = species M + green beans; T7 = species K + green beans. The treatments were replicated three times in each block. See

Appendix 2.1 for experimental layout. Seeds of both green beans and wild mustard including the fertiliser were drilled in furrows at an intra and inter-row spacing of 20 cm and 20 cm, respectively (Figure 2.4). Thinning was done 7 to 10 days after sowing to get a plant population of 250 000 plants ha^{-1}, in 3:2 wild mustard to green bean ratio for the polyculture treatments (T5, T6 and T7). Seven rows were planted per plot in the order (G, W, G, W, G, W, G where G = green bean and W = wild mustard) giving five experimental rows (W, G, W, G, W) and two border rows (G). Each experimental unit was 0.8 m^2, after excluding one row at each plot edge for the creation of border rows.

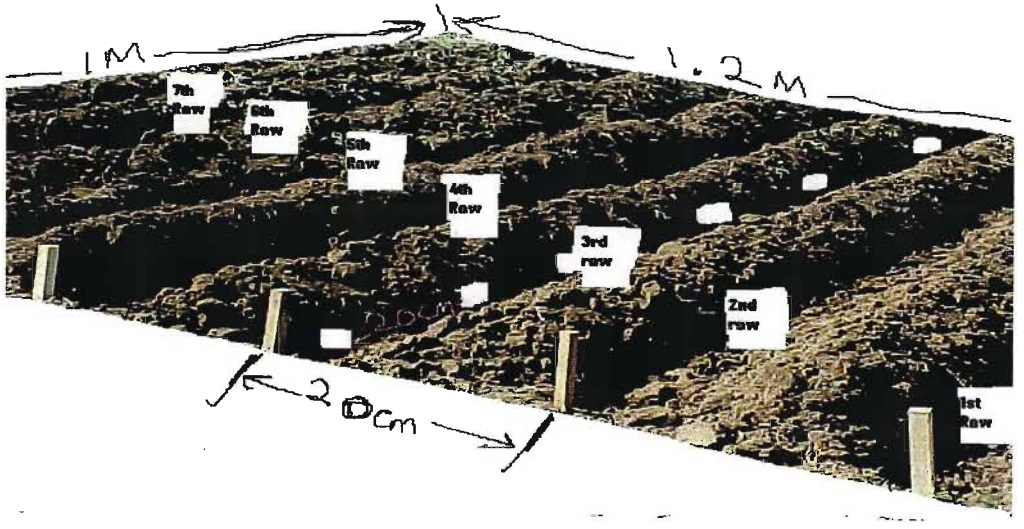


Figure 2.4. Illustration of the field experiment plot.

The University farm experiment was irrigated (25 mm per week during dry spells of each season), while the Umbumbulu experiment was rain-fed. The experiments were conducted consecutively, over four growing seasons to determine the optimum season for wild mustard production. Planting was done in March, June, September and November (Table 2.3).

Table 2.3. The four growing seasons used during the study. Note that the each season is indicated by a shading to indicate the beginning (planting) and the end (harvest). See Figure 2.5 for some of the climatic data during each season.

	2004											2005	
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Autumn													
Winter													
Spring													
Summer													

No pesticides, chemical fertilizers and herbicides were used in the experiments. Hand-weeding was done twice per season between emergence and flowering.

2.2.4 Data collection and statistical analysis

Plant height and leaf number were determined weekly from emergence to approximately six weeks after sowing. Four plants were selected at random within the experimental rows for taking plant height and number of leaves. Plant height was measured from the soil surface to the tip of the top-most leaf and an average plant height calculated. Only expanded leaves were counted during leaf number determination. At ~50% flowering of both the green beans and wild mustard, the above-ground biomass (fresh mass basis) was determined from one half of each experimental plot, and the remainder of the plot was allowed to grow to seed maturity stage. Determination of green bean pod yield was made at the same time as that of total biomass. Data on biomass was used to calculate the land equivalent ratio (LER) according to the method described by Willey and Rao, (1980):

$$LER = \frac{Polyculture\ biomass\ for\ wild\ mustard}{Sole\ crop\ biomass\ for\ wild\ mustard} + \frac{Polyculture\ biomass\ for\ greenbeans}{Sole\ crop\ biomass\ for\ greenbeans}$$

Seeds were harvested at harvest maturity (brown pods and 10 - 15% moisture content determined using oven dry method) and seed yield and germination were determined for the wild mustard species. Data on seed yield and seed germination are discussed in chapter 4. At the time of biomass determination, soil samples were also collected from the top 10 - 15 cm of the rooting zone from each treatment plot to determine mineral nutrient contents and compare them with the soil nutrient content at planting (Chapter 3). Analysis of variance (Genstat®, Rothamsted Experiment Station, U.K.) was used for data analysis and the differences between treatments were determined by LSD and S.E. (mean).

To test the hypothesis that intercrops give more economic benefits than sole crops, the economic gross incomes were computed on the basis of actual yields and based on the market price estimates for the two component crops under conventional production comparing sole and polyculture cropping systems (Figure 2.13).

2.3. Results

2.3.1 Rainfall

The rainfall data for both sites during the four growing seasons are shown in Figure 2.5. The climatic data were collected from the sites using basic equipment for rainfall and data loggers for temperature and humidity. During spring and summer, there was above average rainfall at Umbumbulu, but the autumn and winter rainfall was generally below average, except for the unseasonable July rainfall. At Ukulinga, the rainfall was generally below average, except for the unseasonable rainfall in July, November and January. The

annual rainfall at both sites was however, comparable to the long term annual rainfall (Tables 2.1 and 2.2).

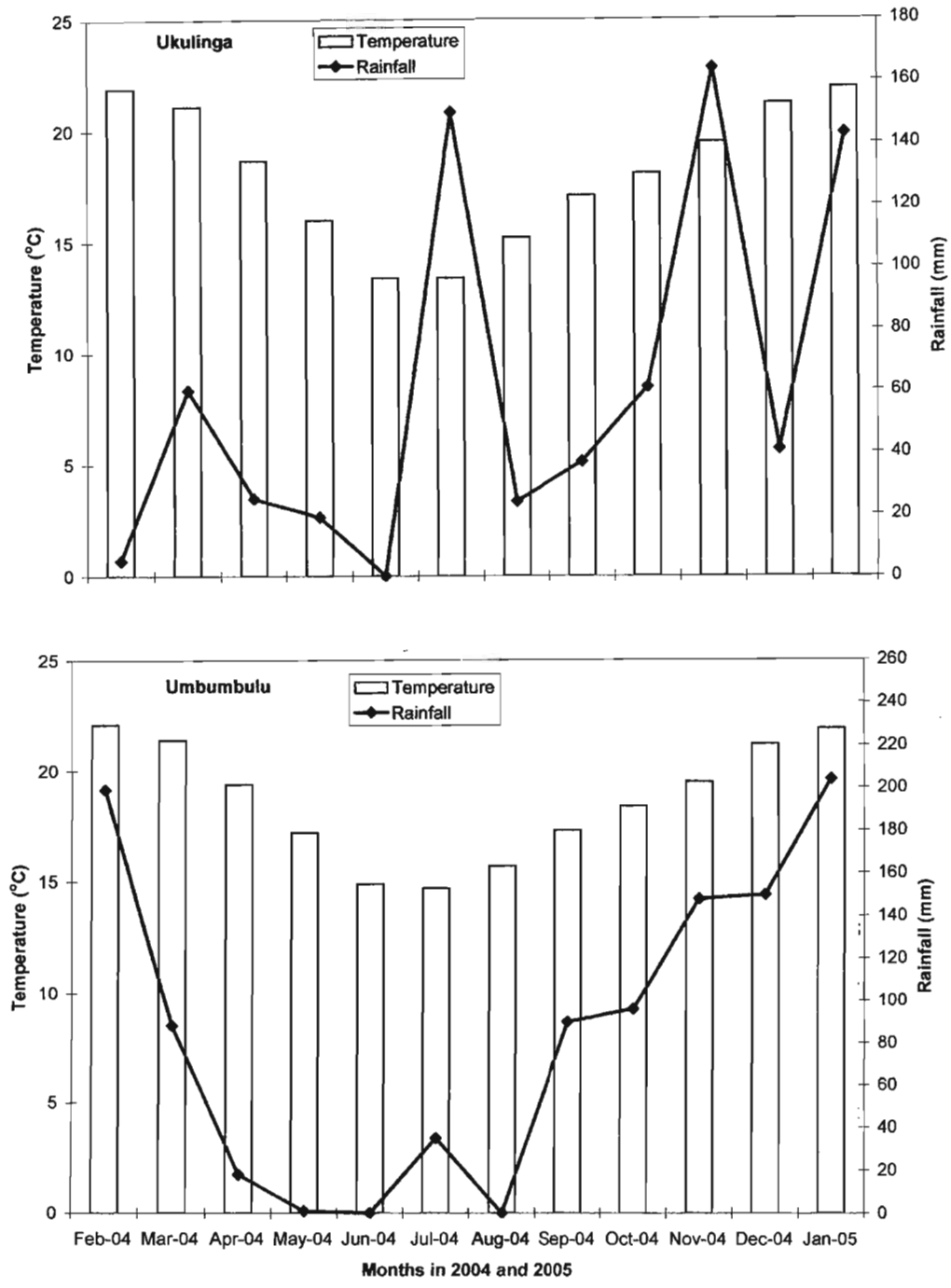


Figure 2.5. Temperature and rainfall at Ukulinga and Umbumbulu experimental sites during the 2004 and 2005 growing seasons.

2.3.2 Temperature

The summary of daily temperatures, in the form of monthly averages of minimum and maximum are presented in Figure 2.5. The autumn and winter temperatures were not significantly different at the two sites, but Umbumbulu was slightly warmer than Ukulinga during summer and spring.

The RH followed a similar trend dropping from above 60% during the months of March and April to between 50 and 60% during the months of June and July, at both sites. RH started to rise reaching 60% between December and March, with the highest RH occurring during the month of January, 2005.

2.3.3. Leaf number and plant height.

Data for leaf accumulation and plant height were collected weekly for six weeks, but only data for days 14, 28 and 42 are presented, for reasons of conciseness, and because omitting data for the other weeks did not change the significance of the results. Leaf number was not significantly affected by fertiliser application (Figure 2.6), but there was a significant ($P < 0.01$) effect of fertilizer on plant height (Figure 2.7). There was a significant interaction ($P<0.01$) between sites and cropping systems with respect to plant height, which was caused by the performance of the species not being consistently better at both sites. For example, although Ukulinga generally produced plants with more leaves than Umbumbulu, in autumn, green beans intercropped with species M produced significantly more leaves at Umbumbulu than at Ukulinga (Figure 2.6). For the first 28 days, leaf accumulation was not different at the two sites (Figure 2.6). However, in

autumn and winter there was a significant leaf accumulation at Ukulinga compared to Umbumbulu on day 42 after sowing (Figure 2.6). With respect to seasons, leaf accumulation showed the general pattern: summer > autumn > spring > winter, throughout all the stages of plant development (Figure 2.6). Leaf number from day 14 to 28, after sowing and in autumn, winter and spring, there was no difference between sole cropping and intercropping for all species at both sites (Figure 2.6). In summer, green beans produced a significantly larger number of leaves in an intercropping with wild mustard compared with sole cropping, and species I produced significantly more leaves under sole cropping compared with the other wild mustard species (Figure 2.6; day 42 Ukulinga). Considering leaf number on day 42 after sowing, at Ukulinga, green bean leaf accumulation was significantly suppressed by intercropping in autumn compared with the other seasons. In autumn, whereas species K was suppressed ($P < 0.05$) by intercropping, species I and M produced more ($P < 0.001$) leaves in intercropping compared with sole cropping (Figure 2.6). In winter, on day 42 after sowing, species M and K produced significantly more leaves than species I and green beans under both sole cropping and intercropping, whereas species I performed better ($P < 0.001$) under intercropping (Figure 2.6). In spring, there was no effect of intercropping on any of the species, across the sites.

Changes in plant height were the same across the seasons; hence, only data for the autumn season are presented (Figure 2.7). There were significant differences between sites ($P < 0.001$) and fertiliser treatments ($P < 0.001$) (Figure 2.7). At both sites, and across all the seasons, green beans grew significantly ($P < 0.001$) taller when produced

under sole cropping compared with production under intercropping (Figure 2.7). On the contrary, all three wild mustard species grew taller under intercropping compared to growth under sole cropping (Figure 2.7). The interaction between fertilizer and cropping system was explained by the reduced difference between sole cropping and intercropping in green beans when there was no fertiliser applied ((Figure 2.7). The interaction between sites and cropping systems was evident when green bean plant height was compared at Ukulinga and Umbumbulu. At Umbumbulu, there was no difference between sole cropping and intercropping for green beans (e.g., sole GB vs GB/M) early during plant development (14 days after sowing), whereas the same treatments were significantly different at the same stage of plant development at Ukulinga (Figure 2.7).

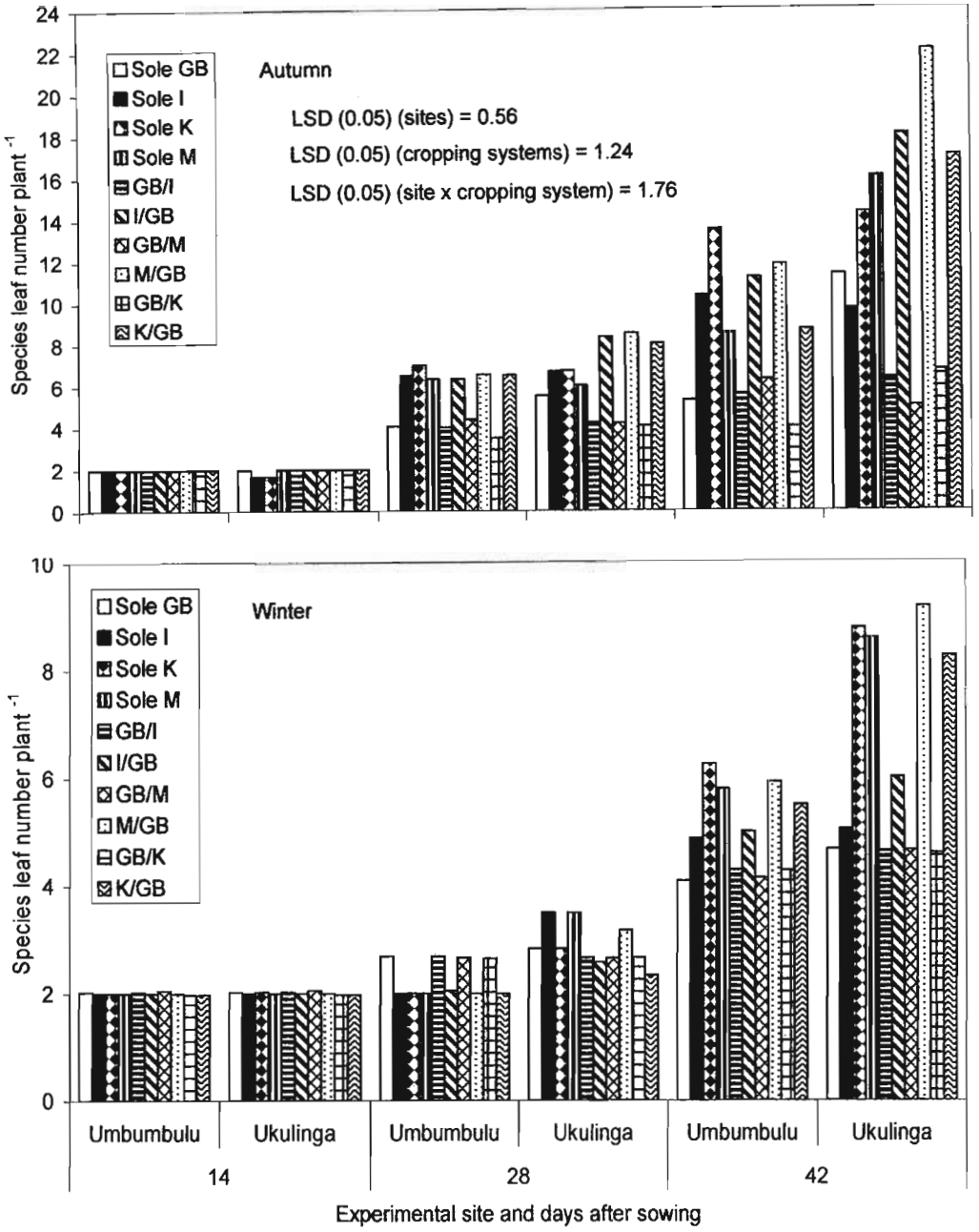
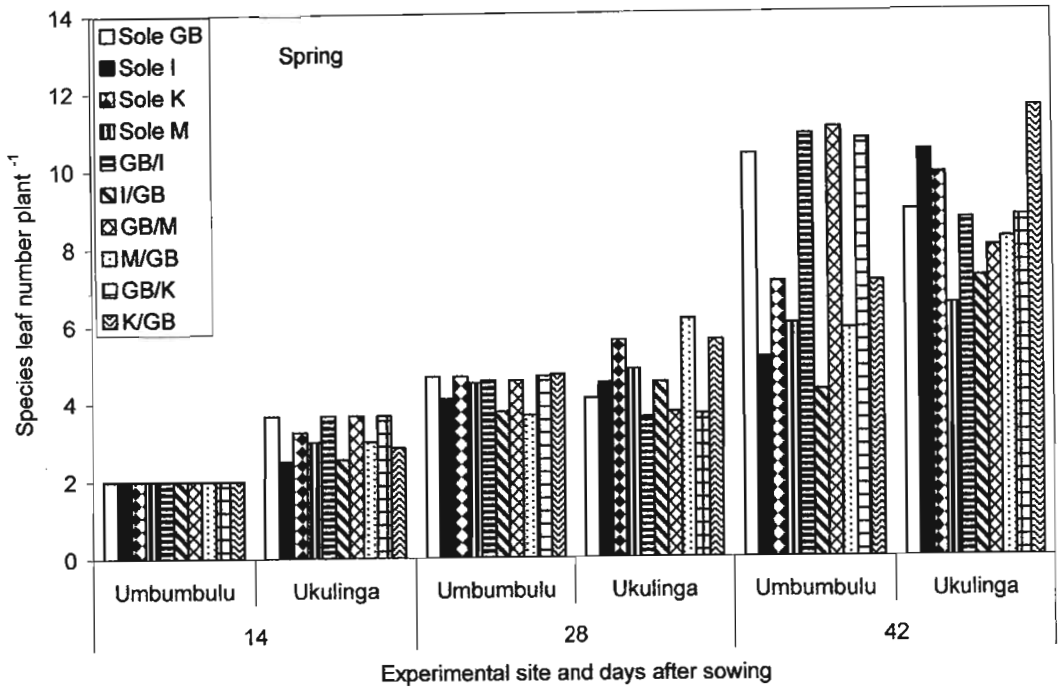


Figure 2.6. Comparison of wild mustard species and green beans for leaf number during sole cropping and intercropping at two sites (Umbumbulu and Ukulinga). Note the cropping system treatments: sole = sole cropping, GB = green beans, I, K and M = wild mustard species, GB/I or M or K = green beans when intercropped with wild mustard, I/ or M/ or K/GB = wild mustard species when intercropped with green beans. The crops were grown in autumn, winter, spring and summer (inset). Figure 2.6 continues on the next page.



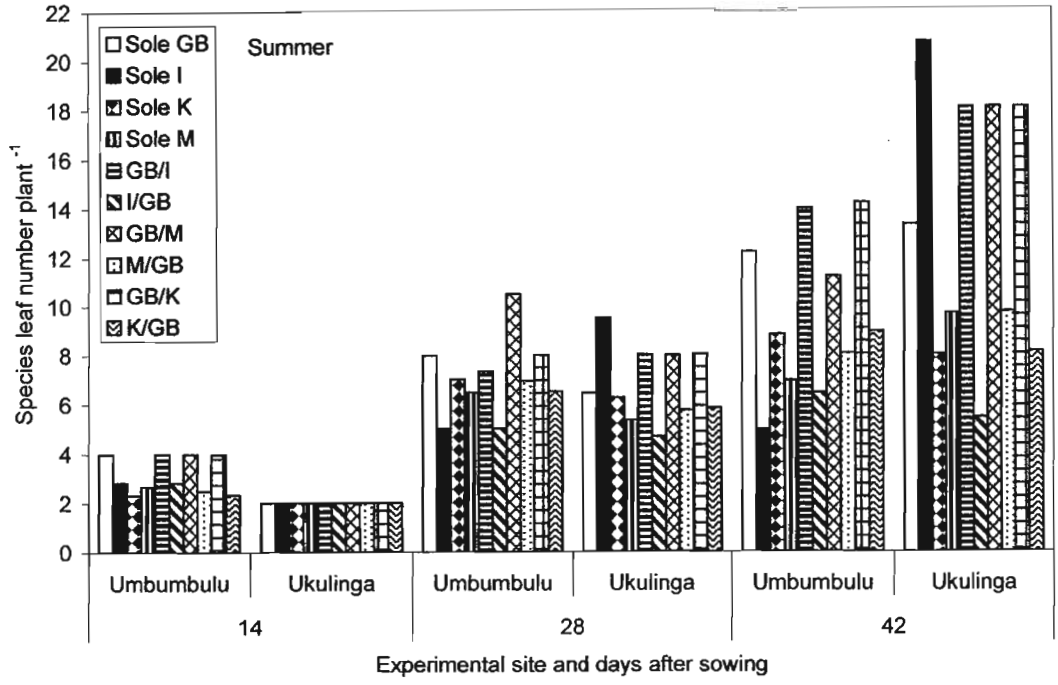


Figure 2.6. (continued). Comparison of wild mustard species and green beans for leaf number during sole cropping and intercropping at two sites (Umbumbulu and Ukulinga). Note the cropping system treatments: sole = sole cropping, GB = green beans, I, K and M = wild mustard species, GB/I or M or K = green beans when intercropped with wild mustard, I/ or M/ or K/GB = wild mustard species when intercropped with green beans. The crops were grown in autumn, winter, spring and summer (inset).

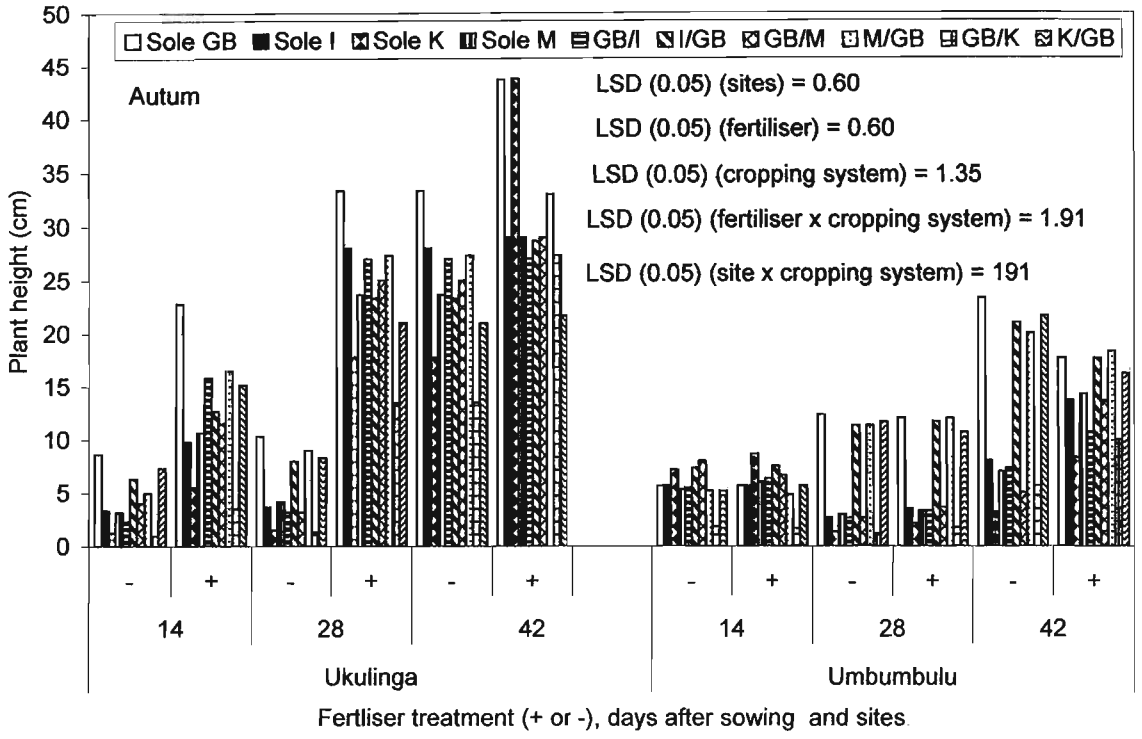


Figure 2.7. Comparison of wild mustard species and green beans for plant height during sole cropping and intercropping at two sites (Umbumbulu and Ukulinga) with (+) or without (-) organic fertiliser. Note the cropping system treatments: sole = sole cropping, GB = green beans, I, K and M = wild mustard species, GB/I or M or K = green beans when intercropped with wild mustard, I/ or M/ or K/GB = wild mustard species when intercropped with green beans. The crops were grown in autumn, winter, spring and summer, but only data for autumn are shown (inset).

2.3.4. Biomass accumulation.

Fertilizer application significantly ($P < 0.01$) increased biomass accumulation at both sites across the seasons (Figure 2.8). For both green beans and wild mustard, there was significantly higher biomass accumulation at Ukulinga compared with Umbumbulu (Figure 2.9 and 2.10). At Umbumbulu, biomass accumulation was significantly ($P < 0.05$) better in spring compared to the other seasons, for both the green beans and wild mustard (Figures 2.9 and 2.10). Wild mustard biomass production at Ukulinga showed the general pattern: autumn = winter > summer > spring (figure 2.9). At Umbumbulu the pattern of wild mustard biomass accumulation

was different: spring > summer > autumn > winter (Figure 2.9). Examination of individual wild mustard species showed that at Ukulinga biomass accumulation for species I generally declined from autumn to summer; for species M there was a biphasic pattern showing an increase in biomass from autumn to winter and a decline from spring to summer; and for species K, biomass accumulation was generally stable across the seasons (Figure 2.9). Intercropping only decreased ($P < 0.05$) the biomass of species I and M in summer, and it had no effect in autumn, spring and winter. For species K, intercropping significantly reduced biomass accumulation in autumn only (Figure 2.9). The comparison between sites for green bean biomass production showed that Ukulinga produced at least double the amount of green bean biomass compared with Umbumbulu, across the seasons and cropping systems (Figures 2.10). Winter production for green beans showed a significantly ($P < 0.01$) poor biomass production at both Ukulinga and Umbumbulu (Figure 2.10). For the remaining seasons, it was found that biomass accumulation at Ukulinga showed no significant difference between autumn, spring and summer, whereas at Umbumbulu spring > summer > autumn (Figure 2.10).

Although green bean biomass was generally reduced by intercropping, the response varied with wild mustard species and in some cases intercropping improved green bean biomass accumulation (Figure 2.10).

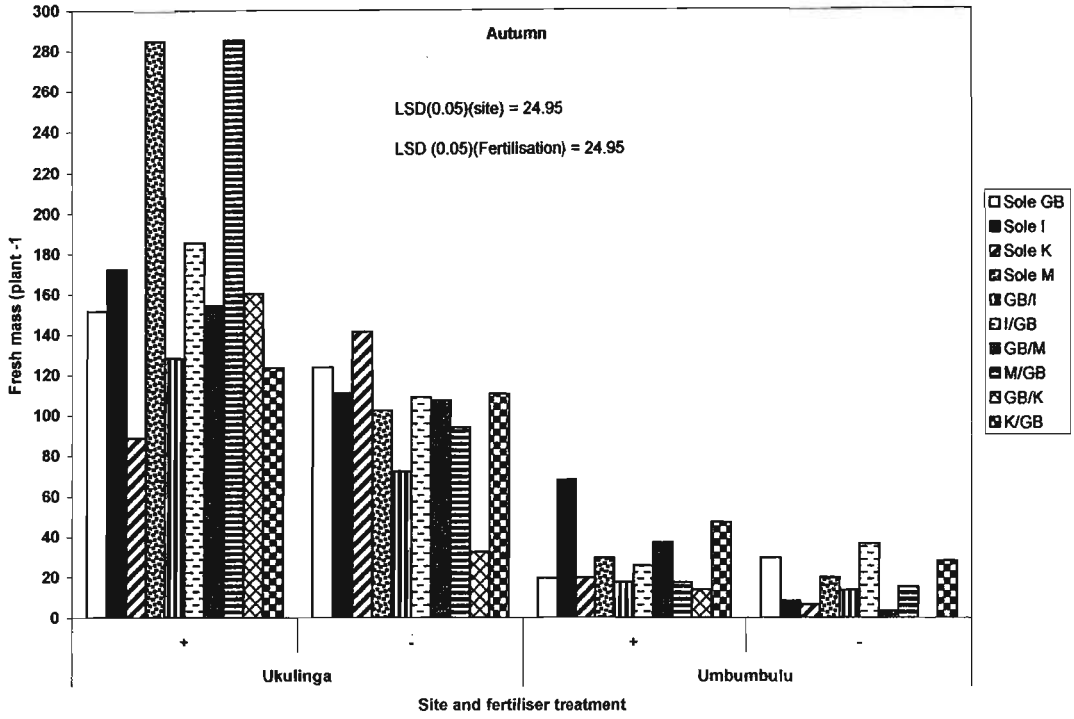


Figure 2.8. Comparison of wild mustard species and green beans for biomass during sole cropping and intercropping at two sites (Umbumbulu and Ukulinga) with (+) or without (-) organic fertiliser. Note the cropping system treatments: sole = sole cropping, GB = green beans, I, K and M = wild mustard species, GB/I or M or K = green beans when intercropped with wild mustard, I/ or M/ or K/GB = wild mustard species when intercropped with green beans. The crops were grown in autumn, winter, spring and summer, but only data for autumn are shown (insert).

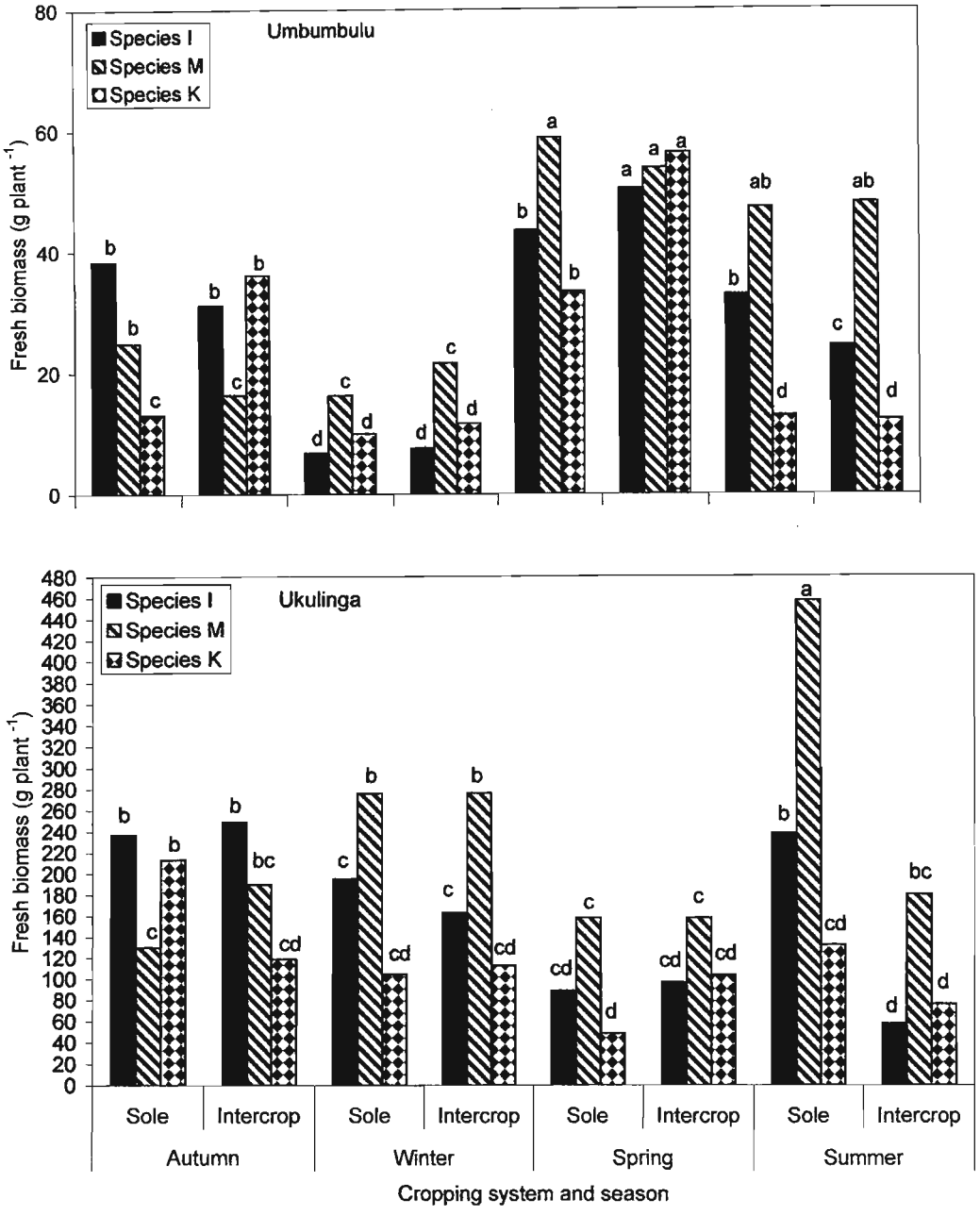


Figure 2.9. Comparison of wild mustard species for fresh biomass six weeks after sowing during sole cropping and intercropping with green beans at two sites (Umbumbulu and Ukulinga). Note the cropping system treatments compared were: sole cropping = monoculture of I or K or M and intercropping = I or M or K when intercropped with green beans. The crops were grown in autumn, winter, spring and summer.

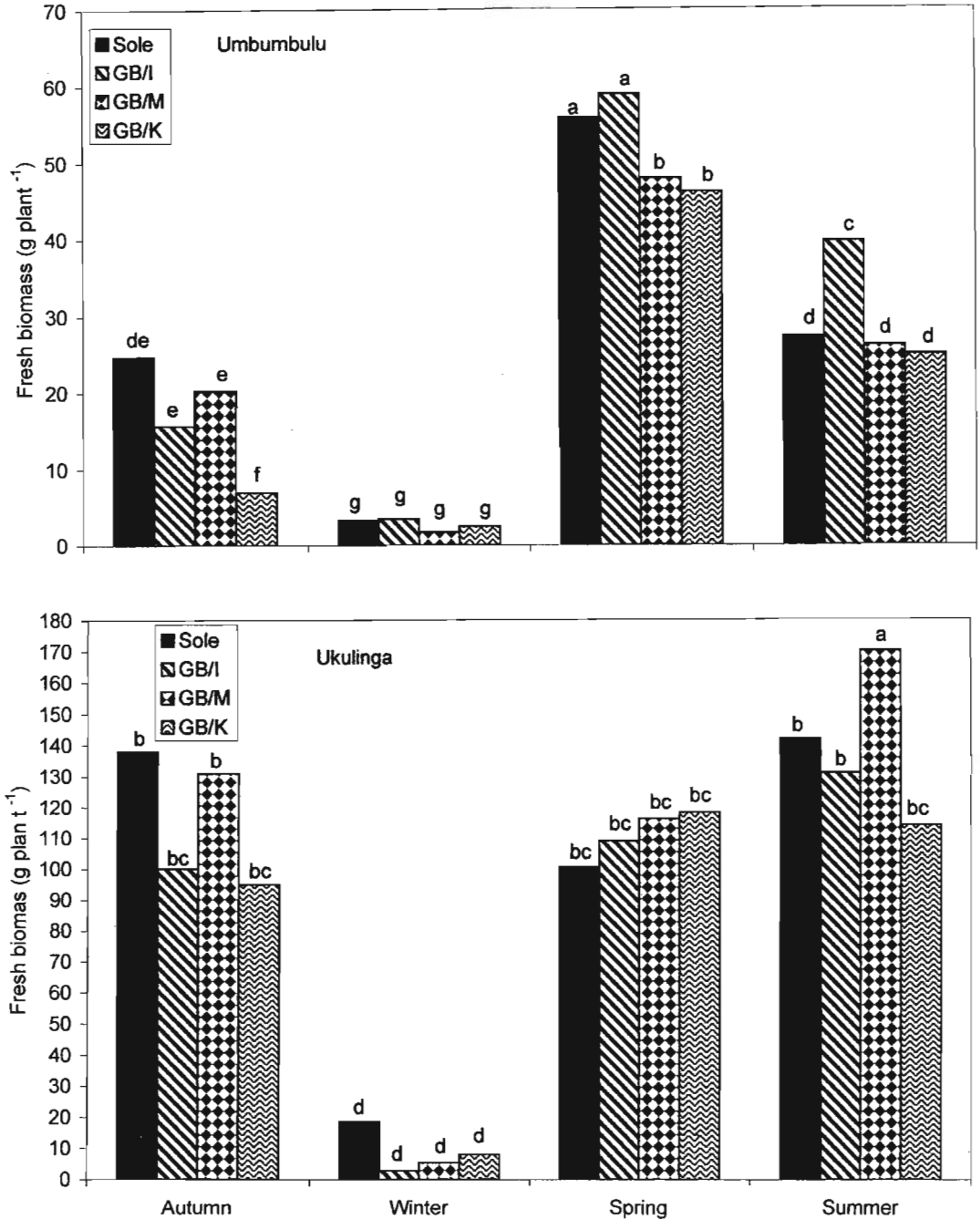


Figure 2.10. Comparison of green beans for fresh biomass six weeks after sowing during sole cropping and intercropping with green beans at two sites (Umbumbulu and Ukulinga). Note the cropping system treatments compared were: sole cropping = monoculture of green beans and intercropping, GB/I or /M or /K, when green beans were intercropped with wild mustard species I or M or K. The crops were grown in autumn, winter, spring and summer.

2.3.5 Total land equivalent ratios.

As shown previously (Siame *et al*, 1998), fertilizer application reduced the total LER for all species, but the LER trend was the same for all cropping systems across sites and seasons. Hence, combined LER values (on fresh mass basis) across fertilizer treatments are presented in Figure 2.11. LER values were generally > 1 for all seasons at Umbumbulu, except for the polyculture of species I and green beans (Figure 2.11). At Ukulinga, winter production had a negative effect on LER values for all polycultures, and in summer the polycultures of green beans and species I and K were < 1 (Figure 2.11). Autumn production showed a significantly greater advantage of green bean – wild mustard species association, with species M and K having greater positive effects than species I. A comparison between sites for autumn production showed that Ukulinga had a more favourable polyculture environment than Umbumbulu (Figure 2.11).

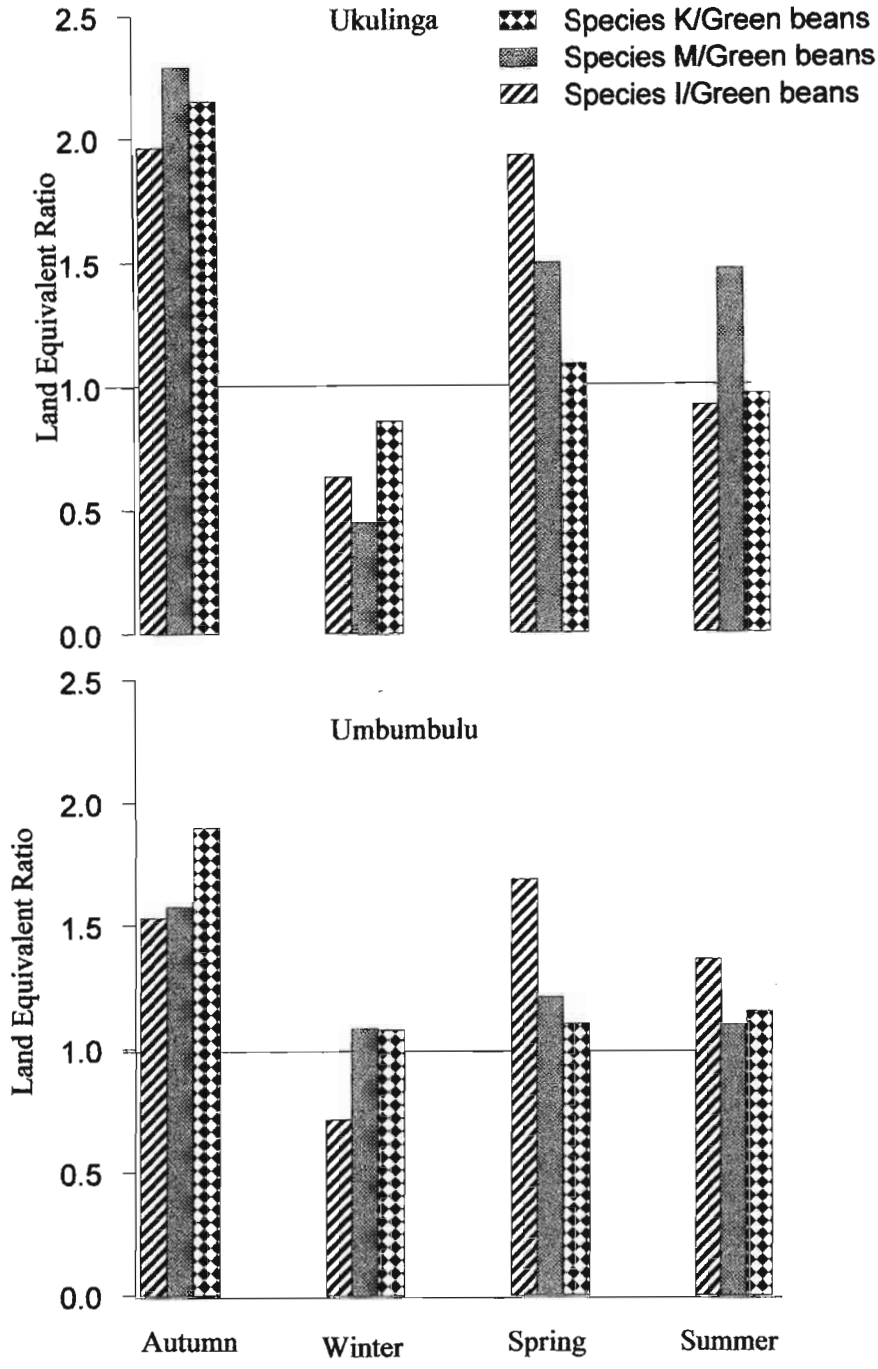


Figure 2.11. Comparison of wild mustard – green bean polycultures (species K or M or I intercropped with green beans) for land equivalent ratios during production in autumn, winter, spring and summer at two sites (Ukulinga and Umbumbulu).

2.3.6 Economic yield

2.3.6.1. Biomass and pod yields: The economic yield for mustard comprised the leaves (fresh biomass) and for the beans, the fresh pods were taken as economic yield. There were no significant differences ($P<0.05$) for wild mustard edible leaves at six weeks after sowing between intercropping and sole crops during autumn, winter and spring measured on the per plant basis (Figure 2.12). The trend was similar for all seasons with sole crop of species M accumulating significantly ($P<0.05$) high economic yield during all the four seasons among the wild mustards, while sole green beans yield was stable over the seasons (Figure 2.12). There was general significant ($P<0.05$) yield reduction in intercrops of both green beans and wild mustard compared to their corresponding sole crops, (Figure 2.12).

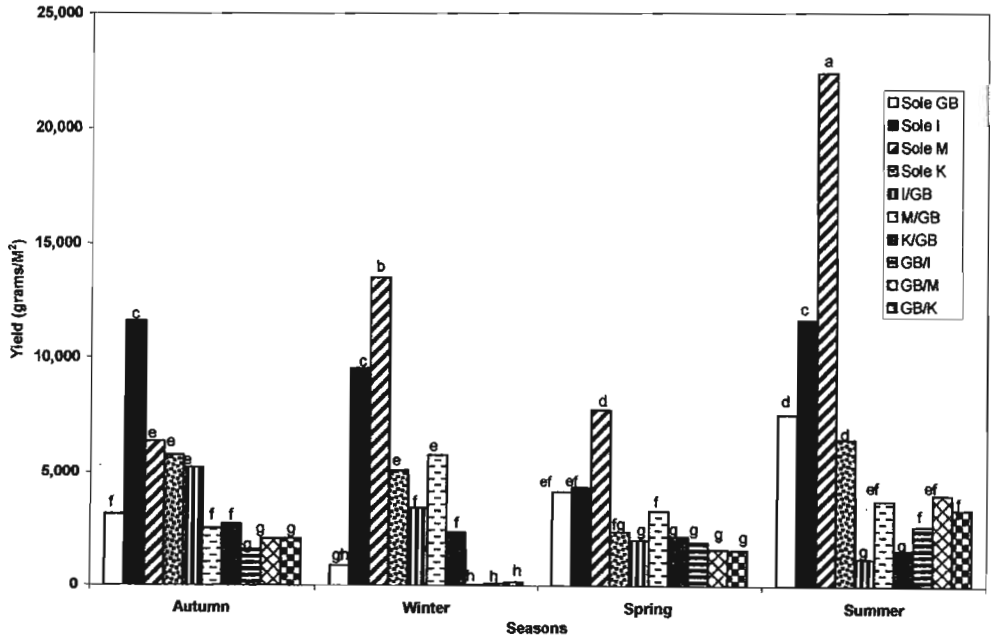


Figure 2.12. Comparison of wild mustard and green beans for economic yield six weeks after sowing in sole cropping and intercropping system. The data are the means for Ukulinga data only. The green beans yield were taken as the means of the green bean pod mass while for wild mustard, the fresh biomass at six weeks after sowing was taken as economic yield. Note the cropping system treatments compared were: sole cropping = monoculture of green beans and intercropping, GB/I or /M or /K, when green beans were intercropped with wild mustard species I or M or K. The crops were grown in autumn, winter, spring and summer. Means represented by bars with similar letter indicates there is no significant difference at $P<0.05$

2.3.6.2. Gross monetary analysis: The economic gross benefits (Figure 2.13) followed the trend of economic yield results presented in Figure 2.12. The gross incomes ranged from R10 per square metre during winter for sole crop of wild mustard to R120 per square metre for sole crop of green beans during summer (figure 2.13). Gross incomes of intercrops were on average 50% higher than sole crops of wild mustard during autumn and spring and 35% during summer. In winter the gross margins for intercrops were much lower than the other seasons in comparisons to their corresponding sole crops of wild mustard, (Figure 2.13). The gross incomes of each of the species over the four seasons indicate that intercropping gave higher gross economic benefits than sole cropping for each of the three wild mustard species during autumn, spring and summer. Intercrops of the three wild mustard species, however, showed no gross economic benefits over sole mustard crop stands during winter but showed higher gross economic benefits compared to sole green beans as shown in Figure 2.13. Sole green beans had higher gross economic returns than both sole and intercrops of all the three wild mustard species during autumn, spring and summer.

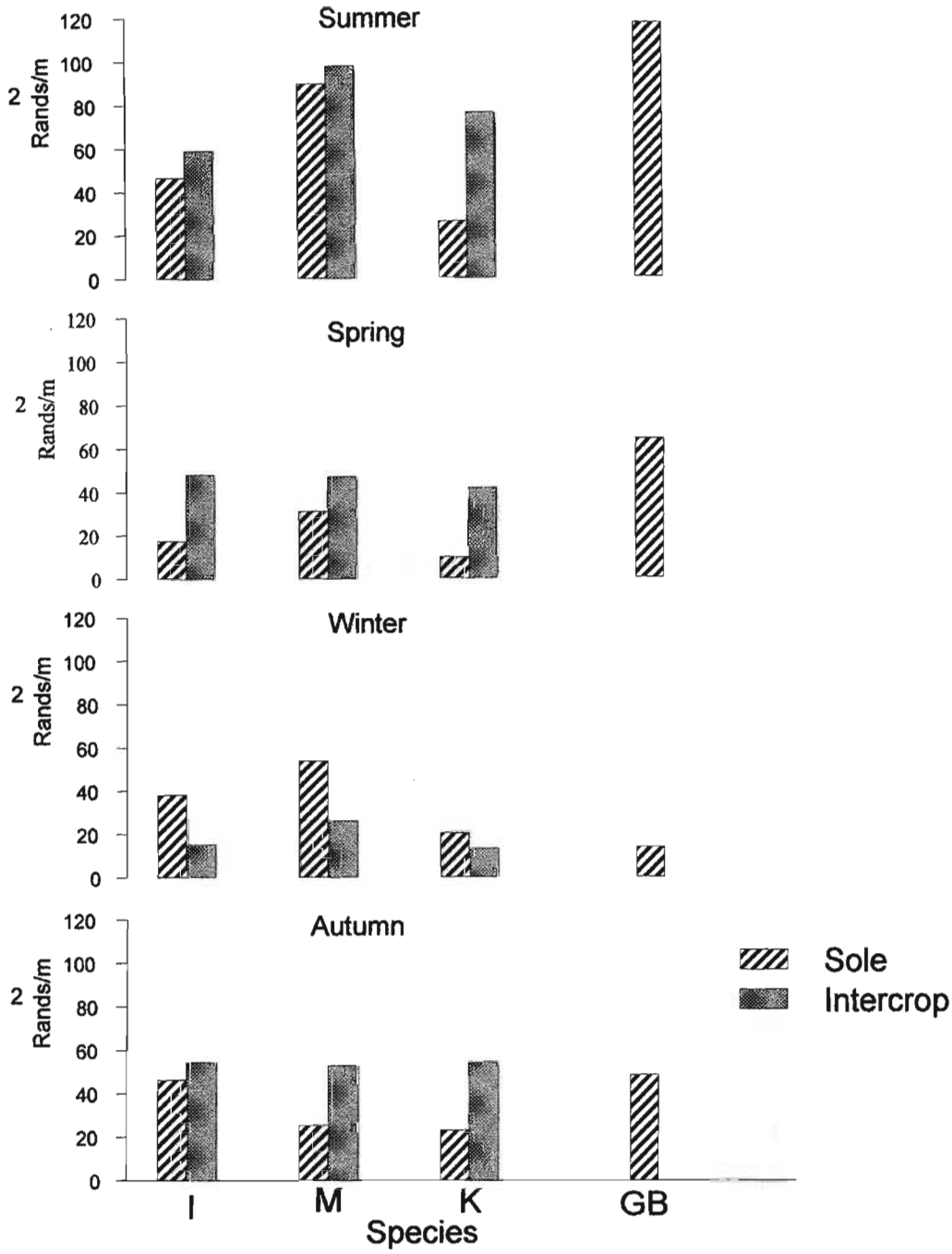


Figure 2.13: Comparison of gross incomes of intercropping to sole cropping; Gross income calculated on a) wild mustard price of R5.58 per kg and b) green beans at R17/kg

2.4. Discussion

The performance of wild mustard and green beans, with respect to leaf accumulation, plant height and biomass was dependent on the temperature and rainfall patterns at Ukulinga and Umbumbulu during the study period (Figure 2.5 compared with Figures 2.6 to 2.10). It is evident from this study that wild mustard can grow all year round at both sites, but the cooler environmental conditions at Ukulinga may be more favourable for plant growth and biomass accumulation compared with Umbumbulu conditions. Spring and autumn were associated with good crop performance, noting that at Ukulinga there was a significantly lower rainfall in spring than at Umbumbulu. At both sites, the cold winter temperatures reduced green bean growth, but wild mustard accumulated four to twenty five times more biomass than green beans (Figures 2.9 and 2.10). This ability of wild mustard to accumulate biomass in winter suggests that the species has a potential for cultivation off the normal crop production season (summer) under rain fed conditions in South Africa. Since the scarcity of vegetables generally occurs in winter and autumn, wild mustard has a potential role in food security for resource-poor farmers.

The generally positive LER values found in this study showed that wild mustard and green beans can be grown in a polyculture with benefits to the farmer. It is important, however, to note that biomass accumulation was determined, directly and indirectly (by leaf number and plant height) at the time prior to harvest maturity for all the species. Therefore, the comparisons between wild mustard and green beans reported in this study were for the purposes of wild mustard production for leafy vegetable consumption. At the stage of biomass determination, green beans had formed pods

that were used to compare the effect of polyculture on green bean economic yield. It was found that polyculture was generally associated with a better green bean pod yield in all seasons, except for winter (data not shown). Those findings indicated that polyculture may have a favourable effect of green bean harvest index, which concurs with the observation that green beans grew taller in sole cropping than in polyculture (Figure 2.7). Therefore, intercropping green beans and wild mustard has a significant benefit to the small-holder farmer who has limited production land.

It is difficult to conclude from this study that the association between green bean, a legume with a potential for nitrogen fixation, and wild mustard could have nutritionally benefited the latter. The findings of a generally better green bean pod yield (Figure 2.12) under polyculture showed that dry matter accumulation in green beans was not suppressed by wild mustard in a polyculture. An investigation into the soil nutrient aspect of the green bean –wild mustard intercropping system reported has been reported in chapter three of this thesis.

The economic returns of vegetable crops are highly variable depending on season. Intercrops of wild mustard yielded higher gross returns (Figure 2.13) than their sole crops of each of the wild mustard species. However, sole green beans crops yielded more gross economic returns than both intercrops and sole crops of wild mustard due to higher economic value (cash value per kg) compared to a kg of wild mustard. During winter, green beans performed poorly and affected the overall gross incomes of the intercropping system. Despite the fact that sole crops of green beans yielded more gross incomes than intercrops, intercropping wild mustard proves a viable option over sole mustard crops. Since the problems of the rural communities range

from malnutrition to lack of money, intercropping at least achieves dietary diversification while maintaining productivity above both sole crops of green beans and sole crops of wild mustard. It would be expected that the sale value of organically produced mustard and green beans would be higher than the sale value presented in Figure 2.13 since conventional vegetable price list was used.

Overall the intercrop seems to offer a greater economic advantage than growing a sole crop of wild mustard, but only in looking at output values. However economic feasibility can only be determined by examining both inputs and outputs. Taking it from theories of the effectiveness of intercrops to reduce weed infestations and pests (Armstrong and McKinlay, 1997), which in turn decreases the need for labour and herbicide inputs, it could be assumed that intercrops could even be more profitable than sole crop of beans.

In conclusion, this study showed that wild mustard has a potential for cultivation as a leafy vegetable. It is recommended that the crop be produced in autumn and spring.

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CHAPTER 3. SOIL NUTRIENT DYNAMICS IN WILD MUSTARD-GREEN BEAN POLYCULTURE

3.1. Introduction

Improvement of agricultural production in sub-Saharan Africa is made difficult by many factors. Among these factors is the challenge of maintaining soil fertility under the intensive annual cropping systems of low-income, smallholder farmers (Machuka, 2003). Successful farming depends on fertile soils, and to maintain fertility in commercial agriculture, nutrients are imported into the agricultural fields through application of fertilisers. However, traditional agriculture is not synonymous to low input agriculture and (or) organic farming, soil fertility is largely maintained by a closed system that relies on in situ sources, such as decomposed organic matter and minerals fixed by live plants (Lockeretz *et al.*, 1981). Therefore, one of the best ways to improve soil fertility is to add organic matter.

Organic fertilisation has been one of the options to amend soils and increased interest in organic crop production has been prompted by both consumer demand and the desire to sustain or improve the soil resources (Hill, 1991). The main concept behind this approach is to conserve natural resources by relying more on biological processes within the soil system to recycle and release nutrients rather than provide high amounts of soluble nutrients from manufactured fertilizers. Organic matter forms the basis of healthy and productive soils. The emphasis in organic production is on nutrient cycling within the soil organic matter fraction and enhancement of biological processes to make nutrients within this fraction available to plant roots (Magdoff and

Van Es, 2000). What is increasingly being considered is that over time, organic fertilisation promotes nutrient build up; soil tilth improves and water retention capacity (Taiz and Zeiger, 1991).

Organic fertilisation can provide many of the nutrients plants need and can further enrich the soil and correct nutrient deficiencies. Plants need nitrogen to develop healthy leaves and stems. Plants also need phosphorous to grow, flower, and develop healthy root systems, and unlike nitrogen, phosphorous lasts a long time once added to the soil (Tisdale *et al*, 1985). Potassium, like nitrogen, turns over quickly in the soil system and must be replenished (Tisdale *et al*, 1985). Calcium, Mg, S and micronutrients (Fe, Mn, Cu, Zn, B, and Mo) needs can be satisfied in most situations through manure, compost, and liming amendments. A major advantage of organic nutrient sources is that they usually contain at least a small amount of all most of the essential plant nutrients (Tate, 1987).

Besides nitrogen-fixation by legumes and green manuring, evidence of soil mineral content enhancement by plants is limited. There are few reports mostly in tree species found in literature on direct determinations of intercropping effects on mineral nutrients in root zone. This study was designed to evaluate the nutrient dynamics in the soil within the root zones of wild mustard and green beans during four seasons of the year in response to organic fertilisation. For selected mineral elements, relative nutrient contents in the soil at flowering (vegetable crop maturity stage) were compared with the nutrient content determined at planting.

3.2 Materials and Methods

Details of the environmental conditions under which this study was conducted are reported in sections 2.2.1 to 2.3.1.2 above. A summary with some minor modifications reprinted here. Soil samples were taken prior to planting of wild mustard and green beans during four seasons (Table 2.3) to determine basal soil mineral nutrient status before application of fertiliser treatments. Fertiliser treatments were constituted by organic fertiliser (1.75 kg m^{-2} Neutrog® containing: N = 30 g kg^{-1}, P = 11 g kg^{-1}, P_2O_5 = 25 g kg^{-1}, K = 10 g kg^{-1}, K_2O = 12 g kg^{-1}, Ca = 25 g kg^{-1}, S = 6 g kg^{-1}, Mg = 8 g kg^{-1}, Zn = 443 mg kg^{-1}, organic matter = 650 g kg^{-1}, moisture = 120 g $kg^{-1}$and the product density = 655 kg m^{-2}) and a control (no fertiliser application). Fertilization was done each season for the fertilized crop and the physical location of the experiment changed each year to avoid having the residual effects from the previous wild mustard crops. From each cropping treatment (see section 2.2 for the list of treatments), soil samples were collected from the top 10-15 cm of the soil in the root zone, at flowering stage (42 days after sowing) of the wild mustard. Three samples were randomly taken per plot with an auger and mixed to obtain a composite plot sample. The soil samples were analysed for pH in KCl, organic carbon, available P, K, Ca, sample density, Mg, exchangeable acidity, total cations, acid saturation, Zn, Mn, Cu and organic carbon, at the Soil Science Analytical Laboratory, Cedara, Pietermaritzburg, South Africa.

Differences between basal nutrient content (pre-planting) and soil nutrient concentration in the root zone of each of component crop in an intercrop and from the

sole crops, determined 42 days after sowing, was used to determine soil nutrient balance (relative nutrient content) due to cropping treatments. Thus, the relative nutrient content was calculated as follows:

$N_r = N_f - N_i$ Equation 3.1

Where: N_r = Relative nutrient content

N_f = Nutrient concentration at flowering

N_i = Initial nutrient concentration before planting

The net values were an indication of each component crop nutrient depletion or replenishment of the root zone. The net balance gives a good approximation of the efficiency of use of the nutrients in a comparison between intercropping and sole cropping. It also gives clear an indication as to whether fertilization has an effect on the nutrient balances between intercrops and sole crops. A negative balance means that the nutrients were depleted beyond what was initially available in the soil. All the mineral elements examined in the soil prior to planting were also analysed in soil samples from the root zone of each cropping system.

Plant mineral analysis was performed as described by Modi (2001). Analysis of variance (ANOVA) was performed using Genstat ® and the differences between treatments were determined at $P \leq 0.05$ (Appendix 3.1). Standard errors of the difference were used to separate means.

3.3 Results

3.3.1 The pre-planting soil nutrient status

Table 3.1 shows soil test results at the beginning (pre-planting) of the experiment for both experimental sites, Ukulinga and Umbumbulu. The Ukulinga soil was generally richer in K, Ca, Mg, Zn, Mn and Cu than the Umbumbulu soil. The pH was also slightly higher at Ukulinga than Umbumbulu. Soil from Umbumbulu, however, had slightly higher P concentration. (Table 3.1).

Table 3.1 Soil sample test results prior to planting at Ukulinga and Umbumbulu.

	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	pH (KCl)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)	Organic C (%)	Clay (%)
Ukulinga	10	124	1660	473	5.13	5.4	9	6.3	4.0	49
Umbumbulu	12	70	1239	114	4.54	1.1	6	1.3	3.1	54

3.3.2 Comparison of intercropping and sole cropping for root zone mineral content

Analysis of variance showed that there were no significant differences between sole cropping and intercropping systems (Appendix 3.1), with respect to changes in root zone mineral element concentrations. Consequently, a comparison of species (wild mustard: I, K and M) and green beans was undertaken using the sole cropping only. Results on analysis of four macronutrients P, K, Mg and Ca and three micronutrients, Zn, Mn, and Cu, which were selected on levels of importance in human diet, are discussed in this section. Based on calculations using the equation 3.1, relative

concentrations in the root zones are presented for each of the three wild mustard species and the green beans cultivar.

3.3.2.1 Macronutrients

In agreement with Table 3.1, there were significant ($p < 0.01$) differences between sites with respect to nutrient concentrations at flowering (N_f) in all seasons (Appendix 3.1). Differences between fertiliser treatments were not consistent across seasons, with respect to nutrient balance. In autumn, spring and summer, there were no significant differences, and in winter there was a highly significant ($p < 0.001$) difference in nutrient concentrations (Appendix 3.1).

Phosphorus showed a significant difference ($p < 0.001$) between fertiliser and no fertiliser treatments, with respect to soil P content at flowering across all four seasons (Figure 3.1). Fertiliser application resulted in a greater soil P content at harvest compared with no fertiliser application (Figure 3.1). With respect to cropping treatments (sole cropping and intercropping), significant differences ($p < 0.05$) in P concentration were found in summer only (Appendix 3.1), where the species I/ green bean intercropping caused greater soil P content (35.2, SED = 4.1) compared to the other intercrops (K/green beans = 29.9; M/green beans = 23.4). However, there was a significant ($P < 0.01$) interaction between site and fertiliser treatment with respect to relative nutrient concentration for P (Appendix 3.1). Whereas there was generally a positive N_r for P, sole cropping for K species showed negative N_r values (Table 3.2).

Across all four seasons, there was a significant difference ($P < 0.001$) between fertiliser and no fertiliser treatments, with respect to soil K content at flowering (Figure 3.1).

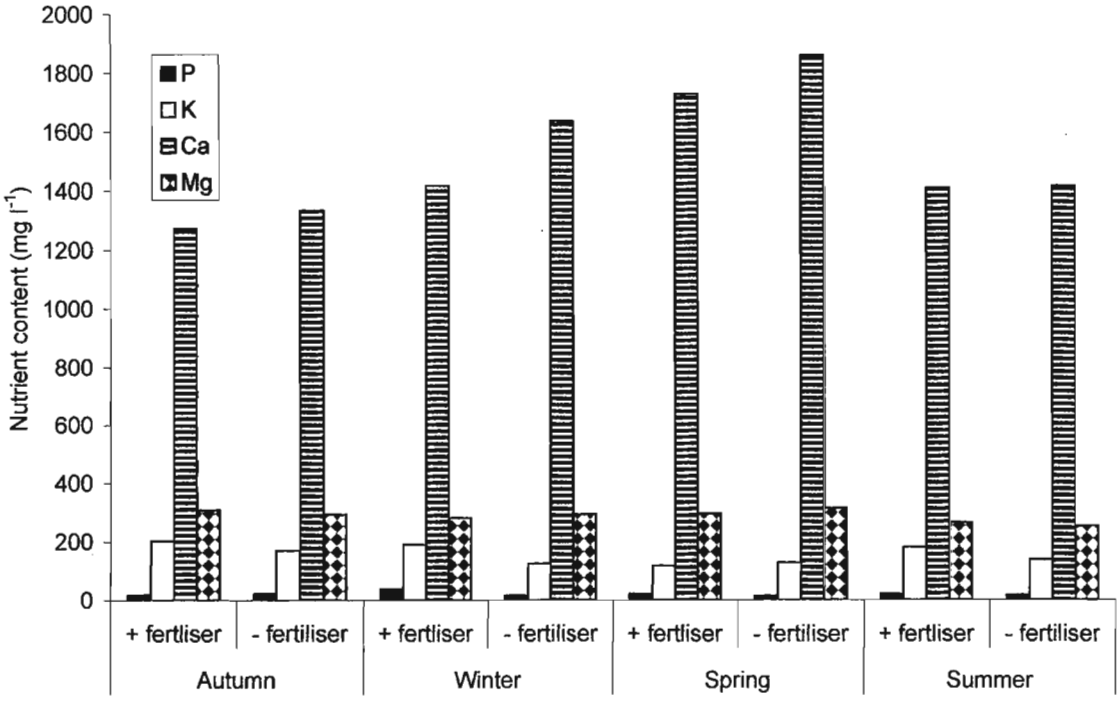

Figure 3.1 Macronutrient content of root zone soil from wild mustard and green bean crops at flowering. Values are means of three replications for all species across two sites. Data were analysed per season. SED values for comparison of treatments are were used: Sed, P(autumn)=1.15; Sed, Ca(autumn)= 37; Sed, K(autumn) = 9.66; Sed, Mg(autumn) = 4.68; Sed, P(winter)=1.82; Sed, Ca(winter)= 44.7; Sed, K(winter) = 8.35; Sed, Mg(winter) = 4.06, Sed, P(spring)=1.12; Sed, Ca(spring)= 59; Sed, K(spring) = 5.68; Sed, Mg(spring) = 7.38, Sed, P(summer)=0.91; Sed, Ca(summer)= 35.5; Sed, K(summer) = 7.92; Sed, Mg(summer) = 3.1.

As with P, fertiliser application caused a greater residual P content at harvest compared with no fertiliser application (Figure 3.1). However, there was no cropping system effect on soil K content at flowering (Appendix 3.1).

There was an interaction between site and fertiliser treatment, for K content at flowering, in spring, summer and winter, but not in autumn (Appendix 3.1).

Generally, there was a positive N_r for K, irrespective of fertiliser application, except for the sole crop of species I, which displayed negative N_r in response to fertiliser application at Umbumbulu in summer (Table 3.2) and sole green beans at Ukulinga in spring.

Magnesium displayed significant differences between fertiliser treatments ($p < 0.01$) and between sites ($p < 0.05$) across seasons (Appendix 3.1). In autumn and summer, there was an increase in Mg soil content at flowering in fertilised treatments compared with non fertilised ones, but the reverse was true for winter and spring (Figure 3.1). In summer and autumn, there was also an interaction between site and fertiliser treatment (Appendix 3.1). For both Ukulinga and Umbumbulu, the N_r values for Mg were variable (Table 3.2). Generally there was positive N_r values for Mg, but there was a significant site x fertiliser interaction for all species (Table 3.2).

There were significant differences between sites ($p < 0.001$) for Ca content at flowering across seasons, and in winter there was also a significant ($p < 0.001$) difference between fertiliser treatments (Appendix 3.1). Absence of fertiliser at planting was consistently associated with greater Ca residual content at flowering across seasons and sites (Figure 3.1). An interaction between site and fertiliser treatment was found in all seasons, except summer (Appendix 1).

Table 3.2.Relative mineral concentration (Nr) for selected nutrients during four seasons. Negative values show depletion while positive values show replenishment.

	Autumn	**Ca**		**K**		**Mg**		**P**	
		+	-	+	-	+	-	+	-
Ukulinga	Sole GB	-166	-133	220	204	30.3	-9.3	14.33	23.67
	Sole I	-110	-14	123.7	113.7	36.7	-8.3	12	21
	Sole K	-239	-30	223.3	118.7	18.7	2.7	17.35	23.67
	Sole M	-93	5	191.3	117	23.3	12.3	14.67	26.33
Umbumbulu	Sole GB	-390	-191	26.7	11.3	-30	10.3	0.33	-2.67
	Sole I	-3	-118	-2	1	27.7	25	0	1
	Sole K	88	-228	15.8	10.3	16.7	-5.7	-1.15	-1
	Sole M	-141	-401	26.7	4.7	22.3	-15.7	0	0.33
SED		**37**	**37**	**9.66**	**9.66**	**4.68**	**4.68**	**1.151**	**1.151**

	Winter	**Ca**		**K**		**Mg**		**P**	
		+	-	+	-	+	-	+	-
Ukulinga	Sole GB	186	11	157.3	-5.3	-3.7	5.3	45.67	10.67
	Sole I	263	-95	26.7	-3.7	-41	5.7	39.67	12.33
	Sole K	272	63	108	0.8	5.7	42.3	52.33	2.39
	Sole M	350	28	71.7	52.7	-5.7	6	47	11.33
Umbumbulu	Sole GB	-380	477	80	57	-25	2	11.67	-2
	Sole I	-324	42	63	39.7	-29.3	-11.7	8.33	-2
	Sole K	-335	108	82	50.7	-19.3	-15	5.33	0
	Sole M	-221	289	80.7	59.7	-8	0.3	8	-1
SED		**44.7**	**44.7**	**8.35**	**8.35**	**4.06**	**4.06**	**1.816**	**1.816**

	Spring	**Ca**		**K**		**Mg**		**P**	
		+	-	+	-	+	-	+	-
Ukulinga	Sole GB	947	371	-29.7	3.3	51.3	94	11	8.67
	Sole I	731	303	14.3	98.3	51.3	86	14.33	14.33
	Sole K	794	260	9.3	20.7	20	53	20	6.67
	Sole M	775	292	4	183.3	46	70.3	18.33	16
Umbumbulu	Sole GB	-139	2	22.7	5	-30.7	-17.3	4	-3.67
	Sole I	10	230	36.7	-3.3	-27.7	-19	6.67	-2.33
	Sole K	-158	-10	37.3	-8.3	-29	-39.8	1	-4.56
	Sole M	-174	353	94	31.3	-24.3	-1.7	6.67	-4.9
SED		**59**	**59**	**5.68**	**5.68**	**7.38**	**7.38**	**1.118**	**1.118**

	Summer	**Ca**		**K**		**Mg**		**P**	
		+	-	+	-	+	-	+	-
Ukulinga	Sole GB	-39	-191	140.7	36	-66	-109.7	17.33	15.33
	Sole I	-101	-91	132	62.3	-56.3	-85.7	13.33	15.33
	Sole K	-27	-35	173.7	103	-57	-101	23.67	21.67
	Sole M	-6	-273	141.3	124.7	-47	-91.7	15.33	10
Umbumbulu	Sole GB	-174	-11	34.8	28	1.6	19.3	4.88	-4.33
	Sole I	-28	-6	-8	56.3	-8.3	10.3	0	-5
	Sole K	36	25	43.7	33.7	-6.3	20.3	3.67	-2.33
	Sole M	23	-62	60.7	28.3	22	13.7	4.67	-3.67
SED		**35.8**	**35.8**	**7.92**	**7.92**	**3.1**	**3.1**	**0.911**	**0.911**

3.3.2.2 Micronutrients

Concentrations of selected micronutrients (Table 3.3), Mn, Zn and Cu were determined from the rhizosphere soil. Significant ($p < 0.001$) differences were observed between sites for nutrient concentrations at flowering (N_f) over the four seasons (Appendix 3.1). There were no significant differences in the nutrient concentration in the root zones for the selected micro elements with regard to cropping system.

There was a significant ($p < 0.001$) difference between fertiliser treatments for Mn content only during autumn, and no significant differences were found in spring, winter and summer (Appendix 3.1). Mn generally had positive nutrient (N_r) balance around the root zone during autumn, winter, and spring and relatively negative (N_r) balances during summer (Table 3.3). There was also a significant ($p < 0.001$) site X fertiliser interaction for Mn during winter, spring and summer (Appendix 3.1).

Zinc, like Mn and most macro elements, showed a significant ($p < 0.001$) interaction of fertilization and sites (Appendix 3.1). Fertilisation treatments caused an increase in Zn content at flowering during winter and spring ,whereas during autumn, fertilisation treatments caused a reduction in residual Zn content (Figure 3.2). There was no significant ($p<0.05$) effect of fertilisation on the Zn content at flowering during summer. There was a generally positive Zn nutrient balance (N_r) concentration at Umbumbulu during all the four seasons, but Ukulinga showed variable patterns (Table 3.3).

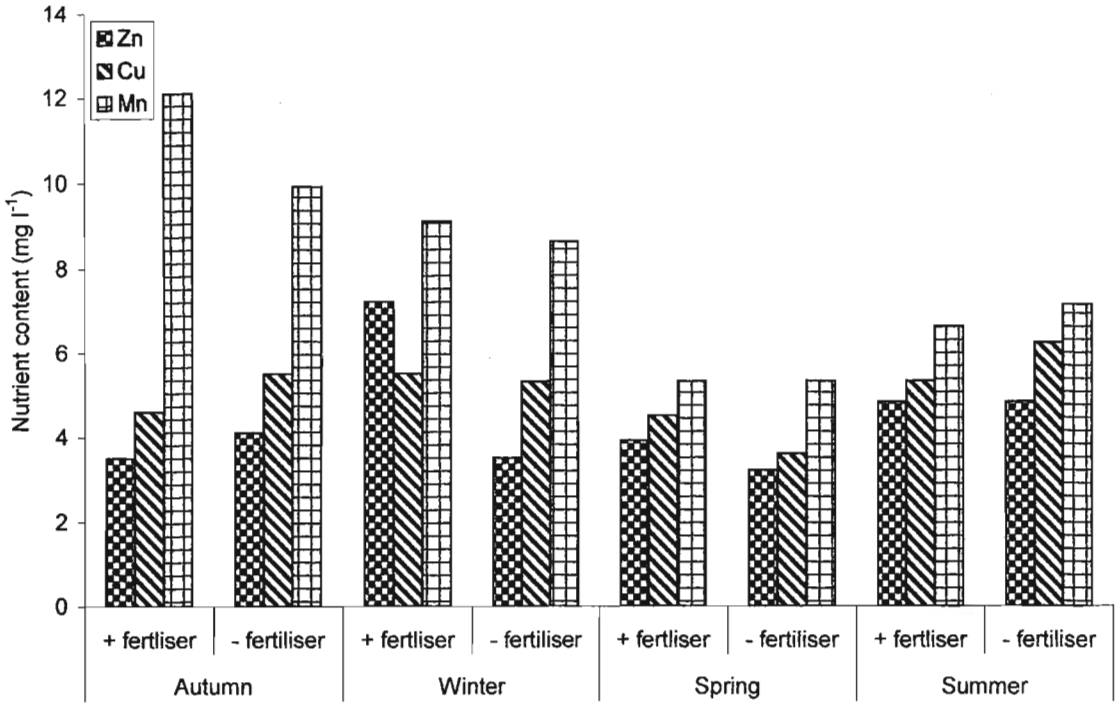

Figure 3.2 Micronutrient content of root zone soil from wild mustard and green bean crops at flowering. Values are means of three replications for all species across two sites. Data were analysed per season. SED values for comparison of treatments are shown in table 3.3.

Copper showed significantly ($P < 0.001$) higher concentrations in the root zone at Ukulinga than Umbumbulu. Fertilisation treatments caused a significant ($P < 0.001$) increase in Cu concentration around the root zone during autumn and summer while a decline with fertilisation treatments was observed during spring (Figure 3.2). There was no significant difference in Cu content in the root zone at flowering between fertilised and unfertilised treatments. There was an interaction effect between site and fertiliser for all the seasons except winter (Appendix 3.1). Contrary to Zn results, Cu showed positive nutrient balance (N_r) at Ukulinga while a variable pattern was observed at Umbumbulu (Table 3.3).

Table 3.3.Relative mineral concentration (Nr) for selected nutrients during four seasons. Negative values shows depletion while positive values show replenishment.

Autumn		Zn		Mn		Cu	
Site	**Species**	**+**	**-**	**+**	**-**	**+**	**-**
Umbumbulu	Green beans	0.3	0.233	1.20	2.63	4.67	4.67
	Species I	0.567	0.6	1.47	3.43	6.00	4.00
	Species K	0.368	1.6	1.63	3.30	8.41	6.33
	Species M	0.767	0.467	1.67	3.10	5.33	9.33
Ukulinga	Green beans	-0.2	1.533	0.10	-0.10	2.67	0.33
	Species I	0.033	0.867	0.03	0.00	0.33	-0.67
	Species K	-0.132	0.967	-0.07	-0.03	0.41	1.33
	Species M	-0.1	1.333	0.07	0.03	2.33	2.67
SED		**0.12**	**0.12**	**0.51**	**0.51**	**0.12**	**0.12**

Winter		Zn		Mn		Cu	
Site	**Species**	**+**	**-**	**+**	**-**	**+**	**-**
Umbumbulu	Green beans	3.07	0.07	0.00	-3.00	-0.07	-0.23
	Species I	7.67	1.8	-0.67	-2.00	0.07	-0.17
	Species K	5	0.37	0.00	-1.67	-0.10	-0.23
	Species M	4.87	0.2	0.00	-2.00	0.00	-0.23
Ukulinga	Green beans	3.57	-0.67	5.67	4.33	4.57	3.90
	Species I	2.13	-0.57	-1.00	7.67	2.87	2.53
	Species K	3.13	-0.85	4.00	6.79	3.43	2.35
	Species M	2.97	-0.9	3.33	4.67	3.37	2.87
SED		**0.52**	**0.52**	**0.48**	**0.48**	**0.17**	**0.17**

Spring		Zn		Mn		Cu	
Site	**Species**	**+**	**-**	**+**	**-**	**+**	**-**
Umbumbulu	Green beans	2.4	0.47	-0.33	-3.00	-0.03	-0.33
	Species I	3.2	0.77	-0.67	-3.33	0.00	-0.27
	Species K	1.3	0.11	-1.00	-3.17	-0.17	-0.42
	Species M	2.4	0.41	-1.00	-3.45	-0.10	-0.37
Ukulinga	Green beans	-1.6	-1.87	-3.67	1.00	1.47	-0.20
	Species I	-0.9	0.17	-2.67	-1.00	1.83	-0.17
	Species K	-0.6	-1.63	-4.00	-2.33	1.63	-0.10
	Species M	-0.4	1.23	-4.00	-1.33	1.33	-0.17
SED		**0.24**	**0.24**	**0.28**	**0.28**	**0.12**	**0.12**

Summer		Zn		Mn		Cu	
Site	**Species**	**+**	**-**	**+**	**-**	**+**	**-**
Umbumbulu	Green beans	1.338	0.8	-0.10	-3.00	0.17	-0.03
	Species I	1.267	0.833	-1.33	-1.67	0.03	-0.23
	Species K	1.6	1.067	-2.33	-2.67	0.10	0.00
	Species M	1.333	1.1	-0.33	-1.00	0.13	0.00
Ukulinga	Green beans	1.433	1.067	-2.33	2.67	2.00	4.93
	Species I	0.867	1.9	0.00	1.33	3.60	5.10
	Species K	2	2.7	-2.33	2.33	2.97	6.37
	Species M	2.367	2.567	3.33	4.33	2.30	3.83
SED		**0.19**	**0.19**	**0.37**	**0.37**	**0.18**	**0.18**

3.3.3 Plant nutrient content of wild mustard and green beans grown in polyculture

3.3.3.1 Wild mustard species

The mineral content of selected macro elements (Ca, Mg, K, and P) showed a variable pattern between fertilised and unfertilised wild mustard species, for all treatments. The calcium content increased with intercropping for species I with a marginal increase of 0.45 in fertilised treatments but with a large increase of 46 % in unfertilised treatments (Figure 3.3). Intercropping also increased the Ca content in fertilised treatments for species M but reduced the Ca content in unfertilised treatments (Figure 3.3). Species K on the other hand showed 30% Ca reduction with intercropping in fertilised treatments and showed a weak increase of 3.1 % Ca content in unfertilised treatments (Figure 3.3).

Magnesium increased with intercropping for species I and M in both fertilised and unfertilised treatments (Figure 3.3). Foe species I, Mg increased by 3.2% and 29.3% in fertilised and unfertilised treatments, respectively, while for species M, Mg increased by 8.6% and 10.3% in fertilised and unfertilised treatments, respectively.

Potassium generally increased with intercropping for all the wild mustard species in fertilised treatments while in unfertilised treatments, species I and M showed an increase in K (Figure 3.3). Intercropping increased the K content by 21.4 %, 26.1 %, and 24.6 % in species I, M and K, respectively, in fertilised treatments and a 6.0 % and 22.2 % reduction for species I and M, respectively, in unfertilised treatments. A 22.4 % K reduction with intercropping was observed for species K in unfertilised treatments (Figure 3.3).

Phosphorus content reduced with intercropping for species I showing a 2.6 % and 30.8 % reduction in fertilised and unfertilised treatments, respectively (Figure 3.3). Species M showed increased P content of 12.8 % and 18.4 % with intercropping in fertilised and unfertilised treatments, respectively (Figure 3.3). Phosphorus increased (2.7 %) with intercropping in fertilised treatments while a reduction (24.5 %) of P was observed in unfertilised treatments for species K (Figure 3.3).

For the micro elements (Zn, Mn, Cu and Fe) there was a general increasing trend in the plant mineral content with intercropping in fertilised treatments for all the wild mustard species and a variable pattern was observed in unfertilised treatments (Figure 3.4).

Zinc increased for species I, M, and K (61.7 %, 12.9 % and 9.3 %, respectively) in fertilised treatments (Figure 3.4). Zinc reduction with intercropping was observed for species I in unfertilised treatments but species M and K increased with intercropping by 20 % and 54.5 % respectively (Figure 3.4).

Manganese, on the other hand, reduced with intercropping for species I (33 %) and species K (5.8 %) in unfertilised treatments (Figure 3.4).

Copper showed higher accumulation with intercropping in fertilised treatments for all the three wild mustard species (Figure 3.4). Intercropping increased copper by 34 % (Species I), an enormous 246 % (species M) and a 32 % (species K) in fertilised treatments, while a reduction of 11 % and 26.7 % (species M) was observed with intercropping in unfertilised treatments (Figure 3.4).

Iron increased with intercropping by 21 % (Species I) and 8.3 % (species K) in fertilised treatments with species M showing a reduction of 56 % with intercropping in fertilised treatments (Figure 3.4). Iron content reductions of 89 %, 56.5 % and 33.5 % for species I, M and K, respectively, were observed with intercropping in unfertilised treatments (Figure 3.4).

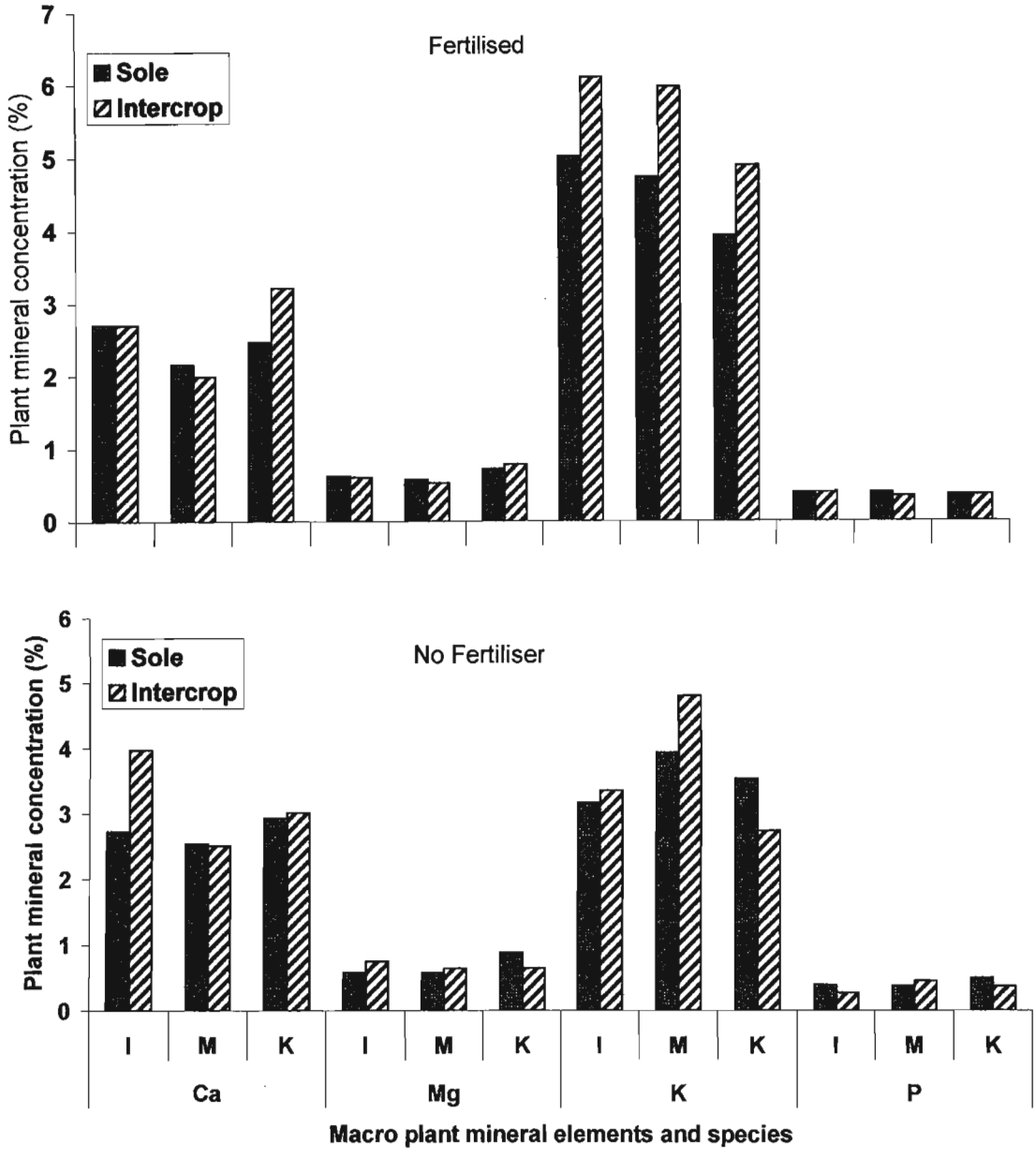

Figure 3.3. Comparison between intercropping and sole cropping of three wild mustard species (I, K and M) in fertilised and unfertilised treatments for Ca, Mg, K and P. The data are individual plant sample analysis for intercropped and sole cropping.

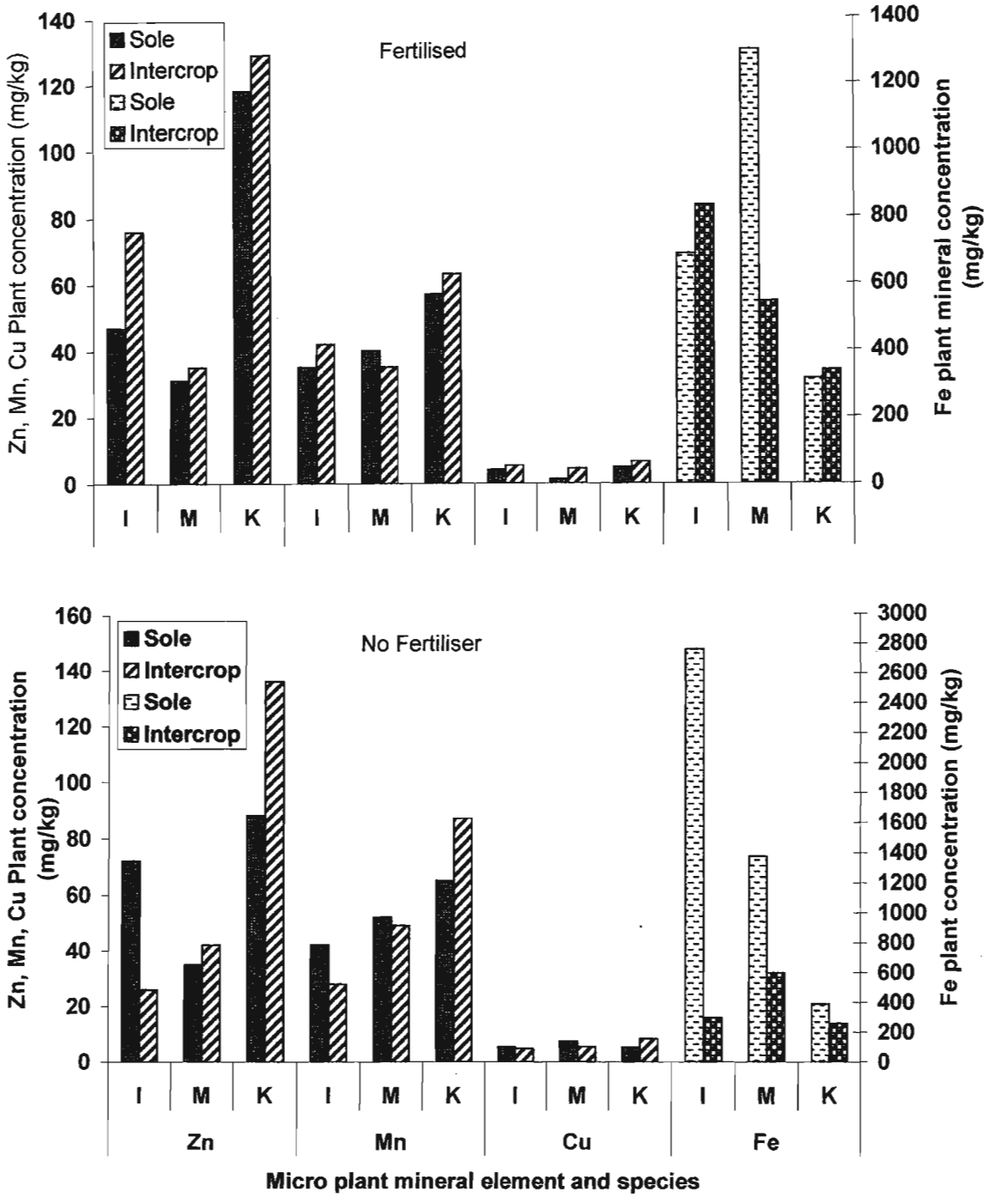

Figure 3.4. Comparison between intercropping and sole cropping of three wild mustard species (I, K and M) in fertilised and unfertilised treatments for Zn, Mn, Cu and Fe. The data are individual plant sample analysis for intercropped and sole cropping.

3.3.3.2 Green beans

In comparison to sole cropping, intercropping generally showed a decrease of N, Ca, Mg, and K in both fertilised and unfertilised treatments for green beans intercropped with any of the three wild mustard species (Figure 3.5). The P content did not show significant differences between sole crops of beans and intercrops of beans and species I, M and K in unfertilised treatments (Figure 3.5). However, there was an increase in K with intercropping for all intercrops between green beans and species I, M and K in unfertilised treatments (Figure 3.5).

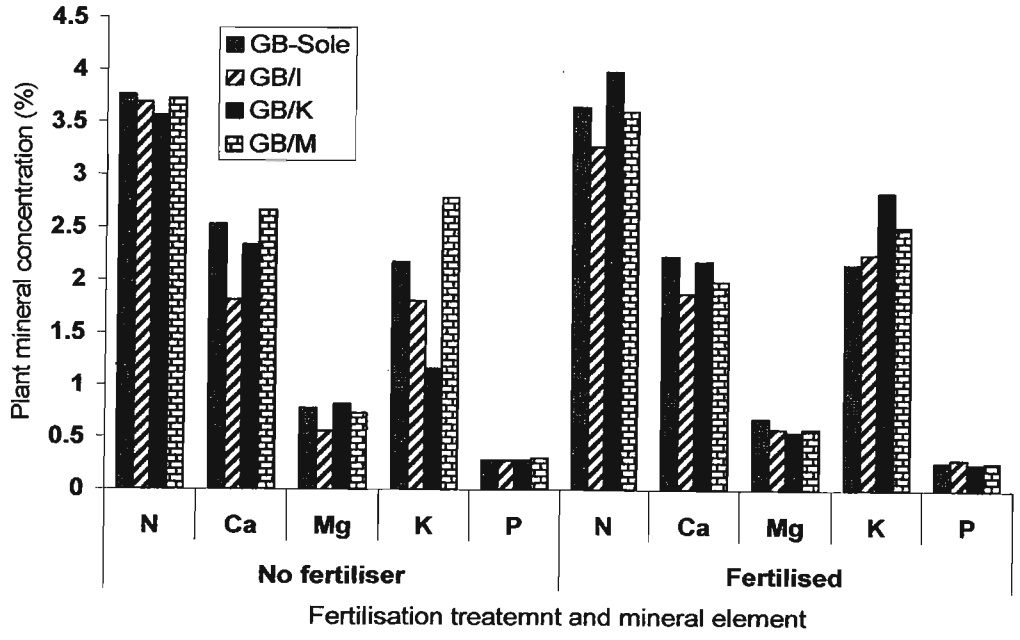

Figure 3.5. Comparison between intercropping and sole cropping of green beans (GB-Sole) intercropped with either species I (GB/I), K (GB/K) or M (GB/M) in fertilised and unfertilised treatments for N, Ca, Mg, K and P. The data are individual plant sample analysis for intercropped and sole cropping.

Intercropping resulted in a decreasing trend of microelements, Cu, Mn and Zn, in unfertilised treatments (Figure 3.6). The reduction in microelements for each treatment was: 26.5 % (GB/I), 23.5 (GB/K) and 20.6 (GB/M) for Zn; 55.3 % (GB/I),

61.7 % (GB/K) and 64. 9 % (GB/M) for Cu and 15.7 % (GB/I), 5.9 % (GB/K) and 9.8 % (GB/M) for Mn in unfertilised treatments (Figure 3.6). The mineral concentration for fertilised treatments showed some variable patterns and an increase for Cu, Zn, Mn and Fe with intercropping was observed in some instances not following any pattern (Figure 3.6).

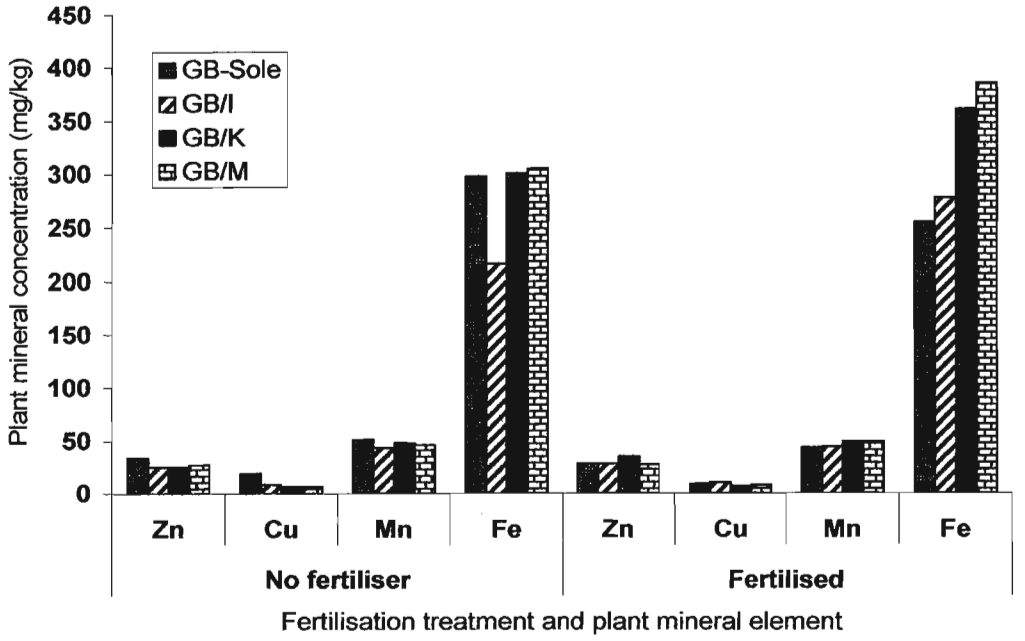

Figure 3.6. Comparison between intercropping and sole cropping of green beans (GB-Sole) intercropped with either species I, K or M in fertilised and unfertilised treatments for Zn, Cu Mn and Fe. The data are individual plant sample analysis for intercropped and sole cropping.

Green bean N concentration was higher in intercropping than sole cropping for all the three wild mustard species in fertilised treatments by 4.9 %, 12.3 % and 17.7% for species I, K and M respectively (Figure 3.7). Intercropping reduced plant N content in all the species indicating reductions of 10.2 %, 4.6 % and 11.2 % for species I, M and K respectively (Figure 3.7). The protein content on the other hand generally reduced

with intercropping in both fertilised and unfertilised treatments except for species M which showed 14 % increase above sole cropping (Figure 3.8). Intercropping reduced the protein content in the wild mustard plants by 6.1 % and 23.9 % in species I and K respectively in fertilised treatments while 13 %, 20.4 % and 7 % protein reduction was observed for species I, K and M respectively in unfertilised treatments (Figure 3.8).

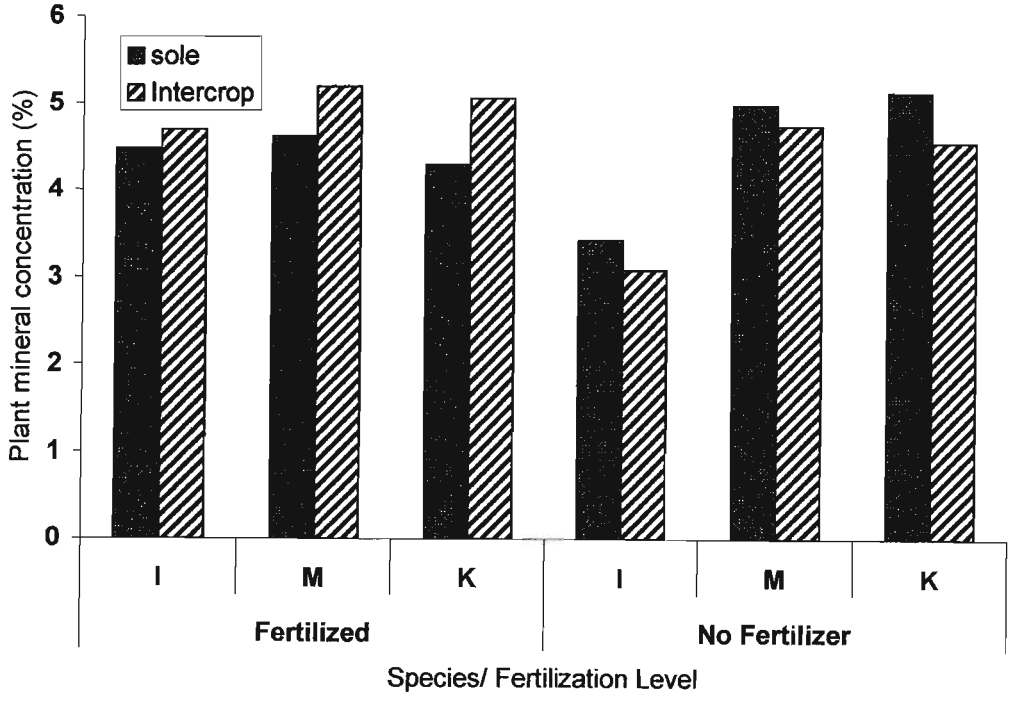

Figure 3.7. Comparison between intercropping and sole cropping of N content in green beans intercropped with either species I, K or M in fertilised and unfertilised treatments.

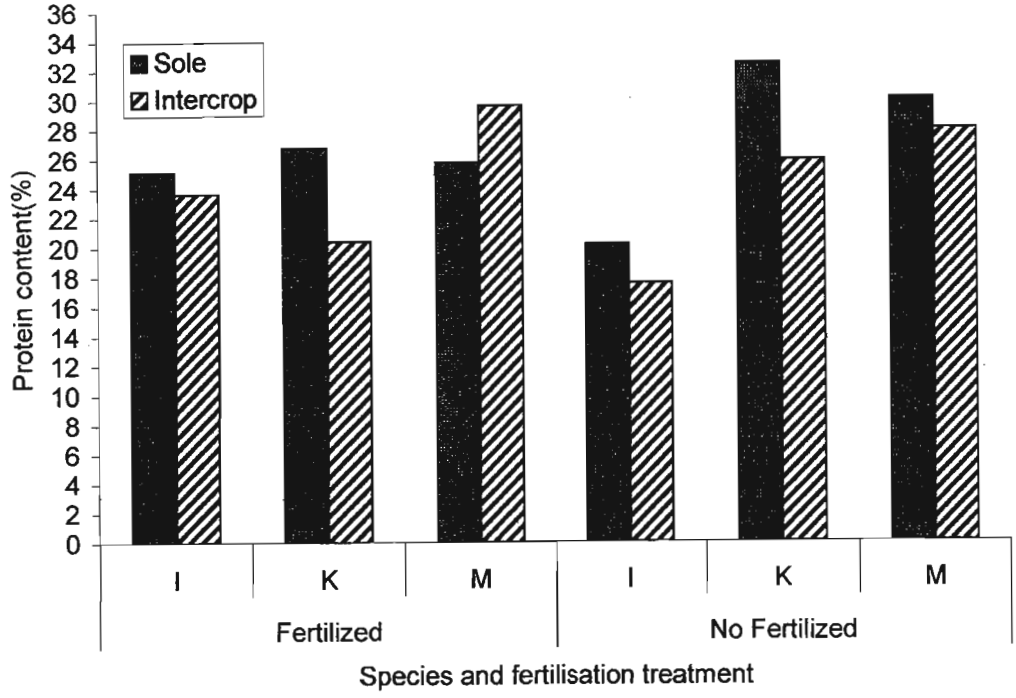

Figure 3.8. Comparison between intercropping and sole cropping of green beans intercropped with either species I, K or M in fertilised and unfertilised treatments for protein. The data are individual plant sample analysis for intercropped and sole cropping.

3.4. Discussion

3.4.1. Effect of wild mustard on soil mineral nutrient contents

As indicated by the results of this study, P, Cu, Mg and K mineral residual content of the soil increased with organic fertilisation through out the four seasons. There is good evidence that organic fertilisation leaves good amount of soil mineral elements. This could lead to a good amount of mineral build up in the soil and improve the soil structure. Earlier evidence was shown that fertilisation increased biomass production

(chapter 2). This finding strengthens the fact that fertilisation is important for producing wild mustard to optimise productivity.

The results presented for phosphorous indicate no significant P increases in the root zones of intercrops compared to sole crops. This result contradicts that reported by Maingi et al. (2001) where there were improvements of P in beans-maize intercrop compared to sole cropping. However, the positive available P balances in the root zones of both sole and intercrops in unfertilized plots could be attributed to accumulation of previously unavailable P during the initial soil test. It would also be assumed that wild mustard/green beans associations may have the ability to alter the pH of the soil within the vicinity of the roots which in most cases determines the availability of P in certain forms which are useful to plants, hence positive balances. This effect of wild mustard may be associated with soil pH changes, because soil P availability is determined by the soil pH (Salisbury and Ross 1978).

The positive phosphorus balances observed could also be attributed to mychorrhizae-like growth on the roots (Figure 3.9) that may have improved the phosphorus release by the wild mustard species (Ames *et al.*, 1983). Mycorrhizal hyphae are known to penetrate the soil beyond the region of phosphorus depletion of the root zone which could have resulted into the use of deeper P reserves. The mycorrhizae are also known to decompose organic sources of P and may have resulted into the increase of P by weathering of P from the soil base material. It is important to note that the Brassica species, to which wild mustard belongs, are not known to be mycorrhizae. Therefore further investigations are needed to classify the nature of the hyphae found associated with wild mustard species in this study.

Except in a few cases where interaction effects were observed, all the three species showed positive soil mineral accumulation effects for elements like K and Ca. This was a good reason to suspect that there is a possibility of the three wild mustard species being able to facilitate availability of some of the elements from organic sources.

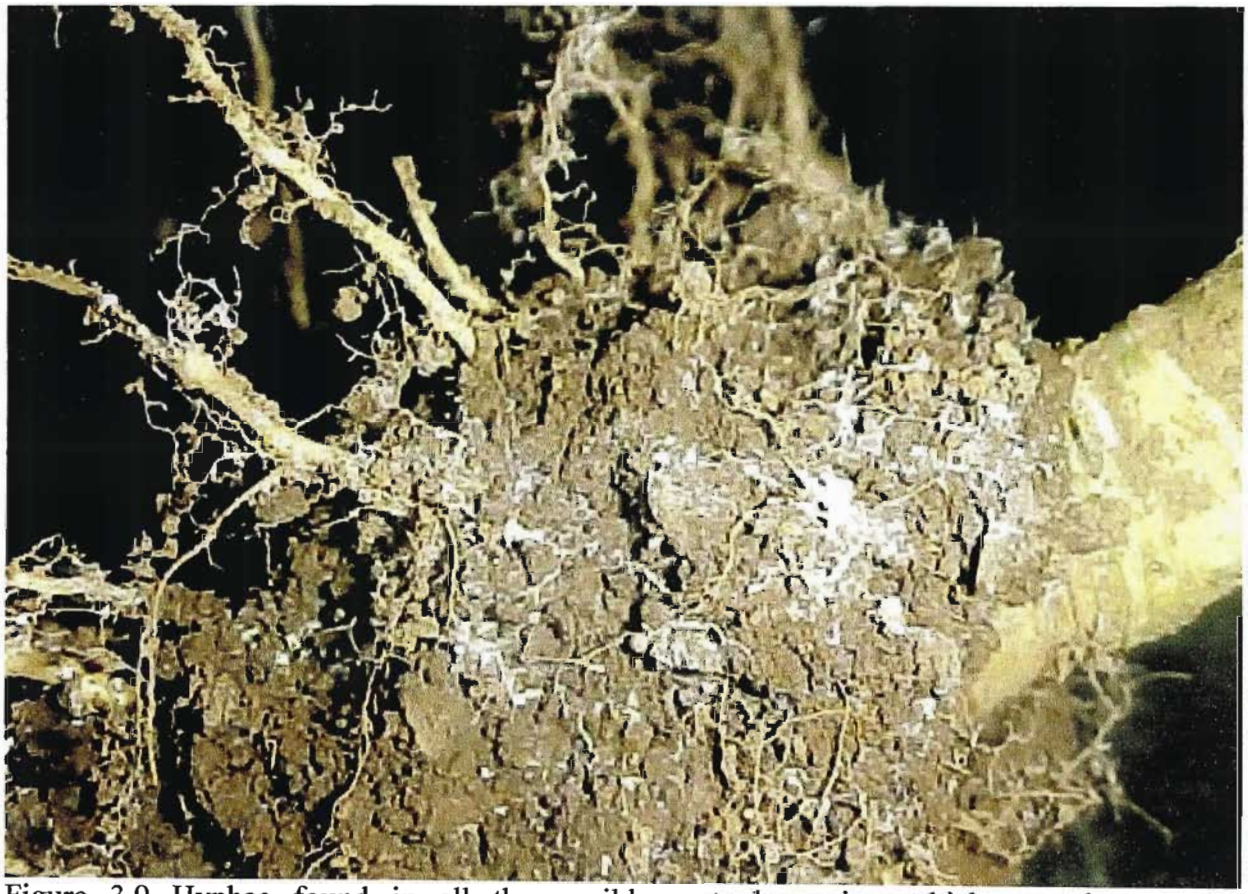

Figure 3.9 Hyphae found in all three wild mustard species, which may be mycorrhizae-like in their effect on soil nutrients.

Magnesium, Cu and Mn showed some general declining trend in the soil during the study, suggesting that wild mustard may have absorbed these elements heavily. Hence additional fertilisation would be needed to meet the requirements for these elements, where wild mustard was grown.

3.4.2. Mineral element content in wild mustard and green beans plants

The results observed for the mineral element concentration in leaves of intercropped wild mustard showed increased concentrations of Zn, Cu, Mn, and K in intercrops compared to their corresponding sole crops with fertilization. Similar findings were reported for K, Ca, P and Mg (Zhang and Li, 2003; Li *et al*, 2003). The decline of some elements in intercropping (e.g., Cu in unfertilized experiments) could mean that sole crops were able to access Cu better than polyculture crops. Results for Fe also suggest that intercropping negatively affects its uptake. This finding contradicts the results reported by Zhang and Li (2003). The implication of these results could be that there is competition between component species while on the other hand it could be said that one component crop was mining more of one nutrient than the other. If it is assumed that the mycorrhizae effect (Figure 3.9) increased uptake of nutrients to companion species (green beans), it could be a possible facilitation. There seemed to be a great advantage in P uptake with intercropping.

Results for plant N concentration showed both facilitative and competitive interactions (Vandermeer, 1989). Intercropping was an effective way of increasing N uptake under organic fertilisation. Similar results on increased N uptake in fertilized treatments were reported by Zhou *et al,* 2000. The reverse trend observed in unfertilized plots partially showed a possible competitiveness for N uptake from the soil, which might have been limiting.

It could be assumed therefore that intercrops retain higher quantities of K and Mg in the root zone. However, this does not directly answer the question of efficiency in

nutrient uptake. The available evidence from literature indicates that crop mixtures take up more nutrients due to the well developed root mass than sole cropping. The increased concentration around the root zone is therefore a more curious observation and requires further investigation.

Intercropping reduced protein content accumulation in the leaves of the wild mustard in all the species in both fertilized and unfertilized treatments (Figure 3.8). The reverse trend seen in species M in fertilized crops could be attributed to differences in the species and their response to organic fertilisation. However using the standard error, intercropping was not significantly different from sole cropping. We could therefore conclude from these results that intercropping reduces protein content in the leaves of wild mustard for all the three species. These findings are similar to observations made by Redfearn *et al.* (1999) who observed lower crude protein content in leaves of intercropped soybeans than sole crops.

Fertilization on the other hand reduced the protein content in all the three species in sole cropping with a similar trend observed in intercropping for species I and K. Species M showed a slight increase in protein content with fertilization, contrary to the rest of the treatments. These results suggest, surprisingly, that fertilization may have reduced protein accumulation in the leaves of wild mustard.

Finally, it must be emphasised that application of organic fertiliser is essential for increasing the productivity of wild mustard for meeting crop nutrient demands. The results of this study, about mycelium on the roots are not conclusive, and there is a need for further investigation into identification of the mycelium. More controlled

studies are also required to investigate the role of the mycelium in plant nutrition. Nevertheless, this study showed that wild mustard may improve P, K, Mg and Cu in its root zone, where fertiliser was not applied. It has also been demonstrated that intercropping improves the nutritional content for Zn, Cu, Mn, and K in wild mustard.

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CHAPTER 4. SEED PRODUCTION AND GERMINATION CAPACITY

4.1 Introduction

Vegetables are harvested for their vegetative (e.g. leaves) or reproductive parts (e.g. fruits and inflorescences). In most cases, the harvest of the market-use crop requires environmental conditions that are very different from those focusing on the reproduction and development of a mature seed crop. For example, ambient temperature, photoperiod, length of growing season, as well as amount and distribution of precipitation may vary for the optimum production of market-use and seed crops (Fan *et al.* 1997; Spetch, 1997; Westgate and Peterson, 1993). Climate determines seed yield, development and maturation (Delouche, 1980). Low seed yields could affect farmers' income from direct seed sales or on the basis of planting value. Mustard seeds have several uses including use as a spice and for oil (Halan, 1992). Wild mustard seeds have not been shown to have similar economic uses, but some rural people in South Africa relish the leaves as a wild leafy vegetable (Modi, 2003).

Seed quality varies greatly with environmental conditions such as temperature and water availability (McDonald and Copeland, 1997). Seed quality relates to the ability of the seed to produce a strong healthy seedling and sufficient plant population to set the framework for a high crop yield potential (McDonald and Copeland, 1997). The planting value for seeds is usually determined by germination test, but many other attributes are important including seed size and seedling vigour (de Villiers *et al.* 2005; Mazibuko and Modi, 2005). Responses to environmental stress during seed

development are diverse and complex, although the effects are generally harmful and result in decline in seed number and quality.

The objective of this study was to determine the effects of provenance and season on wild mustard seed production and seed quality.

4.2 Materials and methods

Descriptions of plant material (three wild mustard species: I, M and K), field experiment sites where seed production occurred (Umbumbulu and Pietermaritzburg, KwaZulu-Natal, South Africa) and field experiment designs, were presented in chapter 2 (section 2.2) above.

Four plants per plot (1.2 m^2) were sampled for seed yield determination on per plant and on per square metre basis. The plants were hand harvested at physiological maturity, when the whole plant had senesced and about 80% of the pods had turned khaki-brown. The plants were allowed to dry in a glass house (~27 °C ± 3°C) for 30 days before threshing them to obtain seed moisture content (10 % ± 2 S.E (mean)). Seed germination proceeded immediately after drying the seed which took roughly 30 days after harvesting for all seasons.

Seed germination was determined according to Ochuodho and Modi (2005). Four replications of 50 seeds were placed in petri-dishes on three whatman filter papers moistened with distilled water. The seeds were incubated in germination cabinets (Labcon, LTGC 20-40) at 20-30oC alternating temperature regime, of 16 h (20oC) and 8 h (30oC) in darkness and light respectively. Germination was allowed to continue for 10 days. Germination counts were conducted at 2-day intervals. Seeds were considered germinated when the radicle had protruded. One thousand (1000)

seed weight was determined for each replicate which comprised of seeds from four plants. One hundred (100) pods seed weight was determined by weighing 100 pods seed from each plant amongst the treatments.

Analysis of variance (Genstat®, Rothamsted Experiment Station, U.K.) was used for data analysis (Appendix 4.1) and the differences between treatments were determined by LSD and S.E. (mean).

4.3 Results

The results presented are only for three seasons (autumn, winter and spring) since there were no seeds harvested during summer.

4.3.1 Seed yield

Seed yield was significantly ($P<0.05$) higher at Ukulinga than Umbumbulu (Figure 4. 1). The winter crop, however, gave higher seed yields than the autumn and spring crop at both locations. Species M had higher ($P < 0.05$) yields than both species I and K across seasons at the two sites. Species I yielded the least during autumn at Ukulinga while no seeds were harvested at Umbumbulu for species I.

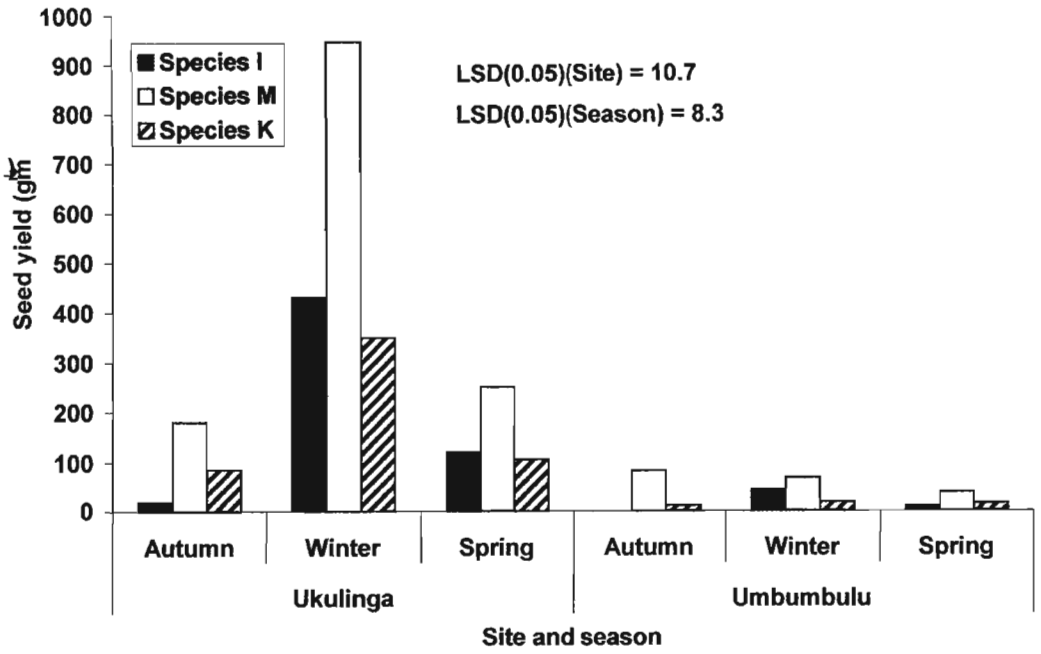

Figure 4.1. Comparison of seed yield for three wild mustard species (inset) during three seasons at the two locations. Data are combined means for fertilized and unfertilized plots.

There were no significant differences between species across sites with respect to the 1000-seed weight (Figure 4.2). However there were significant difference ($P < 0.05$) between species for a 100-pod seed weight at both sites (Figure 4.3). Species I weighed significantly ($P < 0.05$) higher than species M and K for the 100-pod seed weight at both sites (Figure 4.3). No significant differences were observed between species I and species K at Ukulinga, while species I weighed less than species K at Umbumbulu for 100-pod seed weight (Figure 4.3).

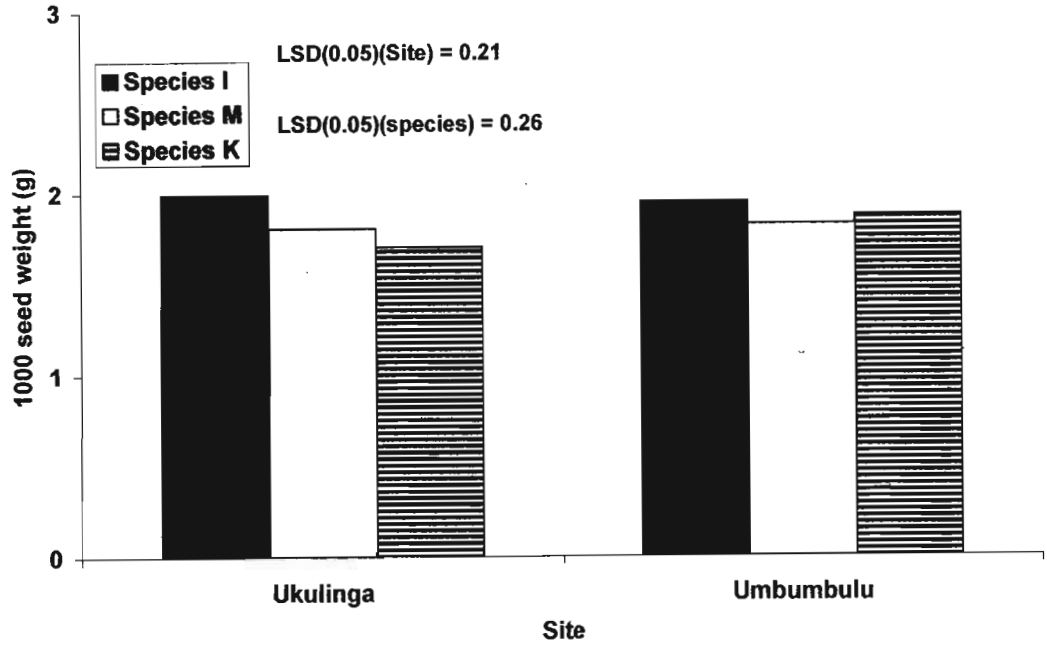

Figure 4.2. Comparison of three wild mustard (inset) species for 1000- seed weight at the two sites. The data are the combined means for sole and intercropping sole crops for both fertilised and unfertilised treatments

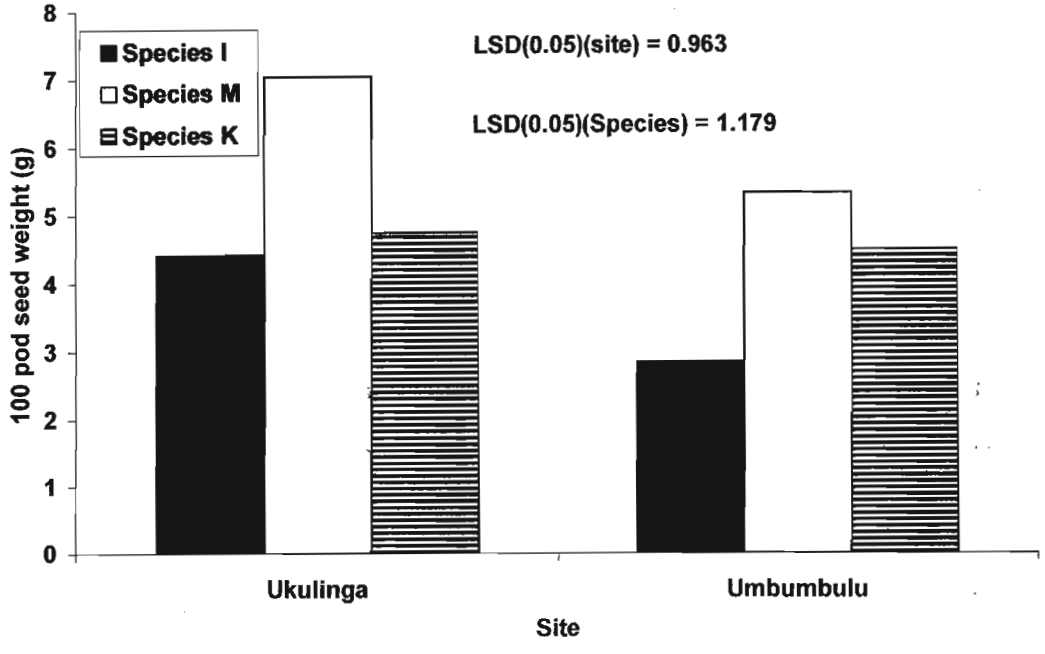

Figure 4.3. Comparison of three wild mustard (inset) species for 100 – pod seed pod weight at the two sites. The data are the combined means for sole and intercropping sole crops for both fertilised and unfertilised treatments.

4.3.2 Seed germination

No significant differences in seed germination were found between species irrespective of whether they were harvested from sole or polyculture plots (Figure 4.4). There were also no significant differences between fertilized and nonfertilised treatments.

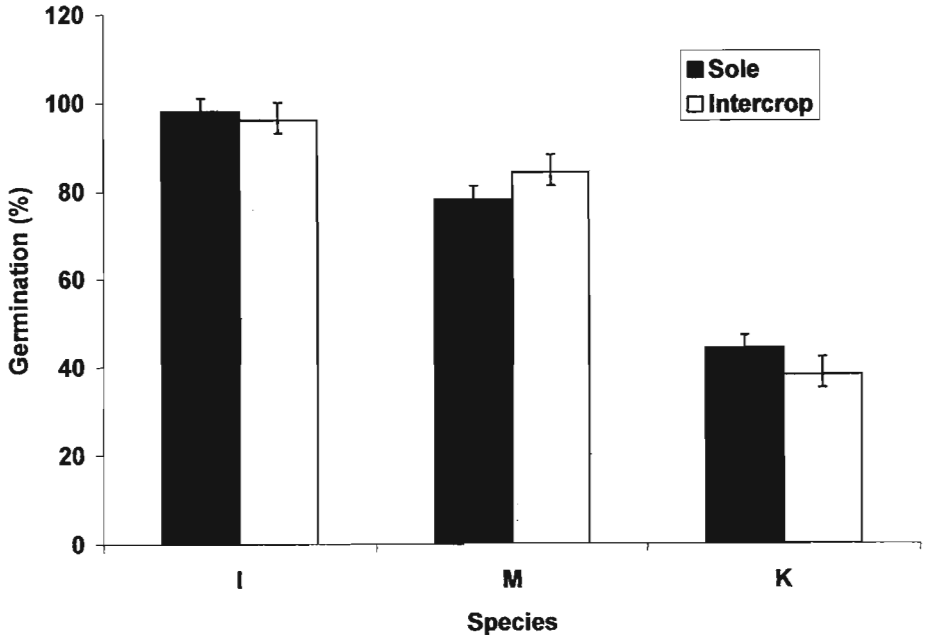

Figure 4.4. Seed germination of three wild mustard species (inset) harvested from intercropping and sole cropping systems. The data are the means for all sites and fertiliser treatments

However, significant ($P < 0.05$) differences in seed germination were observed between species from the three seasons and there were significant interactions between sites x season (Figure 4.5). Seeds of species I gave significantly higher germination percentage at Ukulinga during autumn and spring compared with species K and M (Figure 4.5). No significant differences between species were observed during winter at Ukulinga (Figure 4.5)

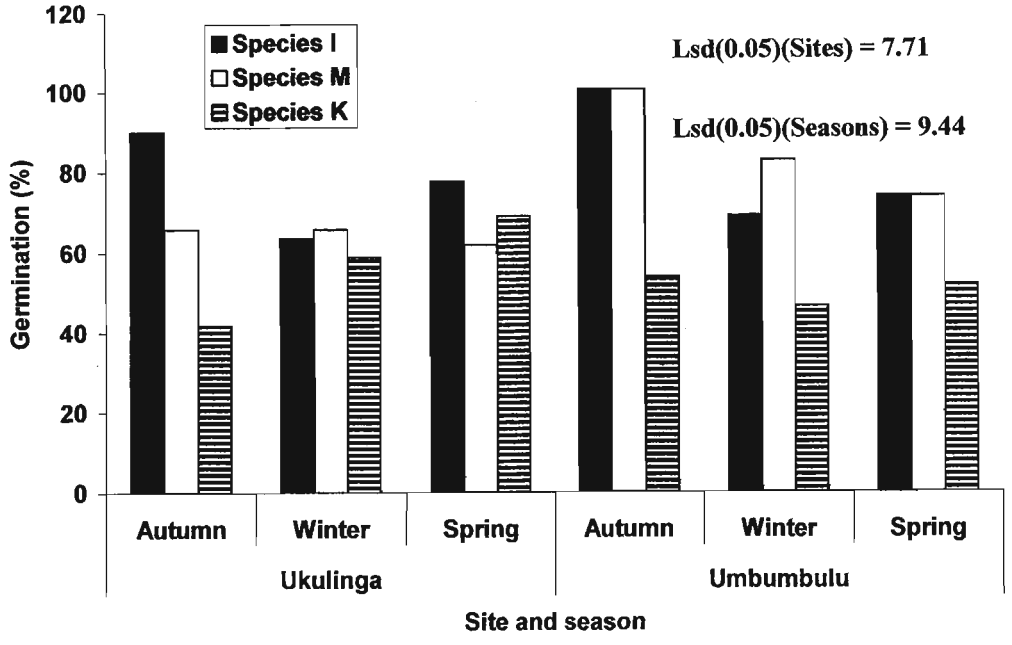

Fig 4.5. Seed germination of three wild mustard species (inset) during three seasons at the two sites. The data are the means of fertilized and unfertilised plots.

Seeds for species K produced at Umbumbulu during winter had low germination percentage than the seeds produced in autumn and spring (Figure 4.5). At Ukulinga, seeds for species K produced during winter and spring had improved germination percentage over seeds produced at Umbumbulu during the same seasons (Figure 4.5). However during autumn, the seeds of species K, produced at Ukulinga, maintained a similar germination capacity as seeds from Umbumbulu (Figure 4.5).

Seeds for species M gave significantly higher final germination count during winter and spring, whereas germination was reduced during autumn to about 60% at Ukulinga. At Umbumbulu, there were no significant differences between seeds of species M produced during all the three seasons, with a germination capacity of ~ 80%. Species K germinated slowly in addition to having a poor germination capacity

at both locations in all the three seasons compared to species I and species M (Figure 4.5)

4.4 Discussion

The results of this study showed that greater seed yield for wild mustard were obtained during the winter season. However, more seeds were obtained at Ukulinga than Umbumbulu. Ukulinga is generally cooler than Umbumbulu (section 2.2). During this study, Ukulinga had a greater rainfall than Umbumbulu (section 2.2). Hence, the climatic differences between the two sites influenced the yield. The results also showed that the difference in seed yield was as a result of the growth habit of the wild mustard. Species M has a lot of branches bearing many pods and therefore recorded higher seeds yields compared with other species.

Seed germination, was higher in seeds produced in autumn and spring for species I. This result does not suggest, however that seeds produced during the seasons of autumn and spring are better than winter since, because the effect of climate was not directly explained in this study. However, factors, such as seed dormancy could have been important too (Simpson, 1990). Species K also contains a higher percentage of the dark seeds compared to the other species (Chapter 2, Figure 2.2) which may be associated with higher seed dormancy because of the presence of tannins (Bewley and Black, 1994). The other two species, I and M, which have fewer darker seeds germinated better than species K.

In conclusion, from the results of this study, wild mustard seed production would be recommended for the cooler seasons, especially winter, because of high yield and

good germination capacity during these periods. The effects of climate require detailed and controlled study before making definite recommendations about them.

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CHAPTER 5. GENERAL DISCUSSION AND CONCLUSIONS

Intercrops of wild mustard significantly out-yielded their pure stands, with the intercrop of species M showing the highest LERs. The merits of intercropping wild mustard and green beans, as an option to increasing productivity per unit area of land and crop diversification were explored in this study and are confirmed by positive LER values obtained for all the wild mustard species. An all year round production of these vegetables was investigated to determine their production potential. The results on the growth parameters that included plant height, number of leaves and overall crop yields (economic and biomass) showed a positive association of the two crops grown in an intercropping system (Chapter two). The productivity across the four seasons also proved that wild mustard could be grown throughout the year. However, the best vegetable yields can be expected during the cool seasons of the year (spring and autumn, with winter having the limitation of water stress). Therefore it is recommended that wild mustard should be grown in spring and autumn, and winter production is possible for frost-free areas if water stress is not a major limiting factor. Although they were not the major focus of this study, pests and diseases were observed to be the major limiting factors for summer production of wild mustard. Organic farming did not result in large increases in relative abundance of most pest species over the period of this study. However, there were some significant short-term problems in individual seasons. Significantly greater damage occurred in autumn and summer. That no chemical disease and pest control were practised may have exacerbated the effect of pests on crop production. In summer, wild mustard also failed to flower sufficiently to produce measurable seed quantities, suggesting that day length may be important in wild mustard production.

For seed production, this study showed that winter was the best season for wild mustard. Winter season would therefore be recommended for seed production while farmers would also be able to harvest some vegetable for their consumption, because leaf production in winter was also prolific. Seed germination (Figure 4.5) was found to follow a similar pattern with seed yields (Figure 4.1). Hence the best seed quality was obtained in autumn. This finding was not surprising, because seed quality is influenced by supply of nourishment from the mother plant. Further investigations are needed into seed quality aspects (other than germination capacity) of wild mustard with respect to production seasons.

This study demonstrated that organic fertilisation improved the vegetative growth of both the wild mustard and the green beans. This finding suggests and recommends that additional organic fertilisation be supplied to increase yields. However as reported by Siame et al (1998), fertilisation affected the overall intercrop productivity as observed by reduced LER with fertilisation. The species responded differently to both intercropping and fertilisation. Despite the fact that all the species withstood all year round production and that they grew well in intercropping, species M would be recommended as best wild mustard choice for production since it had higher vegetative and seed yield in all the four seasons. Species I would be ranked second. The strength of species I was that it flowered earliest in winter, but it maintained vigorous vegetative growth and therefore had a prolonged seed development time. Species K had a weakness of flowering early in all seasons, but its vegetative growth was generally low. It also had smaller leaves than the other two species.

Whereas no significant differences were noticed between intercropping and sole cropping, the soil and plant analysis results provided an interesting trend when looked at more closely with respect to fertilisation regimes. The soil analysis results showed that the balance of some mineral elements in the root zone is affected positively in the presence of wild mustard. The positive effects suggest that wild mustard may have the ability to improve mineral availability. This aspect was not shown conclusively in this study. Therefore it is recommended that further investigations into the role of wild mustard in soil quality be undertaken. That application of fertilisers increased biomass at all sites and suggests that the species and their companion crops in polyculture need supplementary fertilisation and the effect of wild mustard on increasing soil mineral nutrients may not be sufficient to recommend no fertiliser application. However, from the unfertilised treatment results it could also be suggested that wild mustard would grow with low soil nutrition levels.

The plant mineral concentration showed an increase in intercrops compared to sole crops for all the species. Similar observations have been made by Morris and Garrity (1993) who reported increased nutrient uptake by intercrops compared to sole crops. Results of the present study showed increased Mg, Zn, Ca and K in wild mustard with intercropping. This increase could be explained as the efficient use of soil mineral resources in intercropping compared with sole cropping. The result for N showing accumulation in organically fertilised treatments for intercrops also confirmed that where N is not limiting intercrops are efficient in N nutrient uptake. The results for Mg and P which showed no significant differences between intercrops and sole cropping confirmed results that Midmore (1993) found that for immobile macro elements such as P, no competition would exist between component crops of an

intercrop. The protein content decrease with intercropping on the other hand poses interesting questions about the utilisation of N and needs closer investigation at the biochemical level.

In conclusion this study showed that wild mustard and green beans were compatible in polyculture. The use of organic fertilisers has merit, but also resulted in reduced LER values. Although the spring and autumn crops produced the highest vegetative matter yields, it is evident that wild mustard can be grown throughout the year.

The main objective of this study was to determine the compatibility of intercropping wild mustard with green beans and gain insight into the understanding of soil nutrient dynamics in a wild mustard/green bean polyculture with or without organic fertilisation. The unique feature of this study was that it looked into vegetable intercropping (both crops are technically vegetables). During this study, there was no evidence that vegetable intercropping has received much attention in intercropping studies, despite the acknowledgements made by several studies stressing the importance of vegetables in nutrition and food security. Therefore, the main contribution of this study was in providing information about how small scale farmers can utilise and manage their natural and biological resources, which may further contribute to crop and household food diversity.

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APPENDICES

Appendix 2.1. Field plan layout

Block 1=Planted with out fertilizer

1	2	3	4	5	6	7
14	13	12	11	10	9	8
15	16	17	18	19	20	21

Block 2= Planted with Organic Fertilizer

1	2	3	4	5	6	7
14	13	12	11	10	9	8
15	16	17	18	19	20	21

Notes: The field layout shows plot numbers (insert). Treatments were randomly assigned to each plot according to Randomized complete block design (RCBD). The same layout was used for both fertilised and non fertilized treatment across the season but randomisation was done each season.

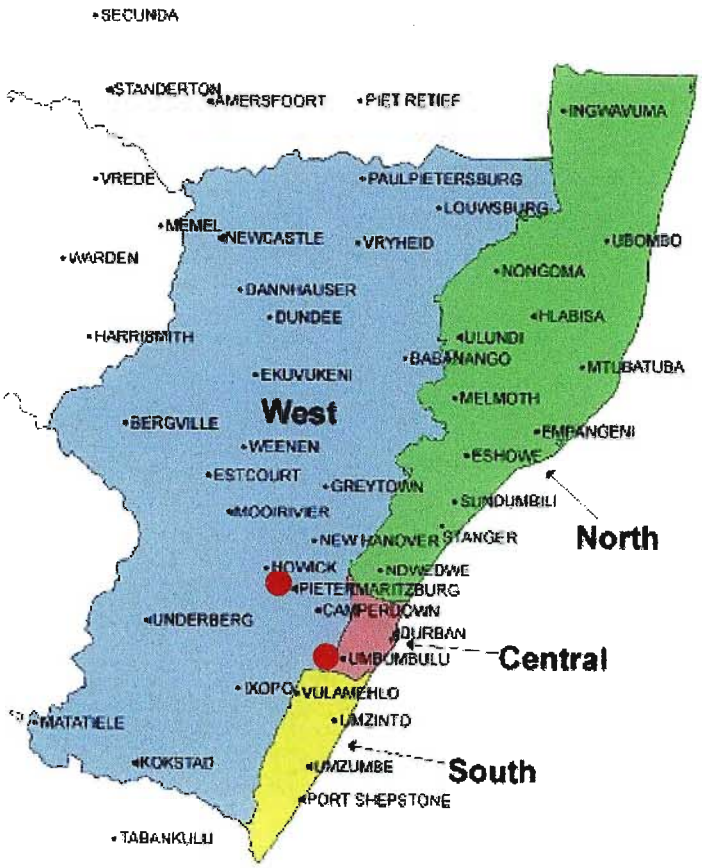
Plot dimensions

Individual plot size:	1.2m X 1.2m =1.44m^2
Between Replicates (rows) spacing:	1m
Between plots spacing (within the replicates):	0.50m between plots
Between fertilized and non fertilized Blocks spacing:	2.5m

Treatments

T1=Sole Green Beans
T2=Sole Species 1
T3=Sole species M
T4=Sole species K
T5=Intercrop of species I and green beans
T6=Intercrop of species M and green beans
T7=Intercrop of species K and green beans

Appendix 2.2. Locations of the research sites (red dots), Umbumbulu and Ukulinga (Ukulinga is in Pietermaritzburg)



Appendix 2.3 Analysis of Variance for number of leaves 42 weeks after sowing at the two sites (Ukulinga and Umbumbulu). Note that the analysis shows 9 df for cropping system which takes into account the component crops in an intercropping system for purposes of data collection and analysis.

a) Autumn

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	6.72	3.36	0.20	
Replicate.*Units* stratum					
Site	1	3544.30	3544.30	211.01	<.001
Fertilization	1	87.03	87.03	5.18	0.023
Croppingsystem	9	9986.64	1109.63	66.06	<.001
DA_50%E	6	19904.46	3317.41	197.50	<.001
Site.Fertilization	1	15.43	15.43	0.92	0.338
Site.Croppingsystem	9	4063.29	451.48	26.88	<.001
Fertilization.Croppingsystem	9	636.26	70.70	4.21	<.001
Site.DA_50%E	6	4285.19	714.20	42.52	<.001
Fertilization.DA_50%E	6	288.90	48.15	2.87	0.009
Croppingsystem.DA_50%E	54	7767.93	143.85	8.56	<.001
Site.Fertilization.Croppingsystem	9	526.49	58.50	3.48	<.001
Site.Fertilization.DA_50%E	6	286.38	47.73	2.84	0.010
Site.Croppingsystem.DA_50%E	54	4350.65	80.57	4.80	<.001
Fertilization.Croppingsystem.DA_50%E	54	1255.93	23.26	1.38	0.041
Site.Fertilization.Croppingsystem.DA_50%E	54	1413.98	26.18	1.56	0.008
Residual	537(21)	9020.08	16.80		
Total	818(21)	64669.39			

b) Winter

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	5.0591	2.5295	3.64	
Replicate.*Units* stratum					
Site	1	45.4386	45.4386	65.41	<.001
Fertilization	1	0.4386	0.4386	0.63	0.427
Croppingsystem	9	76.3151	8.4795	12.21	<.001
DA_50%E	5	4252.5213	850.5043	1224.27	<.001
Site.Fertilization	1	4.2428	4.2428	6.11	0.014
Site.Croppingsystem	9	51.4728	5.7192	8.23	<.001
Fertilization.Croppingsystem	9	23.2681	2.5853	3.72	<.001
Site.DA_50%E	5	500.4349	100.0870	144.07	<.001
Fertilization.DA_50%E	5	11.0352	2.2070	3.18	0.008
Croppingsystem.DA_50%E	45	211.8965	4.7088	6.78	<.001
Site.Fertilization.Croppingsystem	9	13.6820	1.5202	2.19	0.022
Site.Fertilization.DA_50%E	5	5.3262	1.0652	1.53	0.178
Site.Croppingsystem.DA_50%E	45	109.6455	2.4366	3.51	<.001
Fertilization.Croppingsystem.DA_50%E	45	49.2261	1.0939	1.57	0.012
Site.Fertilization.Croppingsystem.DA_50%E	45	26.0481	0.5788	0.83	0.772
Residual	469(9)	325.8170	0.6947		
Total	710(9)	5541.4019			

c) Spring

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	9.696	4.848	1.89	
Replication.*Units* stratum					
Site	1	132.305	132.305	51.49	<.001
Fertilization	1	16.583	16.583	6.45	0.011
Croppingsystem	9	5800.546	644.505	250.80	<.001
DA50%E	4	8522.122	2130.530	829.08	<.001
Site.Fertilization	1	15.763	15.763	6.13	0.014
Site.Croppingsystem	9	1290.011	143.335	55.78	<.001
Fertilization.Croppingsystem	9	10.520	1.169	0.45	0.904
Site.DA50%E	4	1451.417	362.854	141.20	<.001
Fertilization.DA50%E	4	16.579	4.145	1.61	0.170
Croppingsystem.DA50%E	36	5347.970	148.555	57.81	<.001
Site.Fertilization.Croppingsystem	9	17.786	1.976	0.77	0.645
Site.Fertilization.DA50%E	4	46.222	11.556	4.50	0.001
Site.Croppingsystem.DA50%E	36	3043.637	84.545	32.90	<.001
Fertilization.Croppingsystem.DA50%E	36	95.626	2.656	1.03	0.419
Site.Fertilization.Croppingsystem.DA50%E	36	56.203	1.561	0.61	0.966
Residual	398	1022.762	2.570		
Total	599	26895.747			

d) Summer

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	98.28	49.14	2.40	
Replication.*Units* stratum					
Site	1	271.31	271.31	13.24	<.001
Fertilization	1	0.41	0.41	0.02	0.887
Croppingsystem	9	27640.60	3071.18	149.82	<.001
DA_50%E	4	25307.36	6326.84	308.65	<.001
Site.Fertilization	1	0.22	0.22	0.01	0.917
Site.Croppingsystem	9	669.01	74.33	3.63	<.001
Fertilization.Croppingsystem	9	23.95	2.66	0.13	0.999
Site.DA_50%E	4	3065.65	766.41	37.39	<.001
Fertilization.DA_50%E	4	11.33	2.83	0.14	0.968
Croppingsystem.DA_50%E	36	18499.39	513.87	25.07	<.001
Site.Fertilization.Croppingsystem	9	30.43	3.38	0.16	0.997
Site.Fertilization.DA_50%E	4	19.95	4.99	0.24	0.914
Site.Croppingsystem.DA_50%E	36	3539.43	98.32	4.80	<.001
Fertilization.Croppingsystem.DA_50%E	36	125.77	3.49	0.17	1.000
Site.Fertilization.Croppingsystem.DA_50%E	35(1)	134.65	3.85	0.19	1.000
Residual	349(49)	7154.02	20.50		
Total	549(50)	80367.83			

Appendix 2.4 Analysis of Variance for plant height 42 weeks after sowing at the two sites (Ukulinga and Umbumbulu) Note that the analysis shows 9 df for cropping system which takes into account the component crops in an intercropping system for purposes of data collection and analysis.

a) Autumn

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	6163.7	3081.9	5.48	
Replicate.*Units* stratum					
Site	1	30836.3	30836.3	54.81	<.001
Fertilization	1	7.3	7.3	0.01	0.909
Croppingsystem	9	54696.7	6077.4	10.80	<.001
DA_50%E	6	21413.5	3568.9	6.34	<.001
Site.Fertilization	1	21.9	21.9	0.04	0.844
Site.Croppingsystem	9	9649.6	1072.2	1.91	0.049
Fertilization.Croppingsystem	9	8297.2	921.9	1.64	0.101
Site.DA_50%E	6	36998.6	6166.4	10.96	<.001
Fertilization.DA_50%E	6	39031.9	6505.3	11.56	<.001
Croppingsystem.DA_50%E	54	161313.1	2987.3	5.31	<.001
Site.Fertilization.Croppingsystem	9	19577.6	2175.3	3.87	<.001
Site.Fertilization.DA_50%E	6	21239.2	3539.9	6.29	<.001
Site.Croppingsystem.DA_50%E	54	99061.0	1834.5	3.26	<.001
Fertilization.Croppingsystem.DA_50%E	54	55938.0	1035.9	1.84	<.001
Site.Fertilization.Croppingsystem.DA_50%E	54	66457.7	1230.7	2.19	<.001
Residual	551(7)	309988.8	562.6		
Total	832(7)	932994.5			

b) Winter

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	29.773	14.886	4.15	
Replicate.*Units* stratum					
Site	1	1665.513	1665.513	463.87	<.001
Fertilization	1	9.244	9.244	2.57	0.109
Croppingsystem	9	621.645	69.072	19.24	<.001
DA_50%E	5	16812.108	3362.422	936.48	<.001
Site.Fertilization	1	168.943	168.943	47.05	<.001
Site.Croppingsystem	9	738.292	82.032	22.85	<.001
Fertilization.Croppingsystem	9	114.969	12.774	3.56	<.001
Site.DA_50%E	5	2593.607	518.721	144.47	<.001
Fertilization.DA_50%E	5	28.826	5.765	1.61	0.157
Croppingsystem.DA_50%E	45	1705.098	37.891	10.55	<.001
Site.Fertilization.Croppingsystem	9	159.238	17.693	4.93	<.001
Site.Fertilization.DA_50%E	5	272.718	54.544	15.19	<.001
Site.Croppingsystem.DA_50%E	45	888.697	19.749	5.50	<.001
Fertilization.Croppingsystem.DA_50%E	45	117.923	2.621	0.73	0.903
Site.Fertilization.Croppingsystem.DA_50%E	45	220.419	4.898	1.36	0.065
Residual	424(54)	1522.373	3.591		
Total	665(54)	26352.572			

c) Spring

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	385.285	192.643	20.16	
Replication.*Units* stratum					
Site	1	1.148	1.148	0.12	0.729
Fertilization	1	920.206	920.206	96.30	<.001
Croppingsystem	9	7476.136	830.682	86.94	<.001
DA50%E	4	27143.785	6785.946	710.18	<.001
Site.Fertilization	1	230.330	230.330	24.11	<.001
Site.Croppingsystem	9	21.155	2.351	0.25	0.987
Fertilization.Croppingsystem	9	797.272	88.586	9.27	<.001
Site.DA50%E	4	4.594	1.148	0.12	0.975
Fertilization.DA50%E	4	821.090	205.272	21.48	<.001
Croppingsystem.DA50%E	36	1538.731	42.743	4.47	<.001
Site.Fertilization.Croppingsystem	9	92.423	10.269	1.07	0.380
Site.Fertilization.DA50%E	4	921.320	230.330	24.11	<.001
Site.Croppingsystem.DA50%E	36	84.619	2.351	0.25	1.000
Fertilization.Croppingsystem.DA50%E	36	601.254	16.701	1.75	0.006
Site.Fertilization.Croppingsystem.DA50%E	36	369.692	10.269	1.07	0.358
Residual	398	3802.966	9.555		
Total	599	45212.005			

d) Summer

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	316.58	158.29	5.96	
Replication.*Units* stratum					
Site	1	2177.01	2177.01	81.98	<.001
Fertilization	1	362.32	362.32	13.64	<.001
Croppingsystem	9	12080.96	1342.33	50.55	<.001
DA_50%E	4	52094.32	13023.58	490.45	<.001
Site.Fertilization	1	1490.11	1490.11	56.12	<.001
Site.Croppingsystem	9	882.78	98.09	3.69	<.001
Fertilization.Croppingsystem	9	536.06	59.56	2.24	0.019
Site.DA_50%E	4	13076.17	3269.04	123.11	<.001
Fertilization.DA_50%E	4	289.64	72.41	2.73	0.029
Croppingsystem.DA_50%E	36	4612.25	128.12	4.82	<.001
Site.Fertilization.Croppingsystem	9	1722.04	191.34	7.21	<.001
Site.Fertilization.DA_50%E	4	511.60	127.90	4.82	<.001
Site.Croppingsystem.DA_50%E	36	3596.72	99.91	3.76	<.001
Fertilization.Croppingsystem.DA_50%E	36	484.88	13.47	0.51	0.993
Site.Fertilization.Croppingsystem.DA_50%E	36	1064.22	29.56	1.11	0.305
Residual	385(13)	10223.51	26.55		
Total	586(13)	104818.94			

Appendix 2.5. Analysis of Variance for plant biomass 42 weeks after sowing at the two sites (Ukulinga and Umbumbulu). Note that the analysis shows 9 df for cropping system which takes into account the component crops in an intercropping system for purposes of data collection and analysis.

a) Autumn

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	2943.	1471.	0.31	
Replicate.*Units* stratum					
Site	1	389664.	389664.	82.90	<.001
Fertilization	1	38006.	38006.	8.09	0.006
Cropping_system	9	42167.	4685.	1.00	0.451
Site.Fertilization	1	14748.	14748.	3.14	0.081
Site.Cropping_system	9	46778.	5198.	1.11	0.370
Fertilization.Cropping_system	9	48745.	5416.	1.15	0.339
Site.Fertilization.Cropping_system	9	41372.	4597.	0.98	0.465
Residual	72(6)	338420.	4700.		
Total	113(6)	951955.			

b) Winter

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	8290.	4145.	2.25	
Replication.*Units* stratum					
Site	1	350423.	350423.	190.36	<.001
Fertilization	1	70613.	70613.	38.36	<.001
Cropping_System	9	351473.	39053.	21.21	<.001
Site.Fertilization	1	100629.	100629.	54.66	<.001
Site.Cropping_System	9	284003.	31556.	17.14	<.001
Fertilization.Cropping_System	9	83548.	9283.	5.04	<.001
Site.Fertilization.Cropping_System	9	105033.	11670.	6.34	<.001
Residual	75(3)	138066.	1841.		
Total	116(3)	1479046.			

c) Spring

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	3781.	1890.	1.00	
Replication.*Units* stratum					
Site	1	105361.	105361.	55.71	<.001
Fertilization	1	2340.	2340.	1.24	0.270
Cropping_System	9	37911.	4212.	2.23	0.030
Site.Fertilization	1	2649.	2649.	1.40	0.241
Site.Cropping_System	9	20270.	2252.	1.19	0.314
Fertilization.Cropping_System	9	12480.	1387.	0.73	0.677
Site.Fertilization.Cropping_System	9	26544.	2949.	1.56	0.144
Residual	72(6)	136177.	1891.		
Total	113(6)	337374.			

d) Summer

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2068.	1034.	0.11	
Replication.*Units* stratum					
Site	1	574731.	574731.	59.45	<.001
Fertilization	1	52187.	52187.	5.40	0.023
Cropping_system	9	398338.	44260.	4.58	<.001
Site.Fertilization	1	102634.	102634.	10.62	0.002
Site.Cropping_system	8(1)	302900.	37863.	3.92	<.001
Fertilization.Cropping_system	9	222594.	24733.	2.56	0.014
Site.Fertilization.Cropping_system	8(1)	253738.	31717.	3.28	0.003
Residual	65(13)	628384.	9667.		
Total	104(15)	2033767.			

Appendix 3.1 Analysis of Variance for selected mineral elements 42 days after sowing during autumn, winter, spring and summer at Ukulinga and Umbumbulu. Note that the analysis shows 9 df for cropping system which takes into account the component crops in an intercropping system for purposes of data collection and analysis.

(a) Autumn

(i) Calcium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	208220.	104110.	2.54	
Replicate.*Units* stratum					
Site	1	8049989.	8049989.	196.49	<.001
Fertilization	1	106753.	106753.	2.61	0.111
Croppingsystem	9	236698.	26300.	0.64	0.758
Site.Fertilization	1	210994.	210994.	5.15	0.026
Site.Croppingsystem	9	320004.	35556.	0.87	0.558
Fertilization.Croppingsystem	9	213016.	23668.	0.58	0.811
Site.Fertilization.Croppingsystem	9	271802.	30200.	0.74	0.674
Residual	73(5)	2990749.	40969.		
Total	114(5)	12207136.			

(ii) Copper

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	2.4478	1.2239	2.93	
Replicate.*Units* stratum					
Site	1	1666.5679	1666.5679	3983.90	<.001
Fertilization	1	27.9134	27.9134	66.73	<.001
Croppingsystem	9	3.3785	0.3754	0.90	0.532
Site.Fertilization	1	28.8491	28.8491	68.96	<.001
Site.Croppingsystem	9	3.4765	0.3863	0.92	0.510
Fertilization.Croppingsystem	9	1.7393	0.1933	0.46	0.895
Site.Fertilization.Croppingsystem	9	1.0694	0.1188	0.28	0.977
Residual	73(5)	30.5378	0.4183		
Total	114(5)	1675.3017			

(iii) Potassium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	35050.	17525.	6.26	
Replicate.*Units* stratum					
Site	1	1168609.	1168609.	417.18	<.001
Fertilization	1	32373.	32373.	11.56	0.001
Croppingsystem	9	45110.	5012.	1.79	0.085
Site.Fertilization	1	10342.	10342.	3.69	0.059
Site.Croppingsystem	9	56229.	6248.	2.23	0.029
Fertilization.Croppingsystem	9	20884.	2320.	0.83	0.592
Site.Fertilization.Croppingsystem	9	33103.	3678.	1.31	0.245
Residual	73(5)	204490.	2801.		
Total	114(5)	1545981.			

(iv) Magnesium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	7156.6	3578.3	5.45	
Replicate.*Units* stratum					
Site	1	3996573.0	3996573.0	6086.38	<.001
Fertilization	1	7022.2	7022.2	10.69	0.002
Croppingsystem	9	3916.7	435.2	0.66	0.740
Site.Fertilization	1	19095.1	19095.1	29.08	<.001
Site.Croppingsystem	9	2945.2	327.2	0.50	0.871
Fertilization.Croppingsystem	9	6345.4	705.0	1.07	0.392
Site.Fertilization.Croppingsystem	9	11096.4	1232.9	1.88	0.069
Residual	73(5)	47934.8	656.6		
Total	114(5)	3943047.8			

(iv) Manganese

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	93.686	46.843	6.13	
Replicate.*Units* stratum					
Site	1	1631.721	1631.721	213.58	<.001
Fertilization	1	146.203	146.203	19.14	<.001
Croppingsystem	9	126.566	14.063	1.84	0.075
Site.Fertilization	1	6.523	6.523	0.85	0.359
Site.Croppingsystem	9	55.520	6.169	0.81	0.611
Fertilization.Croppingsystem	9	149.781	16.642	2.18	0.033
Site.Fertilization.Croppingsystem	9	65.792	7.310	0.96	0.482
Residual	73(5)	557.704	7.640		
Total	114(5)	2695.948			

(vi) Phosphorus

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	165.35	82.68	2.08	
Replicate.*Units* stratum					
Site	1	10286.02	10286.02	258.79	<.001
Fertilization	1	619.93	619.93	15.60	<.001
Croppingsystem	9	175.36	19.48	0.49	0.877
Site.Fertilization	1	884.95	884.95	22.26	<.001
Site.Croppingsystem	9	234.89	26.10	0.66	0.745
Fertilization.Croppingsystem	9	258.37	28.71	0.72	0.687
Site.Fertilization.Croppingsystem	9	217.71	24.19	0.61	0.786
Residual	73(5)	2901.51	39.75		
Total	114(5)	15059.95			

(vii) Zinc

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	3.1104	1.5552	3.52	
Replicate.*Units* stratum					
Site	1	556.8528	556.8528	1261.95	<.001
Fertilization	1	13.4538	13.4538	30.49	<.001
Croppingsystem	9	1.5860	0.1762	0.40	0.932
Site.Fertilization	1	15.1160	15.1160	34.26	<.001
Site.Croppingsystem	9	5.0186	0.5576	1.26	0.271
Fertilization.Croppingsystem	9	2.0017	0.2224	0.50	0.867
Site.Fertilization.Croppingsystem	9	5.2662	0.5851	1.33	0.239
Residual	73(5)	32.2123	0.4413		
Total	114(5)	611.2457			

(b) Winter

(i) Calcium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	117381.	58690.	0.98	
Replication.*Units* stratum					
Site	1	8175803.	8175803.	136.17	<.001
Fertilization	1	1396539.	1396539.	23.26	<.001
Cropping_system	9	395935.	43993.	0.73	0.678
Site.Fertilization	1	4465698.	4465698.	74.38	<.001
Site.Cropping_system	9	525398.	58378.	0.97	0.470
Fertilization.Cropping_system	9	827358.	91929.	1.53	0.153
Site.Fertilization.Cropping_system	9	436487.	48499.	0.81	0.610
Residual	75(3)	4503070.	60041.		
Total	116(3)	20593679.			

(ii) Copper

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.8218	1.4109	1.61	
Replication.*Units* stratum					
Site	1	1985.6928	1985.6928	2269.42	<.001
Fertilization	1	1.8895	1.8895	2.16	0.146
Cropping_system	9	15.9088	1.7676	2.02	0.048
Site.Fertilization	1	1.9377	1.9377	2.21	0.141
Site.Cropping_system	9	12.3399	1.3711	1.57	0.141
Fertilization.Cropping_system	9	10.3940	1.1549	1.32	0.241
Site.Fertilization.Cropping_system	9	3.0934	0.3437	0.39	0.935
Residual	75(3)	65.6233	0.8750		
Total	116(3)	2055.0966			

(iii) Potassium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	754.	377.	0.18	
Replication.*Units* stratum					
Site	1	26783.	26783.	12.80	<.001
Fertilization	1	123793.	123793.	59.16	<.001
Cropping_system	9	31991.	3555.	1.70	0.104
Site.Fertilization	1	34622.	34622.	16.55	<.001
Site.Cropping_system	9	25990.	2888.	1.38	0.212
Fertilization.Cropping_system	9	23297.	2589.	1.24	0.286
Site.Fertilization.Cropping_system	9	17916.	1991.	0.95	0.487
Residual	75(3)	156935.	2092.		
Total	116(3)	424929.			

(iv) Magnesium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1266.7	633.3	1.28	
Replication.*Units* stratum					
Site	1	3986093.8	3986093.8	8043.96	<.001
Fertilization	1	5237.4	5237.4	10.57	0.002
Cropping_system	9	6228.2	692.0	1.40	0.205
Site.Fertilization	1	2.3	2.3	0.00	0.946
Site.Cropping_system	9	7069.7	785.5	1.59	0.135
Fertilization.Cropping_system	9	2953.8	328.2	0.66	0.740
Site.Fertilization.Cropping_system	9	2752.3	305.8	0.62	0.779
Residual	75(3)	37165.4	495.5		
Total	116(3)	3942256.9			

(v) Manganese

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	15.020	7.510	1.09	
Replication.*Units* stratum					
Site	1	1942.998	1942.998	282.18	<.001
Fertilization	1	7.567	7.567	1.10	0.298
Cropping_system	9	135.620	15.069	2.19	0.032
Site.Fertilization	1	104.399	104.399	15.16	<.001
Site.Cropping_system	9	92.456	10.273	1.49	0.167
Fertilization.Cropping_system	9	118.296	13.144	1.91	0.063
Site.Fertilization.Cropping_system	9	65.865	7.318	1.06	0.400
Residual	75(3)	516.416	6.886		
Total	116(3)	2921.077			

(vi) Phosphorus

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	427.05	213.52	2.16	
Replication.*Units* stratum					
Site	1	17476.84	17476.84	176.65	<.001
Fertilization	1	15682.51	15682.51	158.51	<.001
Cropping_system	9	1226.03	136.23	1.38	0.214
Site.Fertilization	1	4877.55	4877.55	49.30	<.001
Site.Cropping_system	9	1164.66	129.41	1.31	0.247
Fertilization.Cropping_system	9	1113.53	123.73	1.25	0.278
Site.Fertilization.Cropping_system	9	1213.64	134.85	1.36	0.220
Residual	75(3)	7420.28	98.94		
Total	116(3)	46425.69			

(vii) Zinc_

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	37.068	18.534	2.27	
Replication.*Units* stratum					
Site	1	181.786	181.786	22.28	<.001
Fertilization	1	419.642	419.642	51.44	<.001
Cropping_system	9	46.832	5.204	0.64	0.761
Site.Fertilization	1	0.626	0.626	0.08	0.783
Site.Cropping_system	9	57.928	6.436	0.79	0.627
Fertilization.Cropping_system	9	29.895	3.322	0.41	0.928
Site.Fertilization.Cropping_system	9	19.364	2.152	0.26	0.982
Residual	75(3)	611.859	8.158		
Total	116(3)	1345.499			

(c). Spring

(i) Calcium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	87315.	43657.	0.42	
Replication.*Units* stratum					
Site	1	20541429.	20541429.	196.69	<.001
Fertilization	1	278257.	278257.	2.66	0.107
Croppingsystem	9	532048.	59116.	0.57	0.821
Site.Fertilization	1	4078751.	4078751.	39.05	<.001
Site.Croppingsystem	9	730326.	81147.	0.78	0.638
Fertilization.Croppingsystem	9	383649.	42628.	0.41	0.927
Site.Fertilization.Croppingsystem	9	461733.	51304.	0.49	0.876
Residual	74(4)	7728303.	104437.		
Total	115(4)	34134453.			

(ii) Copper

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.9847	0.9924	2.34	
Replication.*Units* stratum					
Site	1	1051.6369	1051.6369	2481.52	<.001
Fertilization	1	20.7014	20.7014	48.85	<.001
Croppingsystem	9	3.2948	0.3661	0.86	0.561
Site.Fertilization	1	10.1842	10.1842	24.03	<.001
Site.Croppingsystem	9	2.9274	0.3253	0.77	0.646
Fertilization.Croppingsystem	9	4.0257	0.4473	1.06	0.406
Site.Fertilization.Croppingsystem	9	4.6306	0.5145	1.21	0.300
Residual	74(4)	31.3603	0.4238		
Total	115(4)	1092.7796			

(iii) Potassium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	11215.1	5607.5	5.93	
Replication.*Units* stratum					
Site	1	99434.3	99434.3	105.08	<.001
Fertilization	1	4056.7	4056.7	4.29	0.042
Croppingsystem	9	53004.4	5889.4	6.22	<.001
Site.Fertilization	1	59331.4	59331.4	62.70	<.001
Site.Croppingsystem	9	12090.4	1343.4	1.42	0.195
Fertilization.Croppingsystem	9	12604.2	1400.5	1.48	0.171
Site.Fertilization.Croppingsystem	9	28013.1	3112.6	3.29	0.002
Residual	74(4)	70025.9	946.3		
Total	115(4)	339071.6			

(iv) Magnesium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4254.	2127.	1.30	
Replication.*Units* stratum					
Site	1	5428448.	5428448.	3319.17	<.001
Fertilization	1	9034.	9034.	5.52	0.021
Croppingsystem	9	12685.	1409.	0.86	0.563
Site.Fertilization	1	491.	491.	0.30	0.585
Site.Croppingsystem	9	12957.	1440.	0.88	0.547
Fertilization.Croppingsystem	9	2576.	286.	0.18	0.996
Site.Fertilization.Croppingsystem	9	5561.	618.	0.38	0.942
Residual	74(4)	121026.	1635.		
Total	115(4)	5424475.			

(v) Manganese

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	7.284	3.642	1.54	
Replication.*Units* stratum					
Site	1	339.393	339.393	143.57	<.001
Fertilization	1	0.027	0.027	0.01	0.915
Croppingsystem	9	16.537	1.837	0.78	0.638
Site.Fertilization	1	162.890	162.890	68.91	<.001
Site.Croppingsystem	9	16.677	1.853	0.78	0.632
Fertilization.Croppingsystem	9	8.742	0.971	0.41	0.925
Site.Fertilization.Croppingsystem	9	12.593	1.399	0.59	0.800
Residual	74(4)	174.930	2.364		
Total	115(4)	694.138			

(vi) Phosphorus

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	517.67	258.83	6.91	
Replication.*Units* stratum					
Site	1	4199.73	4199.73	112.05	<.001
Fertilization	1	1152.62	1152.62	30.75	<.001
Croppingsystem	9	193.22	21.47	0.57	0.815
Site.Fertilization	1	48.02	48.02	1.28	0.261
Site.Croppingsystem	9	128.78	14.31	0.38	0.940
Fertilization.Croppingsystem	9	145.71	16.19	0.43	0.914
Site.Fertilization.Croppingsystem	9	258.25	28.69	0.77	0.648
Residual	74(4)	2773.60	37.48		
Total	115(4)	8964.72			

(vii) Zinc

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4.474	2.237	1.33	
Replication.*Units* stratum					
Site	1	164.700	164.700	97.98	<.001
Fertilization	1	14.411	14.411	8.57	0.005
Croppingsystem	9	15.650	1.739	1.03	0.421
Site.Fertilization	1	32.849	32.849	19.54	<.001
Site.Croppingsystem	9	17.603	1.956	1.16	0.331
Fertilization.Croppingsystem	9	15.805	1.756	1.04	0.414
Site.Fertilization.Croppingsystem	9	9.078	1.009	0.60	0.793
Residual	74(4)	124.388	1.681		
Total	115(4)	382.134			

(d) Summer

(i) Calcium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	484623.	242311.	6.32	
Replication.*Units* stratum					
Site	1	3462670.	3462670.	90.30	<.001
Fertilization	1	712.	712.	0.02	0.892
Cropping_system	9	159481.	17720.	0.46	0.895
Site.Fertilization	1	130925.	130925.	3.41	0.069
Site.Cropping_system	9	35938.	3993.	0.10	0.999
Fertilization.Cropping_system	9	287966.	31996.	0.83	0.587
Site.Fertilization.Cropping_system	9	173448.	19272.	0.50	0.868
Residual	70(8)	2684228.	38346.		
Total	111(8)	6919223.			

(ii) Copper

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	11.788	5.894	5.83	
Replication.*Units* stratum					
Site	1	2441.358	2441.358	2416.13	<.001
Fertilization	1	24.565	24.565	24.31	<.001
Cropping_system	9	9.154	1.017	1.01	0.443
Site.Fertilization	1	34.233	34.233	33.88	<.001
Site.Cropping_system	9	8.513	0.946	0.94	0.500
Fertilization.Cropping_system	9	5.874	0.653	0.65	0.754
Site.Fertilization.Cropping_system	9	4.529	0.503	0.50	0.871
Residual	70(8)	70.731	1.010		
Total	111(8)	2399.568			

(iii) Potassium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	7615.	3808.	2.02	
Replication.*Units* stratum					
Site	1	474888.	474888.	252.21	<.001
Fertilization	1	55211.	55211.	29.32	<.001
Cropping_system	9	25424.	2825.	1.50	0.165
Site.Fertilization	1	8183.	8183.	4.35	0.041
Site.Cropping_system	9	13769.	1530.	0.81	0.606
Fertilization.Cropping_system	9	9998.	1111.	0.59	0.801
Site.Fertilization.Cropping_system	9	18431.	2048.	1.09	0.383
Residual	70(8)	131802.	1883.		
Total	111(8)	698302.			

(iv) Magnesium_

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	997.6	498.8	1.72	
Replication.*Units* stratum					
Site	1	2246748.1	2246748.1	7769.14	<.001
Fertilization	1	4416.8	4416.8	15.27	<.001
Cropping_system	9	2732.3	303.6	1.05	0.410
Site.Fertilization	1	15939.6	15939.6	55.12	<.001
Site.Cropping_system	9	3314.9	368.3	1.27	0.267
Fertilization.Cropping_system	9	2427.4	269.7	0.93	0.503
Site.Fertilization.Cropping_system	9	1289.2	143.2	0.50	0.873
Residual	70(8)	20243.2	289.2		
Total	111(8)	2156461.7			

(v) Manganese

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	19.865	9.932	2.41	
Replication.*Units* stratum					
Site	1	702.822	702.822	170.28	<.001
Fertilization	1	6.697	6.697	1.62	0.207
Cropping_system	9	104.161	11.573	2.80	0.007
Site.Fertilization	1	89.007	89.007	21.57	<.001
Site.Cropping_system	9	35.892	3.988	0.97	0.475
Fertilization.Cropping_system	9	24.190	2.688	0.65	0.749
Site.Fertilization.Cropping_system	9	32.865	3.652	0.88	0.543
Residual	70(8)	288.915	4.127		
Total	111(8)	1266.429			

(vi) Phosphorus

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	301.12	150.56	6.05	
Replication.*Units* stratum					
Site	1	7132.16	7132.16	286.75	<.001
Fertilization	1	832.30	832.30	33.46	<.001
Cropping_system	9	465.12	51.68	2.08	0.043
Site.Fertilization	1	192.45	192.45	7.74	0.007
Site.Cropping_system	9	259.27	28.81	1.16	0.335
Fertilization.Cropping_system	9	185.70	20.63	0.83	0.591
Site.Fertilization.Cropping_system	9	144.88	16.10	0.65	0.753
Residual	70(8)	1741.04	24.87		
Total	111(8)	10280.78			

(vii) Zinc

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.590	0.795	0.69	
Replication.*Units* stratum					
Site	1	743.076	743.076	645.68	<.001
Fertilization	1	0.033	0.033	0.03	0.866
Cropping_system	9	12.561	1.396	1.21	0.301
Site.Fertilization	1	14.706	14.706	12.78	<.001
Site.Cropping_system	9	10.621	1.180	1.03	0.429
Fertilization.Cropping_system	9	8.854	0.984	0.85	0.569
Site.Fertilization.Cropping_system	9	9.671	1.075	0.93	0.502
Residual	70(8)	80.559	1.151		
Total	111(8)	821.343			

Appendix 4.1 Analysis of variance for 100 pod seed weight, 1000 seed weight and germination percentage for Umbumbulu and Ukulinga during the three season.

a) 1000 seed weight

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.03959	0.01979	0.22	
Replicate.*Units* stratum					
site	1	0.01861	0.01861	0.20	0.657
species	2	0.22928	0.11464	1.25	0.306
site.species	2	0.07245	0.03622	0.40	0.678
Residual	21(7)	1.92050	0.09145		
Total	28(7)	2.17448			

b) 100 pod seed weight

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.141	0.070	0.04	
Replicate.*Units* stratum					
site	1	12.768	12.768	6.62	0.018
species	2	39.539	19.769	10.25	<.001
site.species	2	3.871	1.936	1.00	0.384
Residual	21(7)	40.505	1.929		
Total	28(7)	87.504			

c) Germination percentage

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicates stratum					
Species	2	16003.4	8001.7		
Replicates.*Units* stratum					
Location	1	2058.6	2058.6	5.20	0.027
Season	2	4273.3	2136.7	5.40	0.008
Location.Season	2	4296.6	2148.3	5.43	0.008
Location.Species	2	3730.5	1865.3	4.71	0.014
Season.Species	4	7755.6	1938.9	4.90	0.002
Location.Season.Species	2(2)	20.5	10.3	0.03	0.974
Residual	45(45)	17806.6	395.7		
Total	60(47)	28326.4			