CHAPTER 1

1.0 INTRODUCTION

In Zimbabwe, the intake of vegetables is very low, about 30 g per capita day^{-1} compared to Kenya, Malawi, South Africa, Tanzania and Zambia which consume on average 61, 57, 107, 92 and 71 g per capita day^{-1} respectively (Food and Agriculture Organization (FAO), 1996). Low per capita consumption prevalent in Zimbabwe could be as a result of low production levels. For example, in 1999, it was estimated that 145 000 tonnes (t) of vegetables were produced for commercial and non-commercial purposes compared to 1 035 000 t in Tanzania, 253 000 t in Zambia, 2 132 000 t in South Africa and 180 000 t in Mozambique (De Lannoy, 2001).

Vegetables play an important role in human nutrition, providing vitamins, micronutrients, proteins, fibre and sugars. Their role in nutrition is especially critical in rural communities of Zimbabwe, where access to alternative sources of these nutritional elements is limited. Low vegetable production, partially caused by the seasonal availability of vegetables, explains to some extent the high levels of malnutrition in Zimbabwe. Most vegetables consumed in Zimbabwe are exotic vegetables, such as cabbage, Swiss Chard, English Rape and tomatoes (Turner and Chivinge, 1999).

Exotic vegetables are commonly produced in winter (April to August) (Chigumira-Ngwerume, 2000), but their supply usually decreases just before the onset of the rainy season due to the scarcity of irrigation water and high temperatures (van der Mheen-Sluijer and Chihande, 1997). In winter the vegetables are often grown in riverine sites for easy access to water. However, these sites are usually flooded and waterlogged in summer (December to March), making it impossible to grow such vegetables during this period. Upland sites thus become more favourable sites for producing vegetables in summer since they experience better drainage.

The summer season in Zimbabwe is characterized by the production of rainfed field crops such as maize, the main staple food crop, and groundnut, important to smallholder farmers for its oil and flavour (Natarajan and Zharare, 1994). Most farmers have very little extra labour to deal with both staple food production and vegetable production in separate fields, making the intercropping of vegetables with the main field crops essential. However, pest and disease problems, which most exotic vegetables succumb to, are more extensive in summer. Therefore, summer conditions generally restrict vegetable production to traditional vegetables, which grow well during this period.

Traditional vegetables include all plants whose fruits, leaves, pods or roots are used as relish by the rural or urban consumers through custom, habit or tradition (Mnzava, 1989). They are mostly local or native varieties that are usually not commercialized (Martin and Ruberte, 1979). In Zimbabwe, traditional vegetable production is restricted to smallholder farming with limited commercial exploitation. However, in some localised instances, traditional vegetables provide some cash in both rural and urban markets (Kundhlande, Govereh and Muchena, 1994). For instance, in a survey in Mashonaland East Province, only 5% of the farmers marketed mustard rape and pumpkin in the local markets (Turner and Chivinge, 1999). Some traditional vegetables are semi-wild while others are partially cultivated, for instance African nightshades, amaranth and jute mallow are all partially cultivated (Schippers, 2002).

Traditional vegetables supply edible organs in the early season (before main harvest period) when other crops and vegetables are out of season and hence these vegetables become a bridging source of food security. Some of the important cultivated traditional leaf vegetables produced in Zimbabwe include pumpkin (*Cucurbita* spp), mustard rape (*Brassica juncea*), Ethiopian mustard (*Brassica carinata*) and cowpea (*Vigna unguiculata*) (van der Mheen-Sluijer, 1997). The most common of these are pumpkin and mustard rape.

Pumpkin leaves are consumed in all areas of Zimbabwe, locally referred to as “muboora”, “mutikiti”, “muriwo wemhodzi” (Shona) and “ibhobola” and “injolo” (Ndebele) (van der Mheen-Sluijer and Chihande, 1997). Though they may be consumed throughout the year in either fresh or dry state, the frequency of consumption is highest in summer. For instance, the average number of times pumpkin leaves are consumed in a week during the rainy season was recorded as 3.9 in the Uzumba Maramba Pfungwe (UMP) area of Mashonaland East Province in Zimbabwe (van der Mheen Sluijer and Chihande, 1997). Also, pumpkin leaves were found to be the third most important vegetable (of all vegetables consumed), after English Rape and tomato, in Mashonaland West Province and were equally important in Mashonaland East Province of Zimbabwe (Jackson, 1997). Pumpkin grows well in summer, but cannot withstand frost which may occur locally in winter.

Likewise, mustard rape is also consumed in all areas of Zimbabwe and is referred to as "tsunga" (Shona) and "umbida" (Ndebele). In a study, van der Mheen Sluijer and Chihande (1997) found that the average frequency of consumption of mustard rape leaves was 1.8 times per week in the Uzumba Maramba Pfungwe (UMP) area of Mashonaland East Province in Zimbabwe. Mustard rape is mainly grown in winter, even though in summer production is common. Locally, young tender leaves of mustard rape are used as an accompaniment or relish to the main staple. Elsewhere, older leaves and stems may be eaten fresh, canned or frozen for potherbs, and to a limited extent, in salads or mixed with other salad greens (Duke, 1983).

While statistics show the popularity of traditional vegetables, not much research has been done on improved production practices for these vegetables. However, intercropping has been of very limited use in local vegetable production out of concern that the vegetables would be out-competed in the intercrops due to their small height (Mwaja and Masiunas, 1997), and also due to their demand for more water than most field crops.

The local intercropping practices involving traditional vegetables, however, lack scientific backing on optimum populations, planting dates and their effects in relation to the main crop. For instance, Silwana and Lucas (2002) established that 86 % of the farmers who practice intercropping in the Transkei area of South Africa lacked knowledge on crop combination and spatial arrangements that would give them the maximum yields. Apart from crop combinations and populations, relative planting dates are equally important on the performance of the intercrop components. Normally, effects of plant populations and planting dates on the yield performance of intercrop components are quite variable and very specific to crop combinations.

The production of traditional vegetables in maize, sorghum and groundnut mixtures provides a cheaper production system in which the vegetables are raised with little additional purchased inputs. Though traditional vegetable yields benefit from the nutrition meant for the main crop in maize intercrops, mustard rape taste is claimed to be bitter in response to nitrogen fertilization. The bitterness is possibly a result of accumulation of nitrates. Research elsewhere has shown diurnal fluctuations in nitrate levels in plants (Matt, Geiger, Walch-Lui, Engels, Krapp and Stitt, 2001). It has not been established whether timing of leaf harvests during the day can contribute to alleviation of the bitter taste associated with nitrogen fertilization of mustard rape.

Apart from timing during the day, the optimum frequency and intensities of harvests have also not been established in traditional vegetables. For instance, information on farmers' leaf harvesting practices is scarce and inconsistent. Ndoro (2004), on one hand, recorded that leaf harvesting practices in traditional vegetables depend on the abundance of the vegetables in the farmers' fields. On the other hand, van der Mheen-Sluijer and Chihande (1997) recorded that both pumpkin and mustard rape are harvested at least once a week during the prime time of their production. It is not clear whether the leaf harvests implemented by farmers have effects on leaf yields.

Therefore, there is need for improvement of productivity of traditional vegetables through optimal intercropping populations and spatial arrangements, and leaf harvest practices in intercropping systems. There is also need to study the impact of vegetable intercrops on the yield and productivity of maize and groundnut, the main crops that traditional vegetables are commonly grown with. Moreover, the impact of vegetable intercrops on weed pressure should be studied as this has implications on labour demand and ultimate production costs to the farmer. The study reported here attempts to answer some of the questions concerning field crop-vegetable intercrops; related to populations, leaf harvest intervals and intensities, timing of planting and timing of leaf harvests during the day. The specific objectives of the study are listed below:

1.1 Objectives

1. To establish ideal intercrop populations for pumpkin and mustard rape in groundnut and maize-based intercropping systems to achieve optimum vegetable yields and suppress weed growth with minimal yield reductions in the main crops.

2. To determine whether groundnut is a more ideal companion crop than maize for pumpkin and mustard rape intercropping, based on leaf yields and / or fruit yields of the component crops.

3. To determine the effects of leaf harvest intervals and leaf harvest intensities on mustard rape and pumpkin in sole and intercrop situations.

4. To investigate the effects of nitrogen fertilizer rates used in maize – mustard rape intercrops on growth, leaf yield and taste of mustard rape.

1.2 Hypotheses

1. Increasing pumpkin and mustard rape population increases leaf and / or fruit yields and weed suppression effects to an optimum without reducing grain and seed yield of main component crops in maize and groundnut-based intercropping systems.

2. Being of shorter stature hence offering less competition, groundnut is more ideal for intercropping with pumpkin and mustard rape than maize.

3. More intense and frequent harvests increase leaf yields in both pumpkin and mustard rape in sole and intercrop situations.

4. Increases in nitrogen fertilization increase leaf yields but reduce the taste quality of mustard rape.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Importance of Leafy Traditional Vegetables

Traditional vegetables tend to be adapted to the local environment, tolerant to diseases, insect pests and drought and require less in terms of inputs (Attere, 1990). They are consumed by people from all classes of life irrespective of affluence or education level (Chigumira - Ngwerume, 2000). In most parts of Africa, family meals consist of one main dish, the staple, eaten with an accompaniment known as relish or sauce depending on the part of the continent. Green leafy traditional vegetables like pumpkin or cassava leaves are often used as relish (FAO, 2001). Pounded groundnuts and tomatoes are usually added. The addition of groundnut sauce gives the right mixture for maintaining good health (FAO, 2001).

Traditional vegetables are a reliable source of nutrients and vitamins, especially for rural people where access to other alternatives for nutritional requirements is limited. A survey in five rural districts of Zimbabwe, UMP, Murehwa, Tsholotsho, Chiredzi and Nyanga, highlighted the importance of traditional vegetables in supplying relish in the summer season (van der Mheen Sluijer and Chihande, 1997). The most popular vegetables identified were pumpkin and mustard rape, as reflected by their relatively high frequencies of consumption. In addition to being a traditional vegetable, mustard rape is also indigenous to Africa. However, pumpkin, of Central American origin, has become a traditional vegetable in Africa through widespread cultivation and habitual consumption.

Cucurbits, the family to which pumpkin belongs, are widely grown in Southern Africa (Chigwe and Saka, 1994). The cultivated cucurbits include five main species, which are: *Cucurbita moschata* (pumpkins), *C. maxima* (pumpkins), *C. mixta* (squashes), C. *pepo* (marrows) and *C. ficifolia* (gourds) (Chigwe and Saka, 1994). Pumpkin is the most widely grown among all cucurbits. It has the advantage of supplying edible organs early in the season (young leaves and male flowers) and during the later part of the rainy season (fruits). In Zimbabwe, immature pumpkin fruits are used as fresh vegetables, boiled together with the leaves as relish, or are dried, whilst mature fruits are eaten fresh mostly boiled. Elsewhere, immature fruits can be steamed and mature fruits can be used for baking pies and making jam. Mature fruits are also dried for use as a relish or snack later in the year. The fruits are a food source towards the end of the rainy season. For instance, pumpkin fruits may be served frequently, up to 40 % of the daily meals, during the hungry period (pre-harvest season) in Zambia (FAO, 1988).

All cucurbit fruits have traces of vitamins B and C, while the yellow fleshed are also moderately rich in vitamin A. They also contain small quantities of protein (0.5-1.5%) and *C. maxima* is richer than the others, although they are deficient in lysine and sulphur- containing amino acids (Chigwe and Saka, 1994). Furthermore, pumpkins also supply oil (which is rich in unsaturated oleic and linoleic acid), with high amounts of arginine, aspartate and glutamic acid. Pumpkin seed kernels, which can be roasted and consumed, are also nutritious as they contain 25-30% protein, 40-50% oil, carbohydrates, calcium and iron (FAO, 1988). Pumpkin leaves are rich in vitamin A, are a good source of calcium and phosphorus, and contain more protein (2-6%) than fruits (FAO, 1988).

Whilst cucurbit leaves and fruits are both ranked as the most important edible organs, however, the leaves are more popular than fruits as they are available throughout the pumpkin growing season, compared to late availability of fruits. In warmer areas of Zimbabwe, fresh pumpkin leaves are available almost all year round except the dry months of September, October and November (van der Mheen Sluijer and Chihande (1997). In these dry months, the preserved dried leaves are utilized. Usually the young leaves are targeted for harvesting because of their tenderness. However, older leaves may also be harvested, but soda or local potash is added when cooking to soften them (FAO, 1988).

Mustard rape, like pumpkin, is also locally grown for its leaves which are served as relish to the main staple. It can tolerate frost, high temperature and pest problems in summer, hence can be grown throughout the year in Zimbabwe (Schippers, 2002). This implies that mustard rape leaves may be consumed all year round, making it a very important vegetable in the diets of most rural communities.

Mustard rape is equally rich in nutrients, for instance, a cupful (140 g) of mustard rape leaves provides an adult with about 60 % of recommended daily vitamin A requirements, all the vitamin C requirements and about one fifth of the iron requirements (Duke, 1983). Per 100g fresh weight, mustard rape leaf contains about 24 calories, 91.8 g water, 2.4 g protein, 0.4g fat, 4.3 g total carbohydrates, 1.0 g fibre, 160 mg Ca, 48 mg P, 2.7 mg Fe, 24 mg Na, 297 mg K, 1825 μg Beta-carotene equivalent, 0.06 mg thiamine, 0.14 riboflavin, 0.8 mg niacin and 73 mg ascorbic acid (Duke, 1983).

Pumpkin and mustard rape have non-food uses as well. As a hyper accumulator of heavy metals, mustard rape has been used in the phytoextraction of heavy metals such as lead (USDA, 2000) and EDTA (Watanabe, 1997) from the soil. Also, its condiments are known to help digestion and oil extracted from its seed is used in fragrances and as a skin ointment (Duke, 1983). Similarly, pumpkin is also believed to cure ulcers and other digestive disorders.

2.2 Production Systems Involving Pumpkin and Mustard Rape, and Factors Limiting Research

Production of African traditional leafy vegetables is mainly on a subsistence basis. Often, they are intercropped with crops such as bananas, maize, cassava and sorghum, and are usually found around the homestead where they benefit from household refuse and water (Nekesa and Meso, 1997; FAO, 1988). In Southern Africa, pumpkins are routinely intercropped with staple cereal crops including maize, sorghum and millets. Occasionally, they are grown with other field crops such as groundnut and cotton, particularly in the best lands around ant-heaps or homesteads. Pumpkin ranks amongst the most important component crops for maize-based systems in Africa (De Lannoy, 2001). For instance, a study found that in the Mashonaland East Province of Zimbabwe, pumpkin is mainly intercropped with maize (Turner and Chivinge, 1999). Pumpkin is mainly available during summer because it cannot withstand frost found in some high altitude areas of Zimbabwe.

Unlike pumpkin, mustard rape is grown both in summer (in upland sites) and winter (in riverine sites where there is easy access to water). Its fresh leaves are therefore, available all year round. Mustard rape is planted in patches of fields close to homesteads, usually on ant-heaps, or is intercropped with the main field crops such as maize or groundnuts, in summer. In Chinyika Resettlement Area, in Manicaland province of Zimbabwe, farmers broadcast mustard rape in maize fields after the first weeding (at the two-three leaf stage) (Nyagweta, 2000). However, similar to other parts of the continent, following the initial establishment in a field, farmers also nurture volunteer mustard rape plants in the subsequent seasons (Chweya, 1997). The practice of intercropping mustard rape in Zimbabwe was commonplace when summers were very wet, but it has generally waned due to recurrent droughts (Schippers 2002).

Whilst pumpkin and mustard rape have been included in various traditional farming systems, their utilization is still faced with major challenges. To begin with, generally there is preference for other vegetables over the traditional vegetables. For instance in Zimbabwe, due to urbanization, pumpkin and mustard rape have been viewed as poor and inferior, as affluent people prefer other leafy vegetables such as spinach, cabbage and English Rape, which however, tend to be seasonal. Urbanization has also resulted in dietary changes. For instance, the utilization of pumpkin seed kernels is barely known to urban-dwellers (Hart and Vorster, 2006).

Utilization of traditional vegetables also tends to be community specific. It is thus unworthy to embark on a national campaign for their utilization. For instance, Ndoro (2004) recorded great variability in utilization of pumpkin and mustard rape at provincial level in Zimbabwe. These vegetables have resultantly received less research attention and some scientists list most traditional vegetables as unworthy of research (Chweya, 1997). The low levels of utilization stem from a dearth of knowledge on the networks of seed supply and exchanges, nutritive value, utilization and preservation as well as methods of production.

2.3 Performance of Pumpkin and Mustard Rape Under Intercropping Systems

Sardana, Sidhu and Sardana (1997) highlighted that higher yields of mustard rape could be achieved without significant reductions in yield of intercrops, thus leading to higher income from intercropping systems. For instance, mustard rape-based intercropping systems were more productive than sole cropping of Indian mustard.

The highest water use efficiency, land equivalent ratio and monetary returns were obtained in intercropping mustard rape with linseed, whilst the least were in intercropping with barley (Narayan, Prakash, Bushan and Prakash, 1999). Mustard rape has been successfully intercropped with other crops, such as sugar cane, barley, wheat and cassava (Rathore, 2001). Other observations were that the number of branches per plant and the number of seeds per plant were also higher in mustard rape intercropped with lentils compared to pure stands. In the lentil intercrops, mustard rape seed yield was 46 and 23.2 % higher than the sole mustard rape and chickpea crops, respectively (Mandal, Barik, Jana, Saha and Saha, 1997). This shows that performance of a crop in an intercrop is also based on the companion crop.

However, not all mustard rape intercropping systems are successful. For instance, in an intercropping system with wheat, yields of both crops were reduced (Lal, Verma and Ahuja*,* 1998) as were net returns (Dwivedi, Saha, Thakur, Singh, Pandey and Dubey, 1998). The mustard rape intercrops in Asia focused on seed production, which is less important in Zimbabwe. However, it is not clear whether the high seed yields in these intercrops can be translated into high leaf yields in similar intercrops.

Similar to mustard rape, pumpkin has also recorded successes in intercropping. Pumpkin has been shown to be relatively stable in various intercrops, especially when there is sufficient light penetration; hence its inclusion in various intercrops (Joubert, 2000). For instance, Olasantan (2007) reported that pumpkin growth and fruit yields were not affected by intercropping with yams. Similarly, vine length and fruit yield in fluted pumpkin were not affected by intercropping with bananas (Aiyelaagbe and Kintomo, 2002). However, contrary results were also recorded. For instance, Mashingaidze, Nyakanda, Chivinge, Mwashaireni and Dube (2000) recorded reduced vine length in maize-pumpkin intercrops.

It is worthy noting that in the above studies, pumpkin was not subjected to leaf picking for vegetable, therefore it still remains unclear how pumpkin will perform when subjected to leaf harvesting in intercrop situations.

2.4 Established Agronomic Practices for Pumpkin and Mustard Rape

Pumpkin is a warm season crop requiring 85-120 days from planting to maturity (Yamaguchi, 1983). It is adapted to monthly mean temperatures of 18-21^{o}C and is not tolerant of near freezing temperatures. Therefore, pumpkin can not be grown in winter in Zimbabwe except in areas that experience warm winters such as the lowveld (below 600 meters above sea level).

The plants should be grown in fertile well-drained soils, with pH of 6.5-7.5 ($CaCl_2$). A balanced fertilizer of about 110 kg N ha $^{-1}$, 40 kg P_2O_5 ha^{-1} and 90 kg K_2O ha^{-1} is required in pure stands (De Lannoy, 2001). Pumpkin plant stations are spaced about 2-3 m apart between and within rows, with two plants per station in sole cropping. Drought from the period of bushy growth to male flowering was established as the most limiting factor for fruit yield, which was also considerably reduced by a combination of water deficit and high temperature (Rios, Fernandez and Casanova 1998).

Mustard rape can tolerate annual precipitation of 500-4 200 mm rainfall, annual temperatures of 6 to 27 ^{0}C and a pH of 4.3 to 8.3 ($CaCl_2$) (Rice, Rice and Tindall, 1983). Its growing period is from 40-60 days, depending on variety and weather conditions. High temperatures often result in early flowering, thereby shortening its growing period.

Mustard rape can be raised from seedlings or can be direct seeded. Plant rows should be 40-45 cm apart between rows and 30-40 cm apart within the row (Tindall, 1983). For optimum mustard rape growth fertilizer should be applied at 112-135 kg N ha $^{-1}$, 50 kg P_2O_5 ha^{-1} and 90 kg K_2O ha^{-1} (Duke, 1983). Mustard rape responds better to organic manure compared to inorganic fertilizers and therefore, 50 t ha^{-1} of organic manure should be applied before planting (Schippers, 2000). However, farmers often use inorganic fertilizers due to the weed problems associated with organic manure (Smith and Ayenigbara, 2001).

However, in the smallholder sector, there is no precision in the agronomic practices for the two vegetables in intercrops. For instance, pumpkin is broadcast at planting the main crop whilst mustard rape is also broadcast during the first weeding of the main crop, or re-establishes as volunteer plants from the previous season's crop. In the three cases, the result is usually over-seeding or under seeding in different patches in the field. Also, there is no documentation suggesting separate weed, pest and nutrition management for the vegetables in intercrops. However, for adequate nutrition farmers usually grow the vegetables on areas known to be rich in nutrients for instance, near homesteads or cattle kraals (Nekesa and Meso, 1997). The practices of smallholder farmers have implications on the growth and therefore, leaf yields of these vegetables.

2.5 Responses of Pumpkin and Mustard Rape to Leaf Harvesting and Soil Fertility Management Practices

Literature on harvesting practices in both pumpkin and mustard rape is scant. Available information is also variable as practices seem to vary depending on farmers' needs, landrace used and the region of the world. Moreover, information specific to regions is also inconsistent. For instance, FAO (1988), reported that generally, in Africa leaf harvesting in pumpkin starts once the vines are about 60 cm long or about 35-60 days from planting, whereas Ndoro (2004) reported that in the Manicaland Province of Zimbabwe, most farmers start leaf harvesting in pumpkin at four weeks after emergence of the crop. In contrast, Mingochi and Luchen (1997) reported that in Zambia, vines must set fruit first before leaves are harvested as harvesting before vines set fruit causes rotting and abortion of subsequent fruits. Furthermore, according to Marume (1999), pumpkin leaves have to be harvested every two weeks for increase in yields and for tender, fresher and more nutritious leaves. However, elsewhere, pinching treatments had no effect on yield and soluble solids content of pumpkin fruit (Lim, Kim, Kim, Choi and Choi, 1998). Therefore, from the above discourse, it is not clear how pumpkin leaves should be harvested for the optimum leaf yields.

Similarly, for mustard rape, information on effects of leaf harvest intensities is also scarce and inconsistent. For instance, according to Schippers (2002), mustard rape leaves are harvested once every week. However, the leaves are harvested in unknown quantities and with unknown effects on plant regrowth and therefore, leaf yields. In Ethiopian kale (*Brassica carinata)*, which is closely related to mustard rape *(B. juncea)*, more frequent and intense plucking of leaves has been shown to prolong the vegetative phase and hence increase the leaf yields and duration of their availability (Schippers, 2002).

Pumpkin and mustard rape are rarely fertilized in the smallholder sector in Zimbabwe as they benefit from nutrients on the fertile patches of land on which they are grown or fertilizers applied to the main component crop in intercrops. Increases in fertilizer levels have been shown to improve leaf yields in fluted pumpkin, which is closely related to pumpkin (Ossom, Igbokwe and Rykerd, 1998) and in mustard rape (Chigumira-Ngwerume, 1998). The response to nitrogen is the one that has mainly been looked at. In fluted pumpkin, vine length and fruit yield were reported to show a linear response to nitrogen fertilization in pure stands and banana intercrops (Aiyelaagbe and Kintomo, 2002). Similarly, linear responses to nitrogen fertilization were also reported in mustard rape leaf yield (Singh, Singh, Kumar and Tomar, 1997). However, mustard rape leaf taste is negatively responsive to nitrogen fertilization. For instance, the excessive application of manure, especially poultry manure rich in nitrogen, often results in bitterness of the leaves and a foul smell during cooking. However, taste quality analyses have not been done to establish the levels of bitterness.

The responses of pumpkin and mustard rape to harvesting and fertilizer application outlined above indicate that yields in the two vegetables can still be improved upon with further research.

2.6 Priority Areas for Research in Pumpkin and Mustard Rape Cropping Systems

There is very little documentation of research that has been carried out on improving the productivity of these two important traditional vegetables (pumpkin and mustard rape) in Zimbabwe even though preliminary research has shown that it can be improved. Most of the agronomic research work carried out on pumpkin and squash has been targeted at increasing fruit yield, and not leaf yield, yet leaves are equally important as the fruits.

Though pumpkin and mustard rape are important component crops in various intercrops in Zimbabwe, their most ideal companion crops in intercrops have not yet been identified. It has also not been fully established and documented why farmers in Zimbabwe include vegetables in their intercropping systems. Elsewhere, intercropping is carried out for several reasons including; weed control (Francis, 1989), food security (Norman, 1974), pest control (IRRI, 1974), soil conservation, and solving space and resource limitations (Fageria, 1992). The most definite aspect of intercropping is the presence of competition for space, nutrients, water and sunlight between and within components.

Choice of components is one of the several ways of managing competition in intercropping systems (Banik, Sasmal, Ghosal and Bagihi, 2000). There are concerns that vegetables may be out-competed in intercropping systems (Mwaja and Masiunas, 1997). Such concerns might have resulted due to failure to identify the most ideal companion crops for vegetables in intercropping systems. As such, the inclusion of most vegetables in intercrops has been very limited. Intercrops that feature different maturity dates or development periods take advantage of variations in peak resource demand and therefore, lessen the competition between the two crops. Likewise, tall erect crops are intercropped with prostate or erect but short ones. Since effects of vegetable intercrops on the component crops have not been established, studies on improving pumpkin and mustard rape intercrops should also address their effects on the main component crops, maize and groundnut.

Similar to traditional vegetables, very little research has been done on intercropping groundnut in southern Africa (Chiteka, Cole, Freire, Mamba, Mande, Marais, Mayeux, Mouria, Mwenda, Rao, Sibuga, Syamasonta, Schimdt, Hildebrand and Subrahmanyam, 1992) despite the great potential for groundnut in sunflower or maize intercropping systems (Natarajan and Zharare, 1994). Elsewhere, results on intercropping groundnut showed that its yield was reduced by intercropping with maize without any significant effects on the maize yield (Uddin, Rahaman, Bagum, Uddin, and Rahaman, 2003). Due to its short stature, groundnut could therefore, be a good companion crop, with less suppressive effects on pumpkin and mustard rape.

Unlike groundnut, maize as a component of various intercrops has been widely researched, especially in cereal-legume intercrops (Ofori and Stern, 1987). Whilst the stability of maize yields in intercrops is an advantage, it is however, not clear whether the height of maize is not extensively suppressive to pumpkin and mustard rape in intercrops.

Apart from stature of components, competition in intercrops can also be manipulated through management of component crop populations. Various research studies, especially with legume-cereal intercrops, have been carried out to determine the effects of relative populations of component crops. Various reports have shown increased yields with increased densities. However, with increased vegetable densities, contrary results have been obtained. For instance, Singh and Rathi (2003) obtained low grain and biological yields of mustard rape due to increased densities. In Zimbabwe, farmers drop pumpkin seed along the main crop rows during ploughing, whilst mustard rape is established through seed that is broadcast during weeding operations or through volunteer plants that emerge within the main crop fields. In both cases, the relative densities of the vegetables are not known, whereas those of the main crops are known.

Relative planting time of component crops, which is an important technique in addressing crop competition in intercrops, has also not been thoroughly investigated in vegetable intercrops. Results obtained with other crops are inconsistent. The self re-establishment of mustard rape in intercrops suggests that there are differences in the times of emergence in the intercrops. The effects of these differences in emergence have not been investigated in mustard rape intercrops in Zimbabwe. Since mustard rape is a short season crop relative to maize or groundnut, there is potential for two crops of intercropped mustard rape in one season, in a double cropping system. Elsewhere, double cropping is usually practiced in sole crops in areas with long growing seasons (Fujimoto, 1996). However, with such a long growing season as that of maize (150 days to maturity), there is great potential for double cropping of mustard rape at low populations as a way of reducing competition in intercrops.

Apart from competition effects, intercrops may also provide beneficial interactions in the form of the potential to suppress weeds. Being a vining, prostrate and dense crop, pumpkin has the potential to act as live mulch under cereal crops, which may suppress weed germination and reduce moisture loss from the soil. Intercropping maize with trailing crops such as pumpkin (Mashingaidze *et al.*, 2000) and Egusi melon (Akobundu, 1993) has been shown to reduce the frequency of weeding. However, this was applied to intact vines which were not being harvested for leaf vegetable use.

Unlike other component crops in intercrops, leafy vegetables are subject to partial defoliation through leaf picking for relish. The weed suppression potential of vegetables in intercrops is likely to be influenced by management practices such as leaf harvesting intensities through their effects on growth and resultant canopy densities. The effects of leaf harvest intensities and frequencies have not yet been investigated in leafy vegetables, but almost similar work in the form of experiments on partial defoliation of plants have been carried out on various forage species (Hodgkinson, 1974), fruit trees (Yuan, Alferez, Kostenyuk, Singh, Syversten and Burns, 2005) and cotton (Eaton and Ergle, 1954). The results from the studies are quite variable.

Leaves are the source of photo assimilates for growth of the crop and therefore removal during the leaf harvesting operations is likely to have effects on growth of the crop. Some researchers have argued that leaf removal has a rejuvenating effect hence there is compensatory photosynthesis and gas exchange in the remaining leaves (Eaton and Ergle, 1954: Petrie, Trought, Howell and Buchan*,* 2003).

Three mechanisms have been put forward to explain how partial defoliation stimulates leaf photosynthesis. First, removal of some source tissues increases sink demand in a plant, resulting in a change in sink-source relation which stimulates photosynthesis through reduced sugar or starch accumulation (Sweet and Wareing, 1966). Second, it has been observed that defoliation increases leaf nitrogen or concentrations of photosynthesis-related proteins and enzymes (Nowak and Caldwell, 1984; Hoogesteger and Karlsson, 1992). Third, partial defoliation increases the root/leaf ratio, thereby improving water and nutrient status in the foliage. A greater root/leaf balance increases root-to-leaf hydraulic conductivity, and therefore stomatal conductance and photosynthesis (Hart, Hogg and Lieffers, 2000). For these reasons, it has been observed that photosynthetic rates of residual or regrowth foliage often increase compared to non-defoliated controls (Heichel and Turner, 1983).

Other researchers however, proposed source limitations to plant growth (Goldschmidt, 1999: Vanden Heuvel and Davenport, 2005), especially in fruit bearing trees. Much of the research work on partial defoliation was done in trees. It is not clear whether these leaf compensatory activities can be translated to whole plant photosynthesis and biomass in all plant species. Khan and Lone (2005), recorded increases in photosynthesis, growth and seed yield in mustard rape as a result of partial defoliation. Though in the partial defoliation experiments leaf yield was not the ultimate parameter of interest, it is evident that the size of subsequent leaves, hence available leaf area per plant and therefore growth of the crop, are similarly affected.

Leaf harvest management is also important as it could alleviate the poor taste quality often associated with nitrogen fertilization of mustard rape. Bitterness, which limits the promotion and utilization of mustard rape and spider plant (*Cleome gynandra*) is presumably a result of accumulation of free nitrates in the leaves, which increases with increasing nitrogen supply. Leaf nitrate content is a function of the amount of nitrate taken up from the soil and speed at which it is converted by the enzyme nitrate reductase to ammonia (Beeves and Hageman, 1983). There is a need to investigate the levels of bitterness caused by various levels of nitrogen fertilization in mustard rape.

Research elsewhere has also shown variations in plant leaf nitrate content during the day (Matt *et al*., 2001). The diurnal variations are caused by exposure to light, which facilitates the conversion of nitrates to organic compounds, thereby reducing their amounts in cell sap. Therefore, bitterness in mustard rape may be affected by timing of harvesting during the day.

From the foregoing, it is clear that the use of pumpkin and mustard rape in intercrops lacks scientific basis and the benefits derived from such systems may not be optimum. Therefore, the aim of this study was to improve the benefits of pumpkin and mustard rape intercrops by increasing leaf yields through the manipulation of intercrop populations, relative planting times, nitrogen fertilizer levels and leaf harvest intensities and increasing weed suppression through intercrop population management.

CHAPTER 3

3.0 GENERAL MATERIALS AND METHODS

The research was carried out in two areas namely, Chinyika Resettlement Area (CRA) and the University Farm (UZF) in the 2002/3 and 2003/4 rainy seasons. Both areas receive unimodal rainfall. In this report, the term site is used for each location where a study was carried out.

3.1 Location of Study Sites

3.1.1 Location of Chinyika Resettlement Area (CRA)

CRA lies on the latitude 18° 10' South and longitude 32° 17' East, and is 1200 to 1700 metres above sea level (m.a.s.l). It is located 200 km (by road) East of Harare, in Makoni District in the Manicaland Province of Zimbabwe. CRA is a former large scale commercial farming area which was converted into a Model A Resettlement Scheme by the government of Zimbabwe in 1983. Model A resettlements are characterized by having nucleated cluster villages, with six hectare individual land holdings and common grazing land detached from the homesteads. CRA has three main centres which were provided with infrastructure such as schools, clinics and shops and these are Bingaguru, Chinyudze and Gowakowa. It is villages surrounding these main centres that form the three cluster areas of CRA.

3.1.2 Location of the University Farm (UZF) (Thornpark Estate)

UZF lies on the latitude 017° 48' South and longitude 031° 00' East. It is located in the Mazowe District of the Mashonaland Central Province of Zimbabwe, about 14 km North of the Harare City Centre, along the Harare-Bindura road. The farm is divided into two, a commercial section and a Research and Teaching Unit (RTU), where studies in this report were carried out. The RTU is a researcher-managed site specifically meant for research by University of Zimbabwe staff and students. It has a weather station and irrigation facilities for winter crops and supplementary irrigation for summer crops.

3.2 Physical Characteristics of Chinyika Resettlement Area

3.2.1 Soils

The cluster areas of CRA predominantly have loamy sands to sandy soils of granitic origin (Appendix 2.1). The soils belong to the paraferrallitic group classified as Rusape 6G.2 (Zimbabwe), Typic Haplustult (USDA) and Hapic Acrisol (FAO) (Nyamapfene, 1991). Typically, this soil group is low in fertility, especially nitrogen and phosphorus. However, the soils are of agricultural importance as “tobacco soils” in Zimbabwe as their light texture allows easier management of nitrogen which is critical in tobacco production. Apart from tobacco, these well drained soils are also good for maize and groundnut, especially in the smallholder sector (Nyamapfene, 1991), as they respond very well to fertilizer application. Analysis of soil samples taken just before the onset of the 2003/4 season showed that the soil at the Chinyudze experimental site is brown medium grained loamy sand with a pH of 5.2 ($CaCl_2$ scale), whereas that at the Gowakowa site is light brown medium grained sand with a pH of 5.3 ($CaCl_2$ scale). The available P_2O_5 was 20 ppm for Chinyudze and 51 ppm for Gowakowa. Soil samples from the Bingaguru site were not analyzed as they could not be located at the laboratory to which they were sent.

3.2.2 Rainfall and Altitude

CRA receives moderate rainfall, around 800 mm per year, distributed from November to April (Hanyani-Mlambo and Hebinck, 1996). It is alleged that the area also covers three of Zimbabwe’s Agro-ecological Zones (Natural Regions), viz IIb, III and IV (Appendix 1), with annual rainfall ranging from 750 – 1000mm in NR II, 680 – 700mm in NR III and 450 – 650mm in NR IV (Vincent and Thomas, 1961). Bingaguru, Chinyudze and Gowakowa differ in terms of soils, altitude and rainfall.

Though both Bingaguru and Chinyudze fall under Natural Region (NR) IIb and receive almost equal rainfall amounts (about 800 mm per year), the former is cooler than the latter due to higher elevation. Chinyudze represents typical NR IIb of Zimbabwe with reliable rainfall amounts, whereas Bingaguru is cool with erratic rainfall amounts. Gowakowa, the lowest in altitude (about 1250 m.a.s.l), is characterized by higher temperatures and lower rainfall amounts, and falls in NR

III. It is also claimed that some parts of Gowakowa have a very low altitude and receive very little rainfall and fall into NR IV. Rainfall data collected during the period of the study are presented in Figure 3.1. Rainfall data for Bingaguru (both seasons) and Gowakowa (2003/4) were not collected as the hosting farmers kept the rain gauges indoors at night citing theft risks.

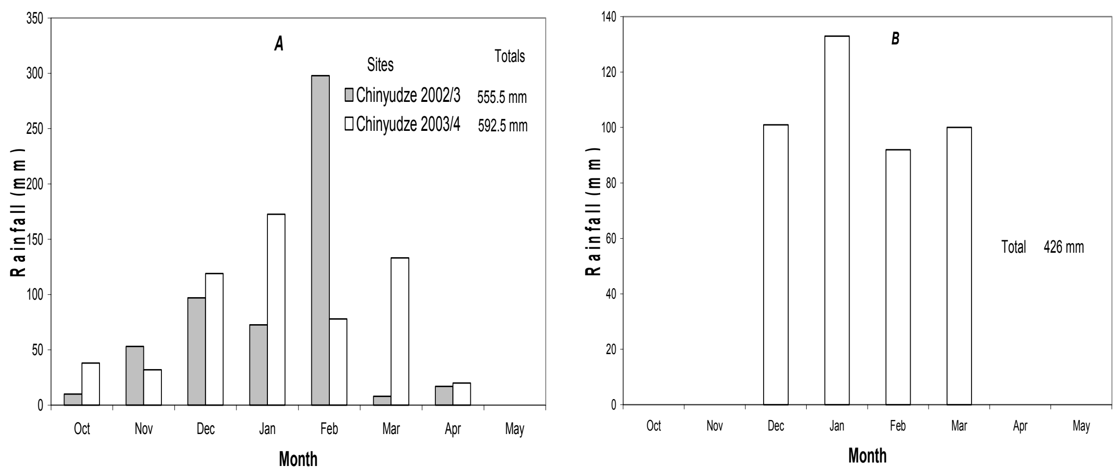

Figure 3.1: Rainfall amounts received at: A) Chinyudze in the 2002/3 and 2003/4 seasons and B) Gowakowa in 2003/4.

3.3 Physical Characteristics of the University Farm (UZF)

3.3.1 Topography and Soils

UZF is characterized by fields with slopes of 2 % or less. The soils are heavy red clays belonging to the fersiallitic group and classified as Harare 5E.2 (Zimbabwe), Typic Rhodustalf, Kandic Rhodustalf or Oxic Paleustalf (USDA) and Chromic Luvisol (FAO) (Nyamapfene, 1991) (Appendix 2.2). Typically, fersiallitic clays are ideal for a wide range of crops, and are very important in Zimbabwe due to their moderate depth and widespread occurrence as they cover most of Zimbabwe's "Maize Belt."

3.3.2 Altitude, Temperature and Rainfall

UZF lies in Zimbabwe's Natural Region IIa, which is a high agricultural potential area as it is ideal for both intensive crop and livestock production. NR IIa is a more reliable cropping area than NR IIb, which is characterized by dry spells within rainy seasons. The farm lies in the highveld and is about 1450 m.a.s.l. The highest point on the farm is 1480 m.a.s.l and the lowest is 1420 m.a.s.l (Kwela, 1998). The altitude gives the area a cool mean temperature of 19°C. However, it also makes the area prone to frosts between late May and early August.

In terms of rainfall, UZF compares well to some of the best cropping areas of Zimbabwe. For example, over a 30-year period it received 576 rainy pentads compared to 600-647 rainy pentads in the best cropping areas of Zimbabwe. The 50-year average annual rainfall (up to 1987) for the farm was 815 mm, ranging from 440 to 1270 mm (Kwela, 1998). Rainfall data collected during the period of the study are presented in Figure 3.2.

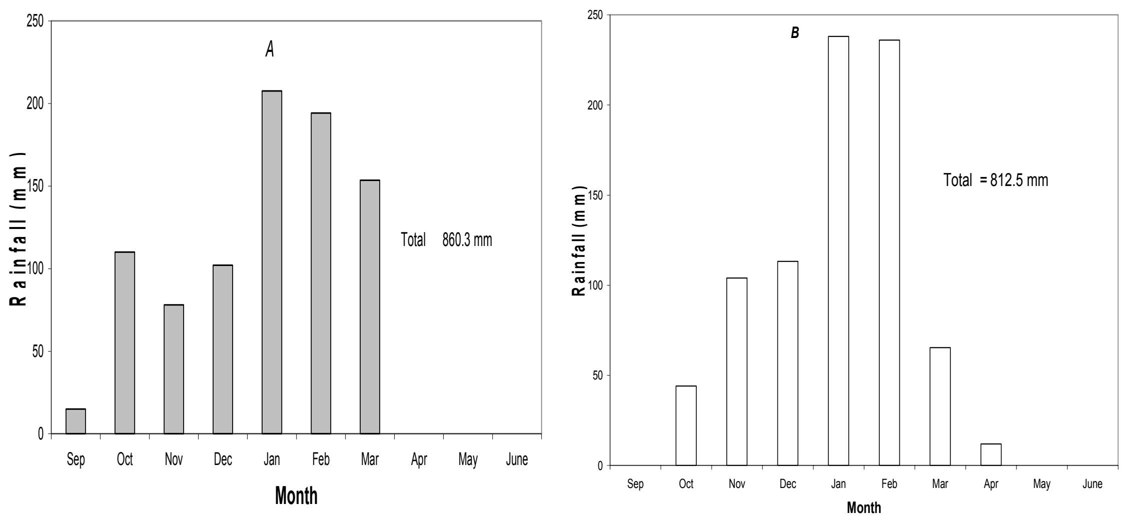

Figure 3.2: Rainfall amounts received at the University Farm (UZF) during the study period: A) 2002/3 and B) 2003/4.

3.4 Crop Cultivars and Sole Crop Spacing Used in the Studies

To avert germination and growth inconsistencies that are brought about by landraces and farm-retained seed, standard seed or commercially available certified seed was used in the studies reported here.

3.4.1 Maize

The maize cultivar used in all the studies was SC 513® from Seed Co. This is a white, dent-type medium maturity maize variety (about 137 days to maturity) and has a medium yield potential (4-9 tonnes ha^{-1}) (Seed Co, 2004). It has very good tolerance to Grey Leaf Spot (GLS), good stress (abiotic and biotic) tolerance and generally wide adaptability (Seed Co, 2000). As such, SC 513® is grown mainly by smallholder farmers since these farmers rely on rainfed crop production and cannot sustain long season cultivars. The cultivar also has a semi-erectophile leaf architecture, which makes it suitable for intercropping. In all the experiments SC 513® was planted at 0.9 m between rows and 0.3 m within rows, to give a population density of 37 037 plants ha^{-1}, which has been the long standing recommendation for smallholder farmers in Zimbabwe. This density was maintained in both sole cropping and intercropping.

3.4.2 Groundnut

'Natal Common' is a short season bunch-type (Valencia type) of groundnut which matures in 110-130 days depending on temperature. It is suitable for dryland production under medium to low rainfall (NR IV and III), especially on light sandy soils (COPA, 1988). Natal Common is however, susceptible to foliar diseases and has a propensity to viviparity at maturity; therefore areas with long seasons should be avoided. It has been grown in Zimbabwe for a long time and is often referred to as "Spanish" (Nyakanda and Hildebrand, 1999). It is mainly grown by smallholder farmers because of its relatively short duration compared to the cultivars grown by large scale commercial farmers under supplementary irrigation. Spacing used in the studies is described in the relevant chapter.

3.4.3 Pumpkin

The pumpkin cultivar used in the studies, Flat White Boer® (Pannar), is a locally available commercial variety in Zimbabwe. Local pumpkin landraces are usually very variable in terms of growth and leaf yields, hence not suitable for experiments where uniformity of material is required. Flat White Boer® is mainly grown on large scale commercial farms for its high fruit yields. The cultivar produces large white fruits with orange flesh. In sole cropping, pumpkin was spaced at 1.5 m between rows and 1 m within rows to give a population of 6 666 plants ha^{-1}. Specific intercrop densities are described under the specific chapters.

3.4.4 Mustard Rape

There is a wide range of mustard rape landraces, but very few commercial cultivars available in Zimbabwe. 'Tsunga' variety produced by Prime Seeds is one of the commercially available cultivars in Zimbabwe and was used for all the experiments in this study. In sole cropping it was spaced at 0.5 m inter-row and 0.3 m in-row, to give a population of 66 666 plants ha^{-1}. This variety can grow up to a height of 1.5 m. Densities used in intercropping are described in the specific chapters.

3.5 Field Operations and Management of Experiments

In both the 2002/3 and 2003/4 seasons, experiments were established late November to early December. Maize and groundnut were harvested in May at harvest maturity whilst pumpkin and mustard rape leaves and fruits were harvested throughout the season. There were some differences in land preparation between UZF and CRA sites. At UZF, experiments were established on disced land, whereas at all sites in CRA experiments were established on land prepared using ox-drawn mould board plough. At UZF supplementary irrigation was administered as was required whilst in CRA crops were purely rainfed.

At UZF mustard rape was double cropped whilst in CRA there was a single planting. Double cropping can be defined as the successive growing of two crops on one piece of land in one season, usually facilitated by short season crops or a long rainy season (Fujimoto, 1996). The two plantings of mustard rape were: one simultaneously planted with the main crop referred herein as the first planting and another, referred to in this report as the second planting, planted at 10 weeks after emergence (WAE) of the main crop. At all sites, crops were protected from pests and diseases whenever there was a threat. Notably, in the 2002/3 season the maize crop in CRA had to be sprayed with Carbaryl® to protect it from a serious armyworm (*Spodoptera exempta*) attack. Also, Dipterex® (Endosulfan) granules were dropped into maize funnels to protect the crop from maize stalk borer (*Buseola fusca*) in both seasons at UZF.

3.6 Data collection and analysis

In this report, suffixes 2002/3 and 2003/4 were used in naming the sites for the three cluster areas of CRA. The former signifies the 2002/3 season, whilst the latter signifies the 2003/4 season. For instance, Gowakowa 2002/3 refers to the Gowakowa site in the 2002/3 season, whilst Gowakowa 2003/4 refers to the same site in the 2003/4 season.

Maize grain yield was standardized to 12.5 % moisture content using the formula below.

Grain yield **(Y)** = **FWP** x **DM** x **S** x **F** x **M** where:

Y = grain yield in kg ha^{-1} at γ % moisture content

FWP = fresh weight of net plot in kg

DM = fraction of dry matter in sample (dry weight / fresh weight) in kg

S = shelling percentage expressed as a fraction

F = conversion factor from / net plot to kg ha^{-1}

M = moisture factor = $100/(100-\gamma)$ for γ % moisture.

γ = recommended moisture at storage = 12.5 % for maize and 7.5 % for groundnut.

At all sites, pumpkin and mustard rape dry leaf yields, and the grain yield of the main crop were used to calculate land equivalent ratio (LER) values. The LER was proposed by Osiru and Willey (1972). It is defined as the total land area required under pure stands to produce the yields obtained in the intercropping mixture under same management level.

LER is calculated as follows:

$\mathbf{LER = Y_{ij}/Y_{ii} + Y_{ji}/Y_{jj}}$, where

Y= yield per unit area, Y_{ii} and Y_{jj} = pure stand yields of crops i and j respectively, and Y_{ij} and Y_{ji} = intercrop yields of components.

When LER > 1, there is an advantage of intercropping over sole cropping, whilst if LER < 1 it means more land area is needed to produce the same yield of component crops in pure stands than with an intercropping mixture. For instance, if LER = 1.32, it means 32 % more land is needed to produce the same yields from components as sole crops as compared to intercropping them.

CHAPTER 4

4.0 EFFECTS OF PUMPKIN AND MUSTARD RAPE POPULATIONS ON PRODUCTIVITY AND WEED SUPPRESSION IN MAIZE – PUMPKIN AND MAIZE – MUSTARD RAPE INTERCROPS

4.1 Introduction

The ever-escalating costs of inputs in vegetable production present the need to explore opportunities for reliable and less costly vegetable production systems. This particularly applies to summer vegetable production where excess rainfall and high humidity create conditions for disease prevalence which demands high inputs including agrochemicals. Unless costs of producing summer vegetables are drastically reduced, the general shortage of vegetables in summer in Zimbabwe will continue to prevail. Traditional vegetables, locally adaptable, have the potential to provide a reliable supply of leaf vegetables with limited inputs. Previous surveys have shown the prominence of mustard rape and pumpkin as some of the most frequently consumed traditional vegetables in summer in Zimbabwe (Jackson, 1997; van der Mheen-Sluijer and Chihande, 1997).

Pumpkin is usually grown as a leafy vegetable mainly for subsistence in the rural and peri-urban areas of Zimbabwe. The peri-urban crop is commercialized to some extent. It is also commercially grown for its fruits by large scale farmers, often in pure stands, whereas in the smallholder sector it is commonly grown in intercrops. Though pumpkin is intercropped with various field crops such as maize, groundnut, cotton and sorghum, its most popular component crop for intercropping in Zimbabwe is maize (Turner and Chivinge, 1999), where both crops are planted at the same time.

Another vegetable adapted for production in summer is mustard rape. It is usually broadcast in the fields during the first weeding operation (about three weeks after the emergence of maize), especially in wetter areas of the country such as the Manicaland Province of Zimbabwe (Nyagweta, 2000). In addition, volunteer mustard rape plants from the previous seasons' crop are also nurtured. Mustard rape is also sometimes introduced in intercrops towards the end of the season, especially in vlei areas where it precedes the start of vegetable production in vlei gardens.

Whilst mustard rape and pumpkin are mainly produced in intercrops in summer, not much research has been done to improve their productivity in such intercropping systems. For instance, their optimum relative populations in maize-based intercropping systems are not known. Whilst the choice of crop combination is critical for the success of intercropping (Saka, Haque, Said, Lupwayi and El-Wakeel, 1993), also equally important are the intercropping populations of the companion crops, as they have a bearing on the interspecific and intraspecific competition. Results on the effects of relative component proportions on yield performance are limited. For instance, Singh and Rathi (2003), obtained low grain and biological yields of mustard rape due to increased densities. Further, the possibility of double cropping mustard rape in maize intercrops needs to be explored. Double cropping, the successive growing of two crops on one piece of land in one season (Fujimoto, 1996), can be practiced given the short duration of mustard rape compared to the maize component in intercrops.

Intercropping has often been found to suppress weeds. For instance, Liebman and Dyck (1993), in an extensive review reported lower weed biomass in itntercrops compared to component crops in 50 % of the studies. Effectiveness of intercropping with pumpkin as a low cost weed management option has been demonstrated (Mashingaidze *et al.*, 2000). Clearly, maize-pumpkin or maize-mustard rape intercrops ensure availability of mustard rape and pumpkin in addition to the maize main crop. Advantages such as reduced weeding may also accrue. However, the best population combinations have not been clearly established, as well as the performance of intercrops when the minor crops, pumpkin and mustard rape, are harvested for leaf vegetable.

The objectives of this study were:

i) To determine the effects of pumpkin and mustard rape populations on growth and yields of all components and weed suppression in maize – pumpkin and maize –mustard rape intercrops.

ii) To evaluate the effects of mustard rape double cropping on leaf yields and grain yields in maize – mustard rape intercrops.

The objectives were based on the following hypotheses:

i) Higher pumpkin and mustard rape populations increase vegetable yields and weed suppression, but reduce maize yields in maize – pumpkin and maize - mustard rape intercrops.

ii) Double cropping of mustard rape increases leaf yields due 'two crops' in one season whilst reducing maize grain yield due to increased competition in maize – mustard rape intercrops.

4.2 Materials and Methods

The study was carried out on-farm in the Chinyika Resettlement Area (CRA) and at the University Farm (UZF) in the 2002/3 and 2003/4 rainy seasons. Both the CRA and the UZF sites are described under Sections 3.1 and 3.2 of the General Materials and Methods. In CRA, the experiment was carried out at sites in each of the three cluster areas namely, Chinyudze, Gowakowa and Bingaguru.

At each site, the treatments were maize intercropped with three pumpkin and three mustard rape populations each of 11.7 %, 23.5 % and 35.3 % of the maize population. Pure stands of maize, mustard rape and pumpkin were also included in the study as controls. The treatments were arranged in a randomized complete block design with four blocks at each site. Spacing in the maize, pumpkin and mustard rape pure stands and characteristics of the cultivars are described in Section 3.4 of the General Materials and Methods. All plots measured 5 m long x 4.5 m wide. The vegetables were planted simultaneously and in the same rows as the maize crop. At UZF, there was double cropping of mustard rape as described in Section 3.5 of the General Materials and Methods.

Three seeds were sown per station for pumpkin, two seeds per station for maize and a pinch of seed per station for mustard rape. At three weeks after emergence (WAE) of maize, all crops were thinned to one plant per station, just after the first weeding. All plots received a basal fertilizer (6 % N, 17 % P_2O_5, 5 % K_2O, and 10 % S), which was broadcast at an application rate of 300 kg ha^{-1}. Crops were also weeded at 6 and 10 WAE of maize. Maize and the sole crops of pumpkin and mustard rape received a nitrogen side dress in the form of NH_4NO_3 (34.5 % N) at 69 kg N ha^{-1} at five WAE of maize. However, to simulate the smallholder practice, the second planting of mustard rape did not receive any fertilizer application. By the time of establishing the second planting, the maize would have received all its fertilizer applications for the season; therefore, no additional fertilizer would be applied to the mustard rape in intercrops.

Weed density and weed biomass were determined by randomly throwing a 0.3 m x 0.3 m wire quadrant five times in each plot before weeding at five and 10 WAE. Weeds in the quadrants were identified, counted, cut at ground level and then oven-dried at 70º C for 48 hours. Weed density and weed biomass were also determined after maize physiological maturity.

Pumpkin leaves were harvested from all vines within each whole plot as the vines were entwined making separation of those from the net plot and the gross plot difficult. However, in mustard rape, leaves were harvested from within the maize net plot (inner three rows) for the intercrop and from the four inner rows of the sole mustard rape plots. For maize and mustard rape, the two outermost plants at the end of each net plot row were used as guard plants and were therefore not harvested. Mustard rape leaves were harvested from three WAE till no further harvestable leaves were produced by the plants. Meanwhile, pumpkin leaves were harvested from six WAE up to the time of harvesting the maize crop.

In both vegetables, the nearly- or fully-expanded tender leaves were harvested, weekly in mustard rape and once in two weeks at each growing tip in pumpkin. After each harvest, leaf area per occasion and per plant was determined, using a LI 3000 leaf area meter (LI-COR Inc., Lincoln, USA). The average leaf size was determined for each occasion was determined by measuring leaf area for 10 leaves and then dividing by 10. After leaf area measurement, the leaves were oven-dried at 70º C for 48 hours then weighed. Vine length, primary branching, fruit and leaf yields and crop duration were assessed for pumpkin, and plant height, harvested leaf numbers and length of the vegetative phase (days to flowering) for mustard rape.

UZF data were analyzed separately from the CRA sites' data. At UZF, the first planting of mustard rape in the 2002/3 season failed due to poor rainfall and breakdown in irrigation facilities at the beginning of the season. Similarly, of the three sites planted in CRA in the 2002/3 season, only Chinyudze had complete data. At Gowakowa maize failed completely just after emergence due to dry weather and rodent damage, whereas at Bingaguru, before the researcher went for harvesting, the hosting farmer harvested and bulked maize from all the plots citing stray cattle damage. For comparative reasons, data from Chinyudze in the 2002/3 season was combined with data from the three other on-farm sites in the 2003/4 season as environments not sites. Mustard rape completely failed in CRA in both seasons due to drought. Therefore, CRA data did not have mustard rape data. Maize grain moisture content was determined using a moisture tester (NJF 1210 Moisture Tester, N.J. Fromet & Co. Ltd, Stamford, England) and yields were standardized to 12.5 % moisture content as described in Section 3.6 of the General Material and Methods.

Land equivalent ratio (LER) values were calculated as described in Section 3.6 of the General Materials and Methods. Data that were not normally distributed, especially weed dynamics data, were transformed to normality as indicated in the tables. All statistical data were subjected to analysis of variance using Genstat Statistical Package (Lawes Agricultural Trust, 2002). Combined analyses over sites and years were only done when variances were found to be homogenous in the test for homogeneity of variances.

4.3 Results

4.3.1 At the University Farm (UZF)

At UZF, the first planting of mustard rape in the 2002/3 season failed due to poor rainfall, unlike the second 2002/3 crop and both of the 2003/4 crops. In both seasons, at UZF maize grain yield was neither significantly ($p > 0.05$) affected by intercrop, nor by mustard rape intercrop populations (Table 4.1). Tests for homogeneity of variances showed that UZF mustard rape leaf size data for the second planting could be combined over the 2002/3 and 2003/4 seasons. Mustard rape leaf size was significantly ($p < 0.001$) reduced by intercropping from 290 cm^2 in the mustard rape sole to 109 cm^2 in mustard rape intercrops with mustard rape intercrop density having no effect.

Table 4.1: Effects of cropping system on maize grain yield and mustard rape leaf size in the second planting at UZF in 2002/3 and 2003/4.

Cropping system	Maize grain yield (kg ha^{-1}) (2002/3)	Maize grain yield (kg ha^{-1}) (2003/4)	Mustard rape leaf size (cm^2) (2002/3 & 2003/4)
11.7 % M-P	6089.00	9239.00	-
23.5 % M-P	5584.00	9362.00	-
35.3 % M-P	5298.00	8793.00	-
11.7 % M-MR	6035.00	9561.00	109.3 b
23.5 % M-MR	5543.00	9228.00	109.5 b
35.3 % M-MR	5472.00	9318.00	109.5 b
Sole maize	5544.00	9483.00	-
Sole mustard rape	**-**	**-**	290.0 a
Significance	ns	ns	***
$LSD_{0.05}$	-	-	18.30
CV (%)	9.20	14.20	11.30

M-P = maize-pumpkin intercrop. M-MR = maize-mustard rape intercrop; Means with the same letter in a column are not significantly different; ***= p<0.001; ns = not significant; $LSD_{0.05}$= Least Significant Difference at p = 0.05; CV = coefficient of variation.

In 2002/3 at UZF, the length of the vegetative phase in the second planting of mustard rape was significantly ($p < 0.001$) reduced by intercropping to 30 days compared to 45 days in pure stands. Intercropping also reduced the total number of leaves harvested per plant to four in mustard rape as opposed to nine in pure stands (Table 4.2). Mustard rape plant height in intercropping was reduced to less than 50 % of the height obtained in pure stands. A similar trend was also observed in the 2003/4 season, where pure mustard rape stands were significantly greater ($p < 0.001$) than the other treatments for the length of the vegetative phase, number of leaves harvested per plant and plant height. Mustard rape intercrop density had no effect.

Leaf size and the number of leaves harvested per plant in mustard rape were influenced ($p < 0.01$) by the interaction of time of planting and intercrop population at UZF in 2003/4. Both parameters were decreased in the intercrops, with the exception of leaf number in the first planting, with the reduction being much greater for the second planting (Figures 4.1A and 4.1B).

Table 4.2: Effects of cropping system on various characteristics of mustard rape in the second planting at UZF in the 2002/3 and 2003/4 seasons.

	UZF 2002/3			UZF 2003/4		
Cropping system	**LVP (days)**	**HLP**	**Height (cm) (cm)**	**LVP (days)**	**HLP**	**Height (cm)**
11.7 % M-MR	29.50 b	4.00 b	44.50 b	31.25 b	3.70 b	58.6 b
23.5 % M-MR	31.75 b	4.75 b	43.25 b	32.25 b	3.58 b	58.4 b
35.3 % M-MR	31.00 b	4.25 b	43.12 b	31.75 b	3.68 b	58.7 b
Sole MR	45.00 a	9.00 a	98.25 a	43.25 a	5.35 a	111.60 a
Significance	***	**	***	***	***	***
$LSD_{0.05}$	2.33	2.44	5.83	5.34	0.44	10.69
CV (%)	4.20	27.80	6.40	9.60	6.70	9.30

M-MR = maize-mustard rape intercrop; MR = mustard rape; LVP = Length of the vegetative phase; HLP = Number of leaves harvested per plant; Means with the same letter in a column are not significantly different; **= p<0.01, ***= p<0.001; $LSD_{0.05}$= Least Significant Difference at p = 0.05; CV= coefficient of variation.

An effect of interaction between planting time and intercrop population similarly influenced length of the vegetative phase in mustard rape at UZF in 2003/4. In the first planting there were no differences amongst the treatments whilst in the second planting mustard rape vegetative period was reduced from 43 days in the pure stands to 32 days in the intercrops, with density having no effect (Figure 4.1C). Mustard rape dry leaf yield was also significantly ($p < 0.001$) influenced by the interaction between planting date and intercrop population. It was reduced by both intercropping and deferred planting. Percentage difference between pure stands and intercrops was larger in the second planting compared to the first planting, with mustard rape density having no effect (Figure 4.1D).

Intercropping reduced ($p < 0.001$) pumpkin leaf size to 217-223 cm^2 as opposed to 390 cm^2 in pure stands at UZF in 2002/3 (Table 4.3). Similarly, pumpkin growth duration was reduced to 91-106 days in intercrops from 158 days in the pure stands. Pumpkin dry leaf yield in the pure stands was more than 350 % of the lowest yield obtained, i.e. in the 11.7 % maize-pumpkin intercrop. However, for the three parameters effects of pumpkin densities were not significant.

At UZF in 2003/4, intercropping reduced ($p < 0.001$) pumpkin leaf size, growth duration and dry leaf yield to 56 %, 65 % and 16.45 % respectively, of the corresponding values in pure pumpkin stands. Unlike leaf size and growth duration, mustard rape dry leaf yield increased with increasing pumpkin intercrop density.

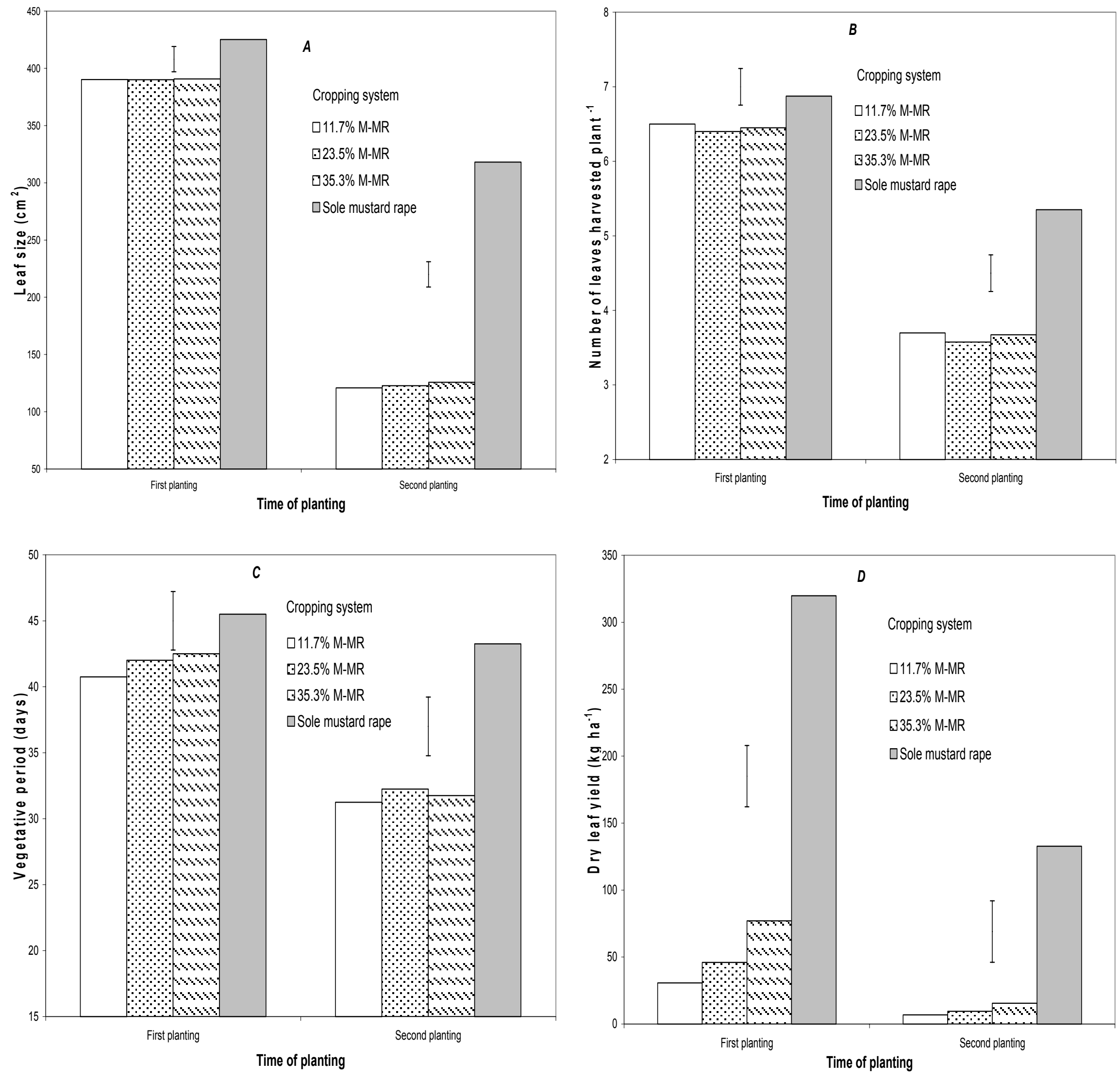

Figure 4.1: Effects of cropping system and planting date on mustard rape characteristics at the UZF in 2003/4: A) harvested leaf size, B) number of leaves harvested per plant, C) length of vegetative period and D) dry leaf yield. M-MR = maize-mustard rape intercrop. Bars on the graphs represent $LSD_{0.05}$ values.

Table 4.3: Effects of cropping system on pumpkin characteristics at the University Farm in the 2002/3 and 2003/4 seasons.

	UZF 2002/3			UZF 2003/4		
Cropping system	**LFSZ☼ (cm^2)**	**Duration (days)**	**DLY¤ (kg ha^{-1})**	**LFSZ☼ (cm^2)**	**Duration‡ (days)**	**DLY¤ (kg ha^{-1})**
11.7 % M-P	223.0 b	90.5 b	17.6 b	314 b	101.8 b	126 d
23.5 % M-P	220.7 b	101.5 b	21.4 b	311 b	103.2 b	234 c
35.3 % M-P	216.7 b	105.8 b	22.5 b	305 b	104.0 b	397 b
Sole pumpkin	390.0 a	158.0 a	62.1 a	549 a	156.5 a	766 a
Significance	***	**	**	***	***	***
$LSD_{0.05}$	52.13	31.49	18.2	73.4	9.53	65.7
CV (%)	12.4	17.3	36.8	12.4	5.1	10.8

¤DLY = Dry leaf yield. ☼LFSZ = Leaf size. ‡ Duration = Pumpkin growth duration; M-P =maize-pumpkin intercrop; Means with the same letter in a column are not significantly different; **= p<0.01, ***= p<0.001; $LSD_{0.05}$= Least Significant Difference at p = 0.05. CV= coefficient of variation.

The interaction between season and intercrop population was significant ($p < 0.05$) on the total number of leaves harvested per vine and vine length in pumpkin at UZF. In both the 2002/3 and the 2003/4 season the two parameters were higher in pure stands, but the difference between pure stands and the intercrops was higher in 2003/4 (Figures 4.2A and 4.2B).

4.3.2 On-farm (CRA)

Homogeneity of variances test showed that maize grain yield, pumpkin duration and pumpkin branching data could be combined over the four on-farm environments. There was no significant interaction between environment and cropping system effects for any of the three parameters, therefore only the means over the on-farm environments are presented in Table 4.4. Intercropping had no effects on maize grain yield whilst it significantly ($p < 0.001$) reduced growth duration and primary branching in pumpkin. However, pumpkin intercrop density had no effects on both pumpkin duration and number of primary branches.

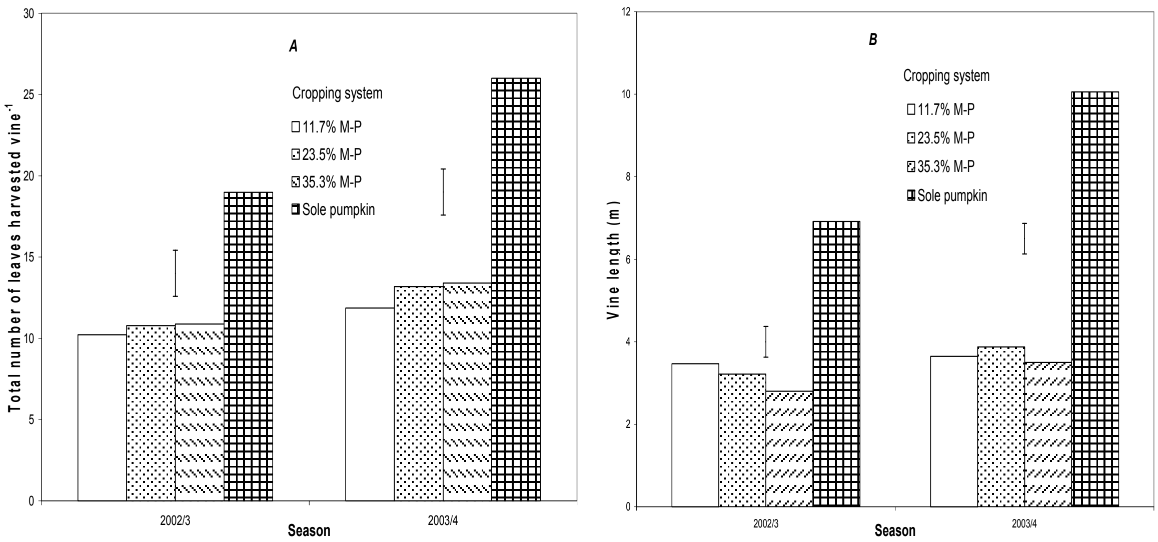

Figure 4.2: Effects of cropping system and season on pumpkin characteristics at UZF: A) the total number of leaves harvested per vine, and B) vine length. M-P = maize-pumpkin intercrop. The bars on the graphs represent $LSD_{0.05}$ values.

Table 4.4: Effects of cropping system on maize grain yield and, duration and branching of pumpkin over the on-farm environments

Cropping system	Maize: Grain yield (kg ha^{-1})	Pumpkin: Duration‡ (days)	Pumpkin: Primary branches vine^{-1}
11.7 % M-P	3764	120.31 b	11.33 b
23.5 % M-P	3804	120.19 b	13.09 b
35.3 % M-P	3381	118.81 b	11.17 b
Sole crop	3889	130.00 a	15.98 a
Significance	ns	***	***
$LSD_{0.05}$	-	3.67	2.09
CV (%)	17.40	4.20	22.60

‡ Duration = Pumpkin growth duration; M-P = maize-pumpkin intercrop; Means with the same letter in a column are not significantly different. ***= p<0.001. ns =not significant; $LSD_{0.05}$= Least Significant Difference at p = 0.05; CV= coefficient of variation.

Pumpkin fruit yield and dry leaf yield were significantly (at least $p < 0.01$) reduced by intercropping at all the on-farm environments. Generally, pumpkin fruit and dry leaf yields increased with increasing pumpkin density with the exception of Chinyudze and Gowakowa where intercrop density had no effect on leaf yield and fruit yields in 2003/4 respectively (Table 4.5).

Table 4.5

The interaction between environment and cropping system effects was significant ($p < 0.01$) for the total number of leaves harvested per plant in pumpkin. At Bingaguru in 2003/4 and Chinyudze 2002/3, there were no significant differences in leaf numbers amongst all the treatments, whilst at the two other environments; the number was significantly higher in pumpkin sole crops (Figure 4.3A).

Pumpkin leaf size was influenced by the interaction between environment and intercrop population. Pumpkin leaf size decreased with increasing intercrop population at Gowakowa in 2003/4 and Chinyudze in 2002/3. However, it was not significantly affected by intercrop population at Bingaguru and Chinyudze in 2003/4 (Figure 4.3B). At all four on-farm environments, pumpkin leaf size was reduced by intercropping.

The interaction effect between environment and intercrop population was also significant ($p < 0.001$) on pumpkin vine length. Pumpkin density had no effects on pumpkin vine length at all other environments, except at Chinyudze in 2002/3 where the longest vines were recorded in pumpkin intercropped at 23.5 % of maize (Figure 4.3C).

Overall, the pumpkin growth parameters; leaf numbers, leaf size and vine length were higher at Gowakowa 2003/4 and Chinyudze 2003/4 compared to the two other environments.

4.3.3 Weed dynamics

Tests for homogeneity of variances showed that weed biomass at maize physiological maturity could be combined over the on-farm environments. Weed biomass at maize physiological maturity was significantly ($p < 0.001$) influenced by the interaction between environment and cropping system. It decreased with increasing pumpkin density at Chinyudze and Gowakowa in 2003/4 whilst it was not affected by pumpkin intercrop density at Bingaguru in 2003/4 and at Chinyudze in 2002/3 (Figure 4.3D). The highest weed biomass was recorded in maize pure stands, except at Gowakowa where it was recorded in the 11.7 % maize - pumpkin intercrop in 2003/4.

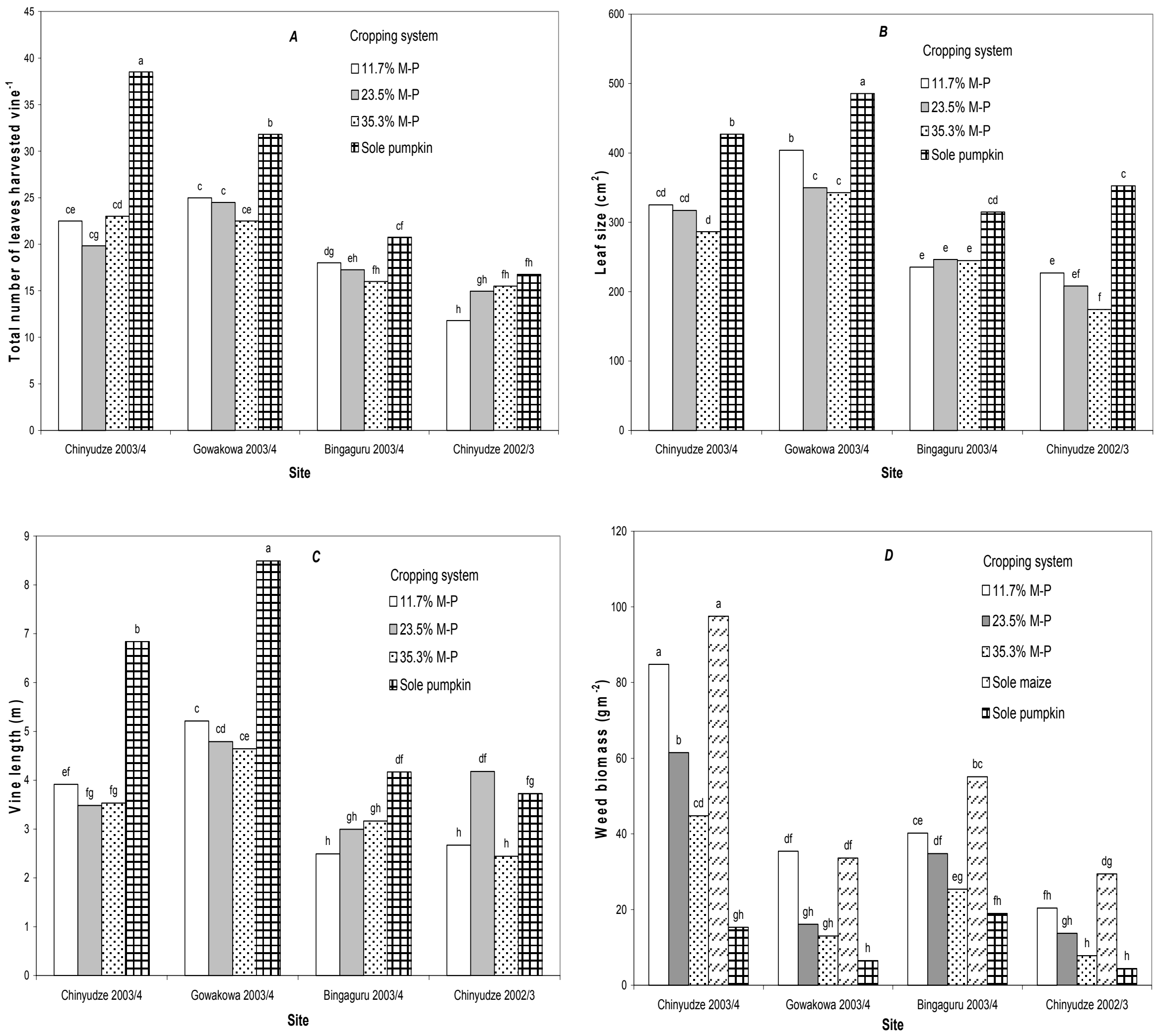

Figure 4.3: Effects of on-farm environment and cropping system on pumpkin characteristics [(A) number of leaves harvested per vine, (B) leaf size and (C) vine length] and weed biomass at maize physiological maturity (D). M-P = maize pumpkin intercrop. Lower case letters on the graphs show mean separation using the Duncan's Multiple Range Test.

Similar to weed biomass at maize physiological maturity at Chinyudze and Gowakowa in 2003/4, weed density and weed biomass at six and 10 WAE, and weed density at maize physiological maturity were reduced by higher pumpkin intercrop densities at all four on-farm environments (Tables 4.6 and 4.7). Also, at all the on-farm environments, the least weed density and weed biomass values were recorded in pure pumpkin stands whilst the highest values were recorded in pure maize stands except for weed density at six WAE at Bingaguru in 2003/4, where the highest values was in the 11.7 % maize-pumpkin intercrop.

Table 4.6

Table 4.7

Tests for homogeneity of variances showed that weed dynamics data from UZF could not be combined over the 2002/3 and 2003/4 seasons. In both seasons, weed dynamics were significantly (at least $p < 0.01$) affected intercropping and sole cropping with the highest weed density and weed biomass being recorded in the maize sole crop and the mustard rape sole crop, whilst the least were recorded in the pumpkin sole crop (Tables 4.8 and 4.9). Lower weed density and weed biomass were recorded in pumpkin intercrops compared to mustard rape intercrops. Weed dynamics at six and 10 WAE for mustard rape intercrops will not be reported due to failure of mustard rape first planting in 2002/3.

In the 2002/3 season, higher pumpkin intercrop densities reduced weed density only at six WAE, whist mustard rape intercrop density had no effect. However, in 2003/4 higher pumpkin intercrop densities reduced weed biomass at six WAE, weed density and weed biomass at 10 WAE and weed biomass at maize physiological maturity, whilst mustard rape intercrop density had no effect. Weed dynamics in mustard rape intercropping were not different from sole maize cropping, except for weed biomass at maize physiological maturity in 2002/3 and weed density at six WAE in 2003/4.

4.3.4 Intercrop productivity

Both pumpkin and mustard rape partial LER values increased with increasing intercrop densities. However, LER values were lower in maize-mustard rape intercrops compared to maize-pumpkin at UZF in 2002/3. The highest intercropping yield advantage (LER) (1.45) was recorded in the 35.3 % maize-pumpkin intercrop whilst the least (1.13) was in the 35.3 % maize-mustard rape intercrop (Table 4.10). Similarly, at UZF in 2003/4, LER values increased with increasing intercrop density and were higher for pumpkin compared to mustard rape intercrops. Mustard rape partial LER values were lower in the second planting compared to the first planting.

Maize partial LER values decreased with higher mustard rape densities and higher pumpkin densities in 2002/3. Overall, LER values for both maize-pumpkin and maize-mustard rape intercrops were above unity in both seasons at UZF.

Table 4.8

Table 4.9

Table 4.10: Effects of vegetable intercrop population on the productivity of maize-based intercrops at UZF in the 2002/3 and 2003/4 seasons

Population	Partial LER		LER	Partial LER			LER
	Maize	Pumpkin		Maize	Mustard rape		
					first∞	second☼	
			UZF 2002/3				
11.7 %	1.11	0.25	1.36	1.11	-	0.05	1.16
23.5 %	1.00	0.31	1.32	1.03	-	0.07	1.10
35.3 %	1.06	0.39	1.45	0.97	-	0.16	1.13
			UZF 2003/4				
11.7 %	1.04	0.17	1.21	0.98	0.10	0.07	1.15
23.5 %	0.96	0.31	1.28	0.99	0.15	0.10	1.24
35.3 %	1.06	0.52	1.56	0.93	0.25	0.15	1.33

∞ First planting of mustard rape; ☼ Second planting of mustard rape.

At the on-farm environments, pumpkin partial LER values for both leaf and fruit increased with increasing pumpkin intercrop density, except at Gowakowa in 2003/4, where fruit partial LER decreased with increasing pumpkin intercrop density (Table 4.11). Maize partial LER was differently affected by pumpkin intercrop density, with a marked decrease with increasing pumpkin density at Bingaguru and Chinyudze in 2003/4 and higher values in the 23.5 % maize-pumpkin intercrop at Chinyudze in 2002/3 and Gowakowa in 2003/4. Gowakowa had the lowest maize partial LER values, 0.69 being recorded in the 35.3 % maize-pumpkin intercrop.

Overall, LER values for all the on-farm environments were above unity, with the highest being 2.36 recorded in the 35.3 % maize-pumpkin intercrop at Bingaguru in 2003/4. Similar to pumpkin partial LER, LER values at the on-farm environments increased with increasing pumpkin density, with the exception of Gowakowa in 2003/4 where the highest pumpkin density recorded the least LER value.

Table 4.11: Effects of pumpkin intercrop population on the productivity of Maize-based intercrops on-farm.

Population	Partial LER			LER	Partial LER			LER
	Maize	Pumpkin			Maize	Pumpkin		
		Chinyudze 2002/3				**Chinyudze 2003/4**		
		Leaf♣	Fruit◊			Leaf♣	Fruit◊	
11.7 % M-P	1.08	0.35	-	1.43	1.10	0.37	0.38	1.85
23.5 % M-P	1.23	0.98	-	2.21	0.95	0.46	0.48	1.89
35.3 % M-P	0.93	1.16	-	2.09	0.99	0.62	0.66	2.27
		Gowakowa 2003/4				**Bingaguru 2003/4**		
		Leaf♣	Fruit◊			Leaf♣	Fruit◊	
11.7 % M-P	0.78	0.27	0.39	1.44	1.13	0.34	0.35	1.82
23.5 % M-P	0.89	0.32	0.38	1.59	1.05	0.48	0.47	2.00
35.3 % M-P	0.69	0.37	0.37	1.43	1.09	0.59	0.68	2.36

♣ Dry leaf partial LER; ◊Fresh fruit partial LER; M-P = maize-pumpkin intercrop.

4.4 Discussion

Generally, the Bingaguru environment, being sandy and having received low rainfall over the two seasons, experienced low yields. At Chinyudze, the soils were less sandy than either Gowakowa or Bingaguru, thus explaining the high yields for both maize and pumpkin. Yields were lower in 2002/3 overall, due to the low rainfall experienced during that season. The lower rainfall received at on-farm environments favoured pumpkin fruit development and increased the duration of pumpkin vines in the intercrops as they were less susceptible to mildew diseases, compared to UZF where vine senescence was hastened by the prevalence of mildew diseases which are associated with high rainfall levels.

However, the lower rainfall that was favourable for pumpkin fruit development on-farm could not sustain mustard rape in the field, resulting in its complete failure. The inadequate moisture effect was also observed at UZF in 2002/3 where the first planting of mustard rape also failed. This result suggests that the intercropping of mustard rape with maize is only possible in high rainfall areas or where supplementary irrigation is available. The result also supports the notion by

Schippers (2002) that intercropping of mustard rape with field crops under rainfed conditions in Zimbabwe has generally waned due to continued decline in rainfall.

The stability of maize yields whether in pure stands or intercropped, especially at UZF suggests that maize was a dominant component in the intercrops. It has been noted that a dominant component in intercrops grows and yields the same as in sole cropping (Saka *et al*, 1993). The height advantage of maize over the vegetables possibly allowed receipt of similar amounts of light whether in intercrops or in pure stands. The stability of the maize yield in the intercrops makes maize-vegetable intercrops attractive to smallholder farmers, whose main goal of intercropping is food security (Njoroge, 1999) and maintenance of a high main crop yield. However, where pumpkin growth is vigorous, maize dominance might be checked. Results from Gowakowa, where soil available phosphorus was higher than Chinyudze indicated a vigorous pumpkin crop can be highly competitive and therefore, reduce maize grain yield significantly. This might present a challenge when farmers introduce pumpkin in maize on fertile patches such as places near cattle kraals.

Competition for growth resources such as light, water and mineral nutrients in the intercrops could have reduced mustard rape growth as indicated by the reductions in plant height, leaf size, length of the vegetative phase and the number of leaves harvested per plant. This was especially so, in the second planting of mustard rape at UZF where shading seemed more intense than in the first planting where the maize canopy had not fully developed by then. Having been established earlier, maize had a competitive advantage over the second planting of mustard rape, for nutrients due to a deeper and more extensive root system, and for light through its height. The competition effect therefore, explains the reduced leaf yields in intercropping compared to vegetable pure stands. However, it is noteworthy that the intercropping advantage expressed as LER, in the second planted mustard rape intercrops is therefore, mainly a consequence of the stability of maize grain yield stability in intercrops.

However, the first planting of mustard rape recorded higher leaf yields and partial LER values compared to the second planting. This can be attributed to less competition at the early stages of growth as the maize plants were then not yet out-competing mustard rape due to shorter height and had a smaller root volume.

The seemingly low mustard rape leaf yields and partial LER values can be also attributed to the low populations used in the intercrops compared to the pure stand densities. Mustard rape intercropped at 11.7 %, 23.5 % and 35.3 % of the maize population was 6.54 %, 13.07 % and 19.61 % of the mustard rape pure stand density respectively. This was however, different in pumpkin, where intercropped at 11.7 %, 23.5 % and 35.3 % of the maize population; it was 55.56 %, 111.11 % and 166.67 % of the pumpkin sole crop population, respectively. This explains the relatively high partial LER for intercropped pumpkin. Pumpkin population densities in the 23.5 % and 35.3 % maize-pumpkin intercrops were higher but yielded less leaves and fruits than the pure stands. This is attributable to the fact that pumpkin plants in these intercrops were so reduced in growth that their higher numbers could not out yield the fewer larger plants in the pure stands. Therefore, this result also emphasises the suppression of pumpkin in maize intercrops.

The above scenario explains why Huxley and Maingu (1978) pointed out the need for yield LER analysis only at optimum populations of both the intercrop and the sole crop. In this study, the results suggest that the LER values are density-dependent since the growth parameters such as leaf size, duration and height or vine length for the two vegetables were not significantly affected by the intercrop densities. The density-dependence of pumpkin fruit partial LER can be attributed to the fact that in pumpkins, each vine has a cultivar specified optimum number of fruits it can produce in a given environment (Rice, Rice and Tindall, 1983).

An increase in LER with increasing relative population means that farmers may increase the densities of the component pumpkin and mustard rape to increase the benefit of intercropping, the supply of relish. For any intercrop to be attractive to the risk-averse smallholder farmer, it has to give a yield advantage as compared to pure stands. In mustard rape intercrops, the second planting (at 11 WAE of maize), can also be used to augment leaf yields from the first planting without any additional fertilizer application.

The reduction in mustard rape growth parameters and leaf yields in both sole cropping and intercropping in the second planting can be attributed to the declining light quality due to frequent overcast conditions, which usually prevail as the season progresses. Light quality is usually very critical for the 'take' of newly established plants (Board, 2000). The reduction in mustard rape leaf size in the second planting may reduce acceptability by farmers. Plant height is also of importance as it determines the clearance of leaves to avoid mud splashed leaves, especially in rainfed mustard rape and therefore, the taller plants in pure stands and in the first planting may increase farmer acceptability.

In pure pumpkin stands growth was better, as shown by the larger leaf sizes and vine length compared to the intercrops, probably due to the absence of competition for growth resources with maize. Therefore, the resultant pumpkin plant canopy was denser than in intercropping. A large or dense plant canopy has been shown to effectively suppress the germination and growth of weeds through limiting the amount of light that reaches the ground. Some weed seeds require light for germination (Pressman, Ngebi, Sachs and Jacobsen, 1977). It has also been observed that the growth of weeds is reduced by filtration of light by a plant canopy (Bridgemohan, 1995).

Therefore, the inclusion of pumpkin in maize intercrops could have had a synergistic effect on reducing the amount of light reaching the under canopy, resulting in lower weed density and weed biomass in maize-pumpkin intercrops compared to maize pure stands. The results suggest that the canopy got denser with increasing pumpkin intercrop density, hence lower weed density and weed biomass at higher pumpkin densities in maize-pumpkin intercropping. Shading by the crop canopy has been recognized as the main factor promoting weed suppression in intercrops (Baumann, Bastiaans and Kropff, 2001).

However, the failure of maize-mustard rape intercrops to significantly contribute to weed suppression can be attributed to the smaller leaf area and erect growth habit of mustard rape compared to the larger-leaved and prostrate pumpkin. Similarly, the failure of mustard rape pure stands to effectively smother weeds can be attributed to the erect growth habit and small leaf area. The suppression of weeds in an intercrop is an attractive advantage to the farmers as this reduces the frequency of weeding; implying that weeding in certain fields can be delayed during times of labour bottlenecks.

Overall, the intercrops studied herein are beneficial compared to sole cropping, but benefits seem to be density-dependent; weed suppression, leaf and fruit yields, and LER values.

4.5 Conclusions

- Intercropping maize and pumpkin reduced pumpkin yield-related attributes such as leaf size, duration and vine extension by 37 %, 39 % and 49 % on average, respectively.
- Similarly, intercropping maize mustard rape reduced mustard rape yield-related attributes such as leaf size (by 8.25 % with simultaneous planting and 62.3 % when planted at 10 WAE of maize) and length of vegetative phase by 30 % irrespective of mustard rape intercrop populations.
- Increasing vegetable intercrop populations to 35.3 % of maize increased pumpkin and mustard rape leaf yields by up to 215 % and 150 % respectively, compared to intercropping at 11.7 % of the maize population.
- Generally, maize grain yield was maintained with intercropping, except at a relatively drier site, Gowakowa where, at 35.3 % of the maize population, vigorously growing and high fruit yielding pumpkin reduced maize grain yield by about 30 %.
- Intercropping with pumpkin significantly reduced weed density and weed biomass, with higher densities being more effective compared to maize sole cropping whilst mustard rape intercropping had very slight effects on weeds.
- Planting mustard rape at 10 WAE of maize reduced dry leaf yields to 40 % and 13 % of the yields in mustard rape pure stands and intercrops simultaneously planted with maize respectively. However, this does not affect maize yields, and therefore, can still be practiced to supplement relish availability.

- Mustard rape intercropping with maize requires relatively wetter environments as was shown by the failure on-farm in both 2002/3 and 2003/4 seasons and at UZF in 2002/3 due to inadequate soil moisture conditions

4.6 Recommendations

- Farmers can adopt the use of pumpkin populations of up to 35.3 % of maize population for reduced weed growth compared to maize sole cropping, and also, higher leaf yields compared to 11.7 % maize-pumpkin intercropping. However, in drier areas pumpkin populations below 35.3 % should be used to minimize maize grain yield losses.
- Mustard rape populations should be increased to levels beyond 35.3 % of maize population to increase leaf yields, and possibly weed suppression as well.
- Farmers should plant mustard rape simultaneously with maize for high leaf yields. Double cropping of mustard rape can be adopted to increase availability of mustard rape in the summer season without additional fertilizer inputs, but only in wetter areas. However, the second planting of mustard rape at 10 WAE of maize, should only be used, if need be, as a supplement to the mustard rape crop simultaneously planted with maize.
- In drier areas, studies should focus on introduction of mustard rape during the ‘wettest’ part of the season.
- There is a need for reducing the suppression of pumpkin and mustard rape in intercrops, possibly by identifying short - statured popular food crops, such as groundnut.

CHAPTER 5

5.0 EFFECTS OF PUMPKIN AND MUSTARD RAPE POPULATIONS ON PRODUCTIVITY AND WEED SUPPRESSION IN GROUNDNUT–PUMPKIN AND GROUNDNUT – MUSTARD RAPE INTERCROPS

5.1 Introduction

Mustard rape and pumpkin are grown in association with important food crops such as maize and groundnut in summer, however, the previous chapter has highlighted their suppression in maize intercrops, probably due to height differences. Therefore, there is a need for assessing their performance in groundnut-based intercrops for improving their productivity in intercropping systems.

Groundnut is one of the important food crops in the smallholder farming systems of Zimbabwe (Natarajan and Zharare, 1994) due to its pleasant flavour, high nutrition and returns. Much of the groundnut produced in Africa is produced in intercrops, for instance, 95% of groundnut is produced in intercrops in Nigeria (Okigho and Greenland, 1976). In Zimbabwe groundnut is not intercropped systematically, though isolated maize, sorghum, sunflower or traditional vegetable plants can be found in groundnut fields. Therefore, the vegetable populations that exist in groundnut intercrops and their effects are not known. Very little research has been done on intercropping groundnut in southern Africa, including Zimbabwe (Chiteka *et al*, 1992). Elsewhere, contrasting results on intercropping populations have been reported in other crops, for instance Herrera, Samson and Hardwood (1975) and Osiru and Willey (1972).

Though intercropping pumpkin and mustard rape with food crops seems to be inherent in Zimbabwe, most smallholder farmers do not seem to appreciate other benefits that are associated with intercropping, apart from supplementary leaf and fruit harvests. For instance, Mashingaidze *et al.* (2000) demonstrated that intercropping maize and pumpkin reduced the frequency of weeding as compared to maize sole cropping in Zimbabwe. Whilst it seems that weeding, which takes up most of the smallholder farmers' time, can be reduced by intercropping systems, the ideal populations that can also assure leaf vegetable availability in summer have not been established.

Previous research, for instance, Lal *et al*. (1998), Narayan *et al*. (1999) and Mashingaidze *et al.* (2000), focused on pumpkin and mustard rape growth parameters and seed yields but not leaf yields, which are equally important in the smallholder farming communities. To date, there are no records of pumpkin and mustard rape leaf yields in groundnut intercrops nor are there specific planting dates. The results from previous research studies are based on pumpkin and mustard rape not subjected to leaf picking for leaf vegetable. Therefore, it remains obscure whether the previous results on weed suppression in intercrops can still apply when the vegetables are harvested for leaf vegetable and in sequentially in groundnut intercrops.

A successful combination of groundnut and pumpkin or mustard rape is likely to generate a lot of interest in women's cropping systems as all the crops in this study are considered women's crops. This study was aimed at investigating the effects of three levels of pumpkin and mustard rape populations on yields of intercrop components and weed suppression in groundnut-vegetable intercrops. The objectives of this study were:

i) To quantify the effects of pumpkin and mustard rape populations on yields of all components and weed suppression in groundnut–pumpkin and groundnut – mustard rape intercrops.
ii) To evaluate the effects of double cropping mustard rape on leaf yields and seed yields in groundnut–mustard rape intercrops.

It was hypothesized that:

i) Higher pumpkin and mustard rape populations increase leaf vegetable yields and weed suppression, but reduce groundnut seed yield in groundnut- pumpkin and groundnut – mustard rape intercrops.
ii) Double cropping of mustard rape increases seasonal leaf yields due to 'two crops' in one season whilst reducing groundnut seed yield due increased competition in groundnut–mustard rape intercrops.

5.2 Materials and Methods

The study was conducted at the University Farm (UZF) in Harare and at three on-farm sites in Chinyudze, Gowakowa and Bingaguru areas of Chinyika Resettlement Area (CRA) during the 2002/3 and 2003/4 seasons. Characteristics of the study areas are described in Sections 3.1 and 3.2 of the General Materials and Methods section. Suffixes to the site names are used as described in Section 3.6 of the General Materials and Methods.

At each site the treatments were groundnut intercropped with three pumpkin relative populations of 0.46 %, 0.92 % and 1.84 % of the groundnut population and three mustard rape relative populations of 4.15 %, 8.29 % and 12.44 % of the groundnut population. Groundnut, mustard rape and pumpkin pure stands were also established as controls. The treatments were arranged in a randomized complete block design with three blocks at each site in CRA and four blocks at UZF.

All plots measured 5 m long x 3 m wide. A short season groundnut variety, “Spanish,” also known as “Natal Common,” was planted in rows 0.45 m apart with inrow spacing of 0.08 m in both intercrops and pure stands. Spacing of pumpkin and mustard rape sole crops and the characteristics of the cultivars are described in Section 3.4 of the General Materials and Methods. The vegetables were planted between the groundnut rows. All crops in the study were planted simultaneously, except at UZF where there were two plantings of mustard rape as described in Section 3.5 of the General Materials and Methods. Three seeds were sown per station for pumpkin and a pinch of seed per station for mustard rape. At three weeks after emergence (WAE) of groundnut, both pumpkin and mustard rape were thinned to one plant per station, just after the first weeding.

All plots received an application of basal fertilizer (5 % N, 17 % P_2O_5, 10 % K_2O, 8 % S, and 0.25 % B) at a rate of 250 kg ha^{-1} at planting. Crops were weeded at 7 and 11 WAE of groundnut. At 8 WAE, groundnut received an application of calcium sulphate at a rate of 250 kg ha $^{-1}$. There was no side dress fertilizer applied to both pumpkin and mustard rape in intercrop and sole plots apart from the basal fertilizer. This was done to simulate smallholder farmer practice; in groundnut intercrops, the intercrops only benefit from the basal fertilizer that is applied to groundnut and there is no additional side dress for particular crops in the intercrop. Weed density and biomass were determined by randomly throwing a 0.3 m x 0.3 m quadrant five times in each plot before weeding at 7 and 11 WAE, and also at groundnut physiological maturity. Weeds in the quadrants were counted, cut at ground level and then oven-dried at 70 ºC for 48 hours.

Leaves were harvested for both pumpkin and mustard rape using traditional criterion of tenderness. Pumpkin leaves were harvested fortnightly from each growing tip from six WAE up to the time of harvesting groundnut. Mustard rape leaves were harvested weekly from three WAE of groundnut till the plants produced no further leaves. Leaf area was measured using a LI 3100 leaf area meter (LI-COR, Lincoln, USA). Pumpkin vine length was also recorded up to the time of harvesting groundnuts. Groundnut seed moisture content was determined using a moisture tester (NJF 1210 Moisture Tester, N.J. Fromet & Co. Ltd, Stamford, England) and groundnut 1000-seed weight and seed yield were standardized to 7.5 % moisture content as described in Section 3.6 of the General Material and Methods. The number of pods per plant was determined from five randomly picked groundnut plants from each net plot. The groundnut net plot was 1.35 m wide x 4 m, while for pumpkin all plants in each plot were subjected to leaf harvesting as the plants had entangled, making it impossible to select plants from the net plot. The mustard rape net plot was 2 m wide x 4 m long in pure stands and all plants in the groundnut net plot in the intercrops

Apart from leaf yields and leaf area, the following were also recorded for pumpkin, vine length, growth duration and fruit yield. The number of days to flowering was also recorded in mustard rape. Pumpkin and mustard rape dry leaf yields and groundnut seed yield figures were used to calculate Land Equivalent Ratio (LER) values as described in Section 3.6 of the General Materials and Methods. All data were subjected to analysis of variance (ANOVA) using Genstat Statistical Package (Lawes Agricultural Trust, 2002) after testing for normality. Combined analysis over sites and seasons were only done when variances were show found to be homogeneous in the test for homogeneity of variances.

5.3 Results

5.3.1 At the University Farm

At UZF, 1000 seed weight in groundnut was significantly ($p < 0.05$) reduced in the 0.92% groundnut-pumpkin intercrop compared to the pure stands in 2002/3 (Table 5.1). Intercropping had no effects on the number of pods per plant in 2002/3 and 1000 seed weight in 2003/4. However, in 2003/4, the number of pods per plant was reduced by increasing pumpkin intercrop density, and not by mustard rape intercrop density.

Table 5.1: Effects of cropping system on 1000 seed weight and number of pods per plant in groundnut at UZF in the 2002/3 and 2003/4 seasons.

	UZF 2002/3		UZF 2003/4	
Cropping system	**1000 seed weight (g)**	**Pods plant^{-1}**	**1000 seed weight (g)**	**Pods plant^{-1}**
0.46 % G-P	172.10 ab	31.20	207.76	25.03 a
0.92 % G-P	137.70 c	23.20	197.19	24.53 ab
1.84 % G-P	166.20 ab	21.80	211.82	21.39 b
4.15 % G-MR	150.10 bc	24.00	205.80	26.43 a
8.29 % G-MR	156.60 abc	24.00	213.64	24.95 a
12.44 % G-MR	172.80 a	28.80	206.99	25.00 a
Sole groundnut	171.50 ab	33.90	201.25	27.00 a
Significance	*	ns	ns	*
$LSD_{0.05}$	22.22	-	-	3.22
CV (%)	9.30	21.60	10.70	8.70

G-P = groundnut-pumpkin intercrop; G-MR = groundnut-mustard rape intercrop; Means with the same letter in a column are not significantly different; *= $p<0.05$; $LSD_{0.05}$= Least Significant Difference at $p = 0.05$; CV= coefficient of variation.

Homogeneity of variances test showed that groundnut seed yield at UZF could be combined over the 2002/3 and 2003/4 seasons. Groundnut seed yield was affected by the interaction between season and cropping system at UZF. In 2002/3, groundnut seed yield was reduced by intercropping with pumpkin whilst it was not affected by intercropping with mustard rape. However, there were no significant effects of pumpkin density on groundnut seed yield. In 2003/4, intercropping with either vegetable had no effects on groundnut seed yield (Figure 5.1A).

Tests for homogeneity of variances showed that vine length, growth duration, leaf size and leaf yield in pumpkin at UZF could be combined over the 200/3 and 2003/4 seasons. The interaction effect of season and intercrop population also influenced pumpkin vine length. In 2002/3, pumpkin vine length was reduced by intercropping at 0.46 % and 1.84 % of groundnut, whilst in 2003/4 there were no differences in vine length between intercrops and pure stands (Figure 5.1B).

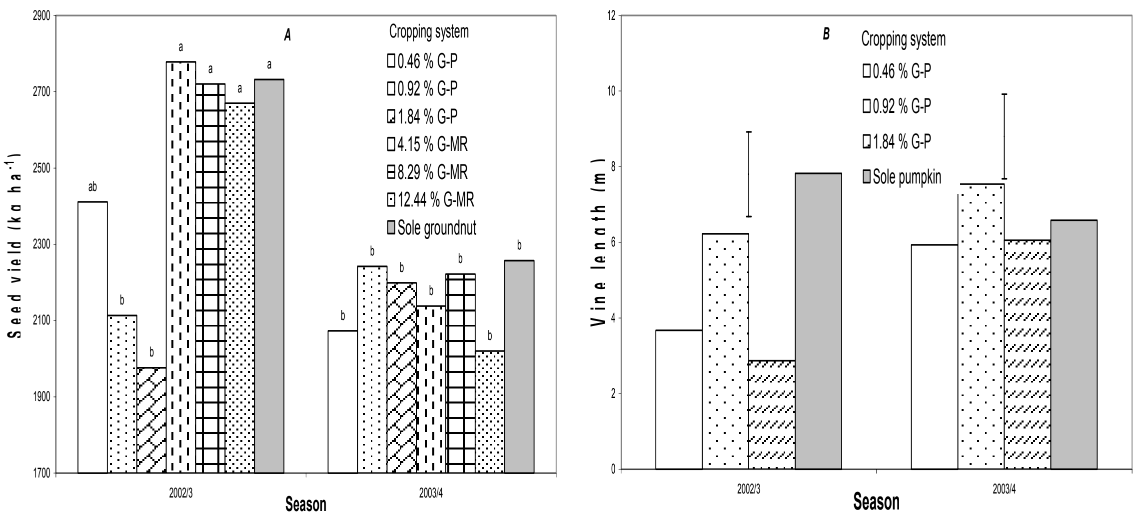

Figure 5.1: Effects of season and cropping system on A) groundnut seed yield and B) pumpkin vine length at the University Farm. MR= Mustard rape. Histograms with different lower case letters on Figure 5.1A indicate significant differences ($p < 0.05$) between means (Duncan's Multiple Range Test). Bars on Figure 5.1B represent $LSD_{0.05}$ values.

The interaction effects between season and cropping system were not significant for growth duration, leaf size and leaf yield. Overall, these parameters were higher in the 2003/4 season compared to the 2002/3 season. Intercropping significantly ($p < 0.001$) reduced pumpkin growth duration from 140 days in pure stands to 128 days at UZF, with pumpkin intercrop density having no effect (Table 5.2). Similarly, pumpkin leaf size and dry leaf yield were reduced by 42 % and 68 % compared to corresponding values in pure stands respectively. Pumpkin leaf size decreased whilst dry leaf yield increased with increasing pumpkin intercrop density.

Tests for homogeneity of variances showed that length of the vegetative phase and dry leaf yield in the second planting of mustard rape at UZF could be combined over the 200/3 and 2003/4 seasons. Mustard rape vegetative period and dry leaf yield values were significantly higher ($p < 0.05$) in 2003/4 compared to 2002/3. Both parameters were significantly reduced ($p < 0.001$) by intercropping, without mustard rape intercrop density effects on the former (Table 5.3). However, increasing mustard rape intercrop population to 12.44 % of groundnut increased mustard rape dry leaf yield to 257 % of the yield in the 4.15 % groundnut-mustard rape intercrop.

Table 5.2: Effects of season and cropping system on pumpkin duration, leaf size and dry leaf yield at UZF over the 2002/3 and 2003/4 seasons

Factors		**Duration‡ (days)**	**Leaf size (cm^2)**	**Dry leaf yield (kg ha^{-1})**
Season	**2002/3**	123.69 b	331.80 b	276.40 b
	2003/4	137.50 a	453.40 a	408.10 a
	Significance	*	***	**
	LSD $_{0.05}$	9.21	33.16	41.06
Cropping System	**0.46 % G-P**	126.75 b	461.20 a	177.30 c
	0.92 % G-P	127.75 b	377.40 b	301.70 b
	1.84 % G-P	128.12 b	267.90 c	341.90 b
	Sole pumpkin	139.75 a	463.90 a	548.10 a
	Significance	***	***	**
	LSD $_{0.05}$	5.10	58.85	42.53
	CV (%)	3.70	14.30	11.80

‡ Duration = Pumpkin growth duration; G-P = groundnut-pumpkin intercrop; Means with the same letter in a column are not significantly different; * = $p < 0.05$, ** = $p < 0.01$, ***= $p<0.001$; $LSD_{0.05}$= Least Significant Difference at p = 0.05; CV = coefficient of variation.

Mustard rape leaf size was significantly influenced ($p < 0.05$) by the interaction between time of planting and cropping system. There were no significant differences in mustard rape leaf size between sole cropping and intercropping in the first planting, whilst leaf size was significantly reduced by intercropping in the second planting. However, there were no density effects on leaf size for both planting times (Figure 5.2A). The interaction effect between time of planting and intercrop population was also significant ($p < 0.001$) for mustard rape dry leaf yield. In the first planting, mustard rape dry leaf yield significantly increased with increasing mustard rape intercrop density, whilst there were no density effects in the second planting. At both planting times, mustard rape dry leaf yield was reduced by intercropping to 41 % and 7 % of the corresponding pure stand yields in the first and second planting respectively (Figure 5.2B).

Table 5.3: Effects of season and cropping system on length of the vegetative period and dry leaf yield in the second planting of mustard rape at UZF over the 2002/3 and 2003/4 seasons

Factors		LVP§ (days)	Dry leaf yield (kg ha^{-1})
Season	**2002/3**	36.27 b	92.00 b
	2003/4	38.88 a	103.00 a
	Significance	*	*
	LSD $_{0.05}$	2.55	8.18
Cropping System	**4.15 % G-MR**	34.91 b	20.30 c
	8.29 % G-MR	33.75 b	26.90 b
	12.44 % G-MR	34.00 b	52.20 b
	Sole mustard rape	47.62 a	290.70 a
	Significance	***	***
	LSD $_{0.05}$	3.35	15.03
	CV (%)	8.50	14.70

§ LVP = Length of the vegetative phase; G-MR = groundnut-mustard rape intercrop.
Means with the same letter in a column are not significantly different;
* = $p < 0.05$, ***= $p < 0.001$; $LSD_{0.05}$= Least Significant Difference at $p = 0.05$;
CV = coefficient of variation.

5.3.2 On-farm (CRA)

Homogeneity of variances showed that 1000 seed weight and the number of pods per plant in groundnut could be combined over the on-farm sites in the 2002/3 and 2003/4 seasons. In 2002/3, 1000 seed weight was significantly affected ($p < 0.01$) by site. Groundnut seed was smaller at Chinyudze compared to Gowakowa or Bingaguru. However, the number of pods per plant was not affected by site. Intercropping and sole cropping had no effects on both 1000 seed weight and the number of pods per plant on-farm in 2002/3 (Table 5.4).

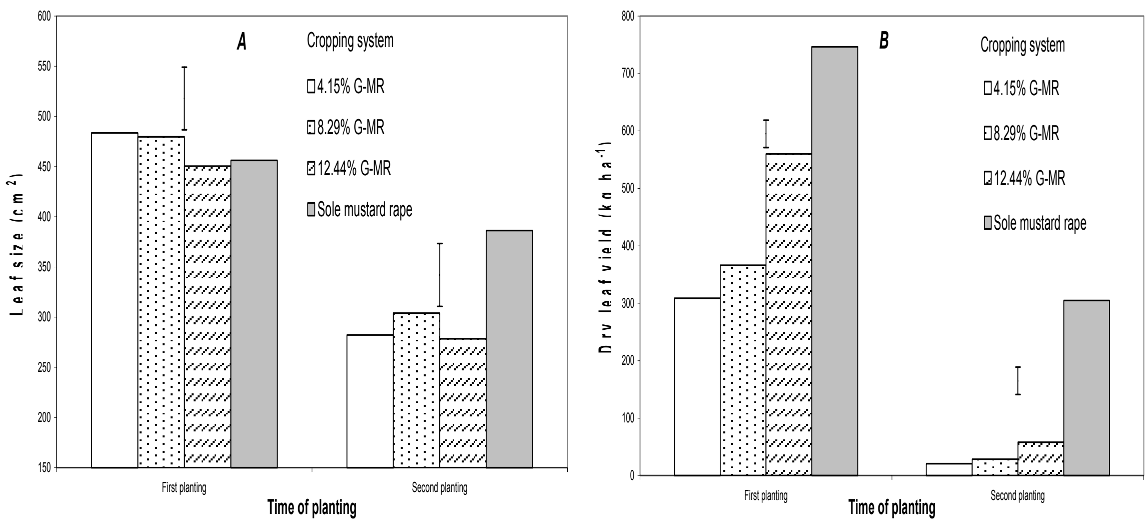

Figure 5.2: Effects of time of planting and cropping system on mustard rape at UZF in 2003/4: A) leaf size and B) dry leaf yield. Bars on the graphs represent $LSD_{0.05}$ values

Table 5.4: Effects of cropping system on groundnut 1000 seed weight and number of pods per plant over the on-farm sites in the 2002/3 season.

Factors		**1000 seed weight (g)**	**Pods plant^{-1}**
Site	**Chinyudze**	137.30 b	13.92
	Gowakowa	155.50 a	13.42
	Bingaguru	156.60 a	14.70
	Significance	**	ns
	$LSD_{0.05}$	10.09	-
Cropping system	**0.46 % G-P**	148.90	15.56
	0.92 % G-P	150.70	14.53
	1.84 % G-P	152.50	13.33
	Sole groundnut	147.00	12.62
	Significance	ns	ns
	$LSD_{0.05}$	-	-
	CV (%)	5.10	19.50

G-P = groundnut-pumpkin intercrop; Means with the same letter in a column are not significantly different; * = $p < 0.05$, ** = $p < 0.01$, ***= $p<0.001$; $LSD_{0.05}$ = Least Significant Difference at $p = 0.05$; CV = coefficient of variation.

In the 2003/4 season, 1000 seed weight and the number of pods per plant was significantly affected ($p < 0.05$) by the interaction effects between on-farm site and cropping system. Groundnut 1000 seed weight was not affected by intercropping or sole cropping at Bingaguru whilst it was reduced by intercropping at Chinyudze and Gowakowa (Figure 5.3A). At the two latter sites, 1000 seed weight significantly decreased with increasing pumpkin intercrop density. Intercropping and sole cropping had no effects on the number of pods per plant at Chinyudze and Bingaguru in 2003/4. However, Gowakowa intercropping reduced the number of pods per plant in groundnut, with pumpkin intercrop density having no effect (Figure 5.3B).

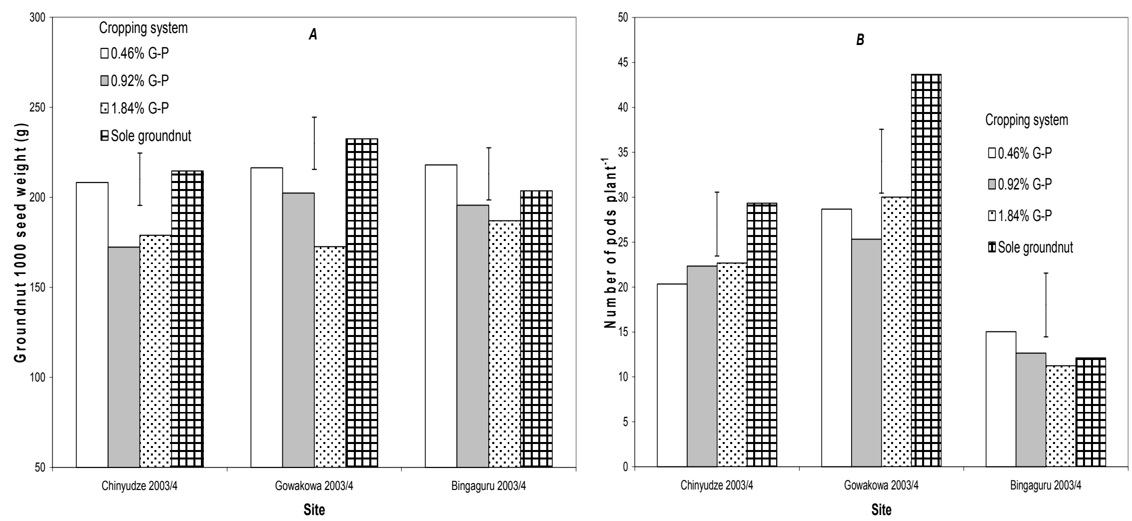

Figure 5.3: Effect of the interaction between site and cropping system on A) 1000 seed weight and B) Number of pods per plant in groundnut on-farm in the 2003/4 season. G-P = groundnut-pumpkin intercrop

Generally, at all the on-farm sites in both the 2002/3 and 2003/4 seasons groundnut seed yield was significantly reduced (at least $p < 0.05$) by intercropping with pumpkin. In 2002/3, groundnut seed yield was reduced by 45 %, 17 % and 19 % in intercrops compared to the corresponding sole crop yields at Chinyudze, Gowakowa and Bingaguru respectively. Groundnut seed yield decreased with increases in pumpkin intercrop population (Table 5.5). Groundnut seed yield was relatively higher in 2003/4 compared to 2002/3.

In 2002/3, intercropping reduced both leaf size and dry leaf yield of pumpkin at all on-farm sites, except at Bingaguru where intercropping had no effect on leaf size (Table 5.6). At all on-farm sites, the largest pumpkin leaves and the highest dry leaf yield were recorded in pumpkin pure stands in 2002/3. Pumpkin leaf yield increased, whilst leaf size decreased with increasing pumpkin intercrop density.

Table 5.5: Effects of cropping system on groundnut seed yield on-farm in the 2002/3 and 2003/4 seasons.

	Groundnut seed yield (kg ha^{-1})		
Cropping system	**Chinyudze 2002/3**	**Gowakowa 2002/3**	**Bingaguru 2002/3**
0.46 % G-P	575.00 b	648.00 ab	553.10 b
0.92 % G-P	440.00 bc	614.70 bc	519.60 c
1.84 % G-P	412.00 c	573.40 c	484.30 d
Sole groundnut	748.00 a	690.50 a	600.00 a
Significance	**	**	***
$LSD_{0.05}$	135.70	48.86	19.52
CV (%)	12.50	3.90	1.80
	Chinyudze 2003/4	**Gowakowa 2003/4**	**Bingaguru 2003/4**
0.46 % G-P	698.00 b	960.00 ab	584.50 ab
0.92 % G-P	635.50 c	860.00 bc	560.30 bc
1.84 % G-P	605.90 c	703.00 c	537.20 c
Sole groundnut	762.50 a	1155.00 a	601.30 a
Significance	***	*	*
$LSD_{0.05}$	46.11	212.40	38.26
CV (%)	3.40	11.60	3.40

G-P = groundnut-pumpkin intercrop; Means with the same letter in a column are not significantly different; * = $p < 0.05$, ** = $p < 0.01$, ***= $p<0.001$; $LSD_{0.05}$ = Least Significant Difference at $p = 0.05$; CV = coefficient of variation.

Similar to the trend in the 2002/3 season, intercropping reduced pumpkin leaf size, dry leaf yield and fruit yield in 2003/4, except for leaf size at Chinyudze and fruit yield at Gowakowa. Pumpkin intercrop density had no effects on leaf size at Bingaguru and, leaf yield at Chinyudze and Gowakowa in 2003/4. However, leaf and fruit yields at Bingaguru, and fruit yield at Chinyudze all increased with increasing pumpkin intercrop density, whilst leaf size decreased with pumpkin intercrop density at Gowakowa in 2003/4.

Table 5.6

5.3.3 Weed Dynamics

Tests for normality showed that some data, from UZF and the on-farm sites needed transformation before being subjected to analysis of variance. Further, tests for homogeneity of variances showed that weed density and weed biomass data at UZF and the on-farm sites could not be combined over the 2002/3 and 2003/4 seasons.

In the 2002/3 season, the first planting of mustard rape at UZF failed, therefore, weed dynamics in mustard rape intercrops before the second planting will not be reported herein. Throughout the 2002/3 season, intercropping with pumpkin significantly reduced weed density and weed biomass compared to groundnut sole cropping, except for weed density at 11 WAE of groundnut. However, there were no effects of intercrop density on weed density and weed biomass at UZF in 2002/3 (Table 5.7). At groundnut physiological maturity weed density and weed biomass were lower in groundnut-pumpkin intercrops compared to groundnut-mustard rape intercrops. Overall, the lowest weed density and weed biomass were recorded in pumpkin pure stands.

Similar to the trend in the 2002/3 season, the highest weed density and weed biomass were in groundnut pure stands whilst the least were in pumpkin pure stands at UZF in 2003/4. Intercropping significantly reduced ($p < 0.001$) weed density and weed biomass compared to groundnut sole cropping throughout the 2003/4 season, with the exception of weed density at 11 WAE of groundnut. However, there were no intercrop density effects, except at groundnut physiological maturity when weed density and weed biomass reduced with increasing intercrop density, only in the groundnut-pumpkin intercrops (Table 5.8). Throughout the 2003/4 season, weed density and weed biomass were lower in groundnut-pumpkin intercrops compared to groundnut-mustard rape intercrops.

In 2002/3 at Chinyudze and Bingaguru, the lowest weed density and weed biomass were recorded in pumpkin pure stands, whilst the highest were in groundnut pure stands. Intercropping reduced both parameters compared to groundnut sole crops, however, effects pumpkin intercrop population were only recorded for weed density at seven WAE of groundnut at Chinyudze, and weed density and weed biomass at seven and 11 WAE of groundnut at Bingaguru (Table 5.9).

Table 5.7

Table 5.8

Table 5.9

At Gowakowa in 2002/3 intercropping and sole cropping had effects on weed density and weed biomass at seven WAE, and weed biomass at groundnut physiological maturity. For these three, weed density and weed biomass reduced with increasing pumpkin intercrop density, but without differences between 0.92 % and 1.84 % groundnut-pumpkin intercrops. The lowest weed density and weed biomass were recorded in the pumpkin pure stands, but were also not different from values recorded in 1.84 % groundnut-pumpkin intercrops (Table 5.10).

Unlike at Gowakowa in 2002/3, intercropping and sole cropping had significant (at least $p < 0.05$) effects on weed density and weed biomass at Bingaguru in 2003/4, with the exception of weed density at seven WAE of groundnut. Increasing pumpkin intercrop density significantly reduced weed biomass at seven WAE, 11 WAE and physiological maturity of groundnut. At all the times when cropping system had significant effects, there were no differences in weed biomass and weed density between pumpkin sole crop and the 1.84 % groundnut-pumpkin intercrop at Bingaguru 2003/4.

Intercropping significantly reduced (at least $p < 0.05$) weed density and weed biomass at Chinyudze and Gowakowa throughout the 2003/4 season compared to groundnut sole cropping, except for weed density at 11 WAE of groundnut at Gowakowa. At Chinyudze 2003/4, weed biomass at seven WAE, weed density at 11 WAE and weed biomass at physiological maturity of groundnut all decreased with increasing pumpkin intercrop density. However, density effects were only significant for weed density at seven WAE and weed biomass at 11 WAE of groundnut at Gowakowa 2003/4 (Table 5.11). At both Chinyudze and Gowakowa, the least weed density and weed biomass were recorded in pumpkin pure stands, whilst the highest were in groundnut sole crops in the 2003/4 season.

Table 5.10

Table 5.11

5.3.4 Intercrop Productivity

At UZF in 2002/3, groundnut partial LER values decreased, whilst mustard rape partial LER increased with increasing mustard rape intercrop density. Correspondingly, higher intercrop LER values were obtained with higher mustard rape intercrop populations, but with no difference between 4.15 % and 8.29 % groundnut-mustard rape intercrops (Table 5.12).

Groundnut partial LER values were reduced to below unity at UZF in 2003/4, except in the 8.29 % groundnut-mustard rape intercrop. Mustard rape partial LER were lower in the second planting compared to the first planting. However, for both planting times, mustard rape partial LER values increased with increasing mustard rape intercrop density. Similarly, overall LER increased with increasing mustard rape intercrop density.

Overall, intercrop LER values were higher in 2003/4 compared to 2002/3. However, for both seasons, LER values for all intercrops were above unity, the highest being 1.87 recorded in the 12.44 groundnut-mustard rape intercrop in 2003/4.

Table 5.12: Effects of intercrop population on productivity of groundnut-mustard rape intercrops at the University Farm in the 2002/3 and 2003/4 seasons.

	UZF 2002/3				UZF 2003/4			
Intercrop	**Partial LER**			**LER**	**Partial LER**			**LER**
population	**G/nut**	**MRape**			**G/nut**	**MRape**		
		first[∞]	second[☼]			first[∞]	second[☼]	
4.15 % G-MR	1.02	-	0.07	1.09	0.97	0.41	0.07	1.45
8.29 % G-MR	1.00	-	0.09	1.09	1.03	0.49	0.10	1.62
12.44 % G-MR	0.98	-	0.17	1.15	0.93	0.75	0.19	1.87

G/nut= Groundnut; Mrape = Mustard rape; G-MR = groundnut-mustard intercrop; [∞] First planting of mustard rape; [☼] Second planting of mustard rape.

In groundnut-pumpkin intercrops, groundnut partial LER decreased with increasing pumpkin intercrop density at all sites, except at UZF in 2003/4. Generally, groundnut partial LER values were lower on-farm compared to UZF. The lowest value was 0.56 recorded in the 1.84 % groundnut-pumpkin intercrop at Chinyudze in the 2002/3 season, whilst the highest was 1.0, which was recorded in the 0.92 % groundnut-pumpkin intercrop at UZF in 2003/4.

Similarly, pumpkin leaf partial LER values were also lower on-farm compared to UZF, except for Bingaguru in 2002/3. However, the values increased with increasing pumpkin intercrop populations both at UZF and on-farm (Table 5.13). Pumpkin fruit yields were only obtained on-farm in the 2003/4 season. Pumpkin fruit partial LER increased with increasing intercrop density on-farm in 2003/4, except for Gowakowa where, the highest partial LER value was recorded in the 0.46 % groundnut-pumpkin intercrop. The values were higher at Gowakowa compared to the two other sites.

Similar to groundnut partial LER and pumpkin partial LER values, the intercrop LER values were also density-dependent. At all sites apart from Chinyudze 2002/3 and Gowakowa 2003/4, LER values increased with increasing pumpkin intercrop density. Also, at all sites, LER values were above unity, the highest being 2.1, which was recorded in the 1.84 % groundnut-pumpkin intercrop at Bingaguru in the 2003/4 season.

Table 5.13: Effects of intercrop population on productivity of pumpkin intercrops at the University Farm in the 2002/3 and 2003/4 seasons, and on-farm in the 2002/3 and 2003/4 seasons.

Intercrop population	Partial LER G/nut	Partial LER Pumpkin		LER	Partial LER G/nut	Partial LER Pumpkin		LER
	UZF 2002/3				**UZF 2003/4**			
		Leaf♣	Fruit◊			Leaf♣	Fruit◊	
0.46 % G-P	0.90	0.24	-	1.14	0.93	0.40	-	1.33
0.92 % G-P	0.80	0.50	-	1.30	1.00	0.60	-	1.60
1.84 % G-P	0.75	0.61	-	1.36	0.99	0.65	-	1.64
	Chinyudze 2002/3				**Chinyudze 2003/4**			
		Leaf♣	Fruit◊			Leaf♣	Fruit◊	
0.46 % G-P	0.78	0.16	-	0.94	0.92	0.29	0.27	1.48
0.92 % G-P	0.60	0.50	-	1.10	0.83	0.41	0.39	1.63
1.84 % G-P	0.56	0.33	-	0.89	0.80	0.59	0.53	1.92
	Gowakowa 2002/3				**Gowakowa 2003/4**			
		Leaf♣	Fruit◊			Leaf♣	Fruit◊	
0.46 % G-P	0.91	0.18	-	1.09	0.84	0.26	0.67	1.77
0.92 % G-P	0.89	0.23	-	1.12	0.74	0.38	0.53	1.65
1.84 % G-P	0.83	0.32	-	1.15	0.62	0.44	0.57	1.63
	Bingaguru 2002/3				**Bingaguru 2003/4**			
		Leaf♣	Fruit◊			Leaf♣	Fruit◊	
0.46 % G-P	0.92	0.29	-	1.21	0.97	0.31	0.28	1.56
0.92 % G-P	0.87	0.51	-	1.38	0.93	0.37	0.47	1.77
1.84 % G-P	0.81	0.71	-	1.52	0.90	0.58	0.62	2.10

G/nut= Groundnut; ♣ Dry leaf partial LER; ◊Fresh fruit partial LER; G-P = groundnut-pumpkin intercrop.

5.4 Discussion

Generally, the growth and yields of crops on-farm improved in the 2003/4 season due to an increase in amounts of rainfall received compared to the 2002/3 season. Rainfall was also lower on-farm compared to UZF and this is the main reason for failure of mustard rape on-farm. Furthermore, the soils in CRA are mostly sandy, with a poor water holding capacity, whilst heavy clays are the soils at UZF. This difference in site characteristics partly explains the low groundnut seed yields on-farm. The on-farm groundnut seed yields are however, within the average yields in the smallholder sector in Southern Africa, which range from 400-700 kg ha^{-1}, in contrast to as much as 4000 kg ha^{-1} obtained in research stations and on large-scale commercial farms (Chiteka *et al*, 1992).

The reduced groundnut seed yields in intercrops, especially pumpkin intercrops, compared to sole crops can be ascribed to effects of competition for growth resources such as light water and nutrients between component crops. Higher intercropping populations of pumpkin exerted more competition than lower pumpkin populations or mustard rape. In intercropping, pumpkin leaves shaded the slow growing groundnut. Though not determined in this experiment, shading by the extensive and closely spaced pumpkin vines was evident in higher density groundnut-pumpkin intercrops. Osiru and Willey (1972) also recorded yield reduction with closer spacing of component crops. Mustard rape, which is shorter, more erect and has smaller leaf area per plant compared to the spreading pumpkin, had very little shading effect on groundnut. This makes mustard rape a suitable companion crop where the yield of the main crop has to be maintained.

The extent of groundnut seed yield reduction was higher on-farm where rainfall was limiting, suggesting that competition was higher on-farm, compared to UZF which had supplementary irrigation. Groundnut seed yield was also low where pumpkin growth was extensive. This explains the poor groundnut yields reflected by partial LER values of intercropped groundnut at Gowakowa in 2003/4, where there was extensive pumpkin vine growth and high fruit yields. This result suggests that the presence of pumpkin fruits on the vines might also modify the level of competition between groundnut and pumpkin in intercrops.

Similar reductions in groundnut seed yields were also recorded when groundnut was intercropped with maize or sunflower (Natarajan and Zharare, 1994). This is, however, contrary to the suggestion by Rem and Espig (1991) that cultivars in Africa have been selected for low light and are suitable for intercropping. The low groundnut yields in intercrops were related to the lower number of pods per plant and smaller kernel test weight compared to pure stands. The development of pegs in groundnut is known to be restricted by higher densities (Rem and Espig, 1991), hence lower pod development in intercrops. However, Durand (1995) reported higher numbers of pods per plant in sorghum-groundnut intercrops compared to sole groundnut crops under water deficits. Though groundnut intercropping is limited due to sensitivity of groundnut to shading, however, farmers still benefit from reduced rosette virus incidence in intercrops compared to sole crops (Tungani, Mukhwana and Woomer, 2002).

High levels of pumpkin intercrop density also had negative effects on growth of pumpkin plants through reducing pumpkin vine length and harvestable leaf size. This can be explained by higher level of competition at higher densities causing a reduction in plant size. Naturally pumpkin has a prostrate growth habit and requires a lot of space for good vining behaviour (Nonnecke, 1989), which was however, not available at high population levels in intercropping. Similar reductions in pumpkin vine growth were recorded in maize-pumpkin intercrops (Mashingaidze *et al,* 2000). However, in an intercrop with a similarly short statured yam component, Olasantan (2007) recorded increased vine length.

On the contrary, mustard rape intercrop densities had no effects on mustard rape leaf size and growth. This result suggests that mustard rape could have been suppressed to the lowest limit by intercropping, such that it could not respond to any further competition, such as through density. This could have been particularly so in the second planting. Leaf yields, leaf size, duration and partial LER of mustard rape were lower in the second planting compared to the first planting. This can be explained in two ways. First, mustard rape was introduced into an already established maize crop, which had height and probably root network advantages, suggesting that in terms competition for light, water and nutrients, mustard rape was out-competed. Second, the second planting of mustard rape did not receive any fertilizer application whilst the first had received basal fertilizer and topdressing. The latter explains the lower mustard rape leaf yields in sole pure stands in the second planting compared to the first planting. However, for both planting times, the increase in mustard rape leaf yield with increase in intercrop density emphasizes the importance of increasing density for higher productivity of intercrops (Trenbath, 1976).

Though pumpkin plants were small in size at high levels in intercrop populations, they out-yielded the bigger but fewer plants in lower intercrop populations. Concomitantly, leaf yields and partial LER values of pumpkin increased with high levels of pumpkin intercrop populations. This reveals the dependency of intercrop productivity on component populations. Morgado and Willey (2003), recorded similar progressive increments in bean yields with increasing intercrop populations in maize-bean intercrops.

The effects of densities were also observed in fruit yields and leaf yields in pumpkin and mustard rape. It is worth noting that mustard rape intercropped at 4.15%, 8.29 % and 12.44 % of groundnut was 17.29 %, 34.58 % and 51.87 % of mustard rape population in pure stands respectively. Similarly, pumpkin intercropped at 0.46 %, 0.92 % and 1.84 % of groundnut was 19.15 %, 38.33 % and 76.67 % of the pumpkin population in pure stands. Therefore, the lower yields in intercrops compared to sole crop and reduced partial LER values can be attributed to the lower populations of the vegetables in intercrops. These densities also explain the increase in vegetable leaf yields and leaf partial LER due to an increase in ‘harvestable units’ per unit area

An attempt to simulate smallholder farmers’ practice of not spraying pumpkin for pest control resulted in substantial fruit losses due to extensive fruit fly infestation in 2002/3. The fruit yields obtained were a consequence of mere escape of damage, rather than intercropping. In 2003/4, pumpkin fruit yield was reduced by intercropping through a general decrease in vine growth and leaf size. The number of fruits per vine in pumpkin usually depends on vine growth and the available leaf area per vine (Tindall, 1983). Naturally, a smaller leaf area per plant will support a lower number of fruits. Therefore, the reduced pumpkin fruit yield in intercropped pumpkin compared to pure stands could be linked to reduced leaf area per plant. However, the increase in pumpkin fruit yield and pumpkin fruit partial LER with increasing pumpkin intercrop density can be attributed to an increase in the number fruit-bearing units per unit area as the number of fruits per vine for each pumpkin variety is almost fixed (De Lannoy, 2001).

Apart from higher intercrop productivity, higher intercrop densities, especially for pumpkin were also beneficial in suppressing weeds compared to sole cropping of groundnut. The dominance of intercrops over weeds has been mainly attributed to the ability of intercrops to reduce light reaching the weeds (Liebman and Dyck, 1993). Therefore, in this study, the inclusion of pumpkin in intercrops could have increased the leaf area index which reduced light penetration the ground compared to the leaf area index of groundnut alone. Similar to these results, Obuo, Adipala and Osiru (1997) recorded lower weed biomass in sorghum-pumpkin intercrops compared to sorghum pure stands. Spreading crops such as pumpkin have been found to reduce or eliminate completely weeds in intercrops with crops such as maize or sorghum (Joubert, 2000). However, this study shows that pumpkin can also be effective in suppressing weeds in groundnut intercrops.

In this study, unlike Mashingaidze *et al.* (2000), who recorded better weed suppression in maize-pumpkin intercropping as compared to pumpkin sole cropping, the highest weed suppression effect recorded in pure pumpkin stands. This can be explained by the expansive growth of pumpkin in pure stands, which allowed very little light penetration through to the underlying weed seeds resulting in their poor germination and growth. However, the suppression of weeds in intercrops will be an attractive feature to smallholder farmers who often produce low yields chiefly, due to weed infestation (Joubert, 2000).

It is worth noting that in the current study, no ammonium nitrate topdressing was applied to the pumpkin. This might also have influenced vine length and leaf area development, hence weed suppression.

Overall, all groundnut-pumpkin and groundnut-mustard rape intercrops in this study had intercropping advantage over sole cropping, as shown by LER values above unity. However, all the intercropping advantages such as productivity, weed suppression and leaf or fruit yields seem to be density-dependent and therefore higher densities are recommended to farmers wishing to adopt the intercrops in this study.

5.5 Conclusions

- Increasing pumpkin and mustard rape populations to 1.84 % and 12.44 % of the groundnut populations respectively increased leaf yields by 145 % and 172 % compared to intercropping at 0.46 % and 4.15 % of the groundnut population.
- Intercropping groundnut with pumpkin at populations of up to 1.84 % of the groundnut population, reduced groundnut seed yield by up to 45 % whilst intercropping with mustard rape up to 12.44 % of groundnut had no significant effects on groundnut seed yields.
- Intercropping groundnut with 1.84 % pumpkin or 12.44 % mustard rape produced the highest yield advantages (up to 110% and 87 % respectively) of intercropping over groundnut sole cropping as measured by LER.
- Intercropping groundnut with mustard rape had no weed suppressive effects, whilst intercropping with pumpkin, especially at 1.84 %, significantly reduced weed density and biomass compared to groundnut sole cropping.
- Planting mustard rape at 11 WAE of groundnut reduced dry leaf yields to 40.5 % and 6.7 % of the corresponding values of mustard rape simultaneously planted with groundnut in pure stands and intercrops respectively, but slightly improved productivity of the intercrop.

5.6 Recommendations

- In groundnut-pumpkin intercropping, farmers are recommended to use pumpkin populations below 0.92 % of the groundnut population for high pumpkin leaf yields and weed suppression without significant losses in groundnut seed yield.
- Mustard rape populations should be increased to levels beyond 12.44 % of groundnut population to increase leaf yields, and possibly weed suppression as well. However, intercropping mustard rape with groundnut is only recommended in wetter areas or where supplementary irrigation is available.

- Farmers should plant mustard rape simultaneously with groundnut for high mustard rape leaf yields. A second planting of mustard rape at 11 WAE of groundnut, should only be used, if need be, as a supplement to the crop simultaneously planted with groundnut. However, this requires evaluation by smallholder farmers.
- Measurement of light penetration in these intercrops is highly recommended.
- There is a need to optimize leaf harvest practices to improve leaf yields of pumpkin and mustard rape in intercrops.

CHAPTER 6

6.0 EFFECTS OF LEAF HARVEST INTERVALS AND INTENSITIES ON PUMPKIN GROWTH AND LEAF YIELDS

6.1 Introduction

Whilst it is clear from the previous chapters that pumpkin thrives in intercrop situations, there is however, a need for optimizing the intercrops with respect to the most ideal leaf harvesting practices. Pumpkin leaves, fruits, seeds and male flowers are consumed in common meals, but it is the leaves that are of prime importance in both rural and urban communities in Africa. Locally, pumpkin leaves may be consumed up to seven times a week during the peak period (Ndoro, 2004).

The production of pumpkin dates back a long time, and farmers still employ traditionally derived harvesting practices due to lack of scientific research and documentation of leaf harvest practices. As a result, yield and growth of leaf-harvested pumpkin remain highly variable and unpredictable. Usually, leaf harvest practices in pumpkin depend on the farmers' needs and the availability of other relishes. Therefore, there are some inconsistencies in the available information on leaf harvesting in pumpkin. For instance, in Zambia, leaf harvesting only starts when the vine has set fruits and may continue until the senescence of the vines, well after the end of the rainy season (Mingochi and Luchen, 1997), whilst generally in Africa leaf harvests start when vines are 60 cm long (FAO, 1988).

It seems in Zimbabwe farmers begin leaf harvesting at four weeks after emergence (WAE) of pumpkin (Ndoro, 2004). Generally, fully expanded tender leaves are harvested, and at times young shoots are harvested as well, but tenderness of the leaves is the main criterion used when selecting leaves for harvesting. At each harvest, 15-20 cm of shoot tips may be harvested (FAO, 1988). Intensity of leaf harvesting is likely to be influenced by production system. For instance, it is likely to be more intense as pumpkin leaves find their way to urban markets during periods of peak supply in Zimbabwe (Chigumira-Ngwerume, 2000) than in a fully subsistence system. The effects of these leaf harvesting practices have not been investigated in pumpkin.

In other crop plants, leaf harvest practices have been known to affect re-growth and therefore, leaf and shoot biomass variably, depending on species. Plant growth depends directly on the available light and the available leaf area to capture it: however, defoliation may change amount of available leaf area and light interception, causing important effects on growth patterns (Vos and van der Putten, 2001). However, it has been reported that after partial removal of the leaf area, plant biomass is not necessarily reduced by the same percentage as leaf area. It has even been found that lightly defoliated plants may increase sufficiently in biomass to end up larger in mass than non-defoliated controls (Harris, 1974; McNaughton, 1983). Some experiments on partial defoliation recorded reduced plant growth and yield with more severe defoliation than with less severe defoliation (Petrie *et al.,* 2003). However, other experiments have recorded dissimilar results (Khan and Lone, 2005). Much of the available literature on partial defoliation is from studies on perennial crops, such as fruit trees. It is not clear whether the principles of compensatory growth also apply to seasonal (short duration) crops such as pumpkin, especially in intercrop situations where components have to compete for light.

In intercrops, partially defoliated components are made less competitive, thereby strengthening the advantage of the other component (e.g. Nyeko, Edwards-Jones, Day and Ap-Dewi, 2004). Therefore, it is still remains unclear whether partial removal of leaf area in the minor component in a maize-pumpkin intercrop will result in compensatory growth or weakening and suppression of the minor component. Unlike, in the partial defoliation studies discussed above, the residual leaf area is the main parameter of interest in pumpkin intercrops as the leaves will be picked for leaf vegetable.

The available information on leaf harvests in pumpkin does not relate precisely to harvests per vine basis. For instance, the consumption of pumpkin seven times a week (Ndoro, 2004) does not reflect harvest intervals and intensities per plant. There is a need to determine precise harvest frequencies and intensities in pumpkin to improve leaf yields and therefore, local vegetable availability. This report presents results of a study that was aimed at investigating the effects of leaf harvest severity on pumpkin growth and leaf yields.

The objectives of this study were:

i) To determine the effects of leaf harvest intervals and leaf harvest intensities on growth and leaf vegetable yields of pumpkin in pure stands and in maize intercrops.

ii) To establish the optimum harvest intensities and intervals that give high leaf yields with minimum effects on maize grain yield.

The objectives were based on the following hypotheses:

i) More intense and frequent leaf harvests increase pumpkin vegetable leaf yields due to increased number of leaves harvested per plant and compensatory growth in pumpkin compared to the current practice.

ii) Severe harvesting of pumpkin leaves reduces maize grain yield due to increased competition with maize resulting from increased compensatory growth.

6.2 Materials and Methods

The study was conducted at the University Farm (UZF) over the 2002/3 and the 2003/4 rainy seasons. The characteristics of the site are described in Section 3.3 of the General Materials and Methods. The study was a 2 x 3 x 3 factorial experiment. The first factor was cropping system and had two levels: pumpkin sole cropping and intercropped pumpkin. The second factor was leaf harvest intensity and had three levels: two, four or six leaves harvested per growing tip per occasion. The third factor was harvest interval, with levels of 5, 10 or 15-day intervals. The controls were a maize sole crop and also, a pumpkin sole crop harvested every 12 days to simulate smallholder farmer practice. In the pumpkin control, there was no specific harvest intensity, but the leaves were harvested using the traditional criterion of tenderness. These twenty treatment combinations were arranged in a randomized complete block design with four blocks.

Both crops were direct seeded and planted simultaneously within the same row. In intercropping treatments, pumpkin was planted 1.4 m apart into all maize rows to achieve a population of 11.7 % of the maize population. Spacing for maize and the sole crops of pumpkin and characteristics of the cultivars used are described in Section 3.4 of the General Materials and Methods. All plots measured 4.5 m x 5 m and each received basal fertilizer (6 % N, 17 % P_2O_4, 5 % K_2O and 10 % S) at planting at a rate of 300 kg ha^{-1}. Lime ammonium nitrate (28 % N) was applied as top dressing at 250 kg ha^{-1} at six weeks after emergence (WAE) of maize. The plots were hoe-weeded at three, six and nine WAE of maize. The net plot for maize comprised of the three inner rows, excluding the two outermost plants at the end of each row. However, for pumpkin, leaves were harvested from all plants in each plot as the vines were entwined making it difficult to separate plants from the border and the probable net plot.

Pumpkin leaf harvests started at five WAE of maize until all vines in the respective plots had senesced. At each harvest, the number of live vines was recorded. All pumpkin plants in each plot were subjected to respective leaf harvest intensities in both intercropping and sole cropping. Immediately after each leaf harvest, leaf area for all harvested leaves from each plot was also determined using a leaf area meter (LI-COR, LI-3100, Lincoln, USA). The average harvested leaf size for each harvest was calculated by dividing total leaf area per harvest by the number of leaves. These harvest averages were then used to calculate the average leaf size for the season. There was no equipment available to measure light interception in the field. After leaf area measurements, the leaves were then oven-dried at 70°C for 48 hours to obtain dry weight.

Pumpkin vine length for each plot was obtained by averaging out the final vine length of five and eight random plants from each plot in intercropping and sole cropping respectively. Duration of the pumpkin crop was assessed from time of emergence to 75 % senescence of the vines in each plot. The number of female flowers and primary branches was also recorded at each harvest and the end point was tagged. The tag would then be used a starting point for subsequent counts. In both seasons, no pumpkin fruits were obtained due to extensive fruit fly infestation and damage.

For maize, grain yield from the net plot (4 m of the inner three of the five rows) was determined. Maize grain moisture content was determined using a moisture tester (NJF 1210 Moisture Tester, N.J. Fromet & Co. Ltd, Stamford, England) and yields were standardized to 12.5 % moisture content as described in Section 3.6 of the General Material and Methods. Also, cob length was determined by averaging out lengths of five cobs randomly selected from each net plot. Land equivalent ratio (LER) was calculated as described in Section 3.6 of the General Materials and Methods. For pumpkin leaf yields, the sole crop simulating farmer practice was the one used as the control for calculating the pumpkin partial LER values. All data were subjected to analysis of variance (ANOVA) using Genstat Statistical Package (Lawes Agricultural Trust, 2002) after testing for normality. For combined analysis over the two seasons, data were first tested for homogeneity of variances.

6.3 Results

Tests for homogeneity of variances showed that maize grain yield was the only maize character that could be combined over the two seasons. Maize cob length was not affected ($p > 0.05$) by leaf harvest intervals and intensities in the component pumpkin crop in 2002/3 (Table 6.1). However, harvesting six leaves per growing tip per occasion reduced maize cob length to 16.52 cm from 17.45 cm obtained by harvesting four leaves per growing tip per occasion in 2003/4. Over the 2002/3 and 2003/4 seasons, maize grain yield was not affected ($p > 0.05$) by seasons and leaf harvest intervals and leaf harvest intensities in the pumpkin component.

However, over the 2002/3 and 2003/4 seasons, pumpkin leaf size progressively decreased ($p < 0.001$) with shortening harvest intervals (300.3 cm^2 to 244.2 cm^2) and increasing harvest intensity (291.5 cm^2 to 261.2 cm^2). Generally, the control, a pure pumpkin stand, which was harvested at 12-day intervals without strict intensity, produced even larger leaves. Pumpkin vine length was significantly reduced ($p < 0.05$) to 2.63 m by five-day leaf harvest intervals from 3.18 m obtained at 15-day intervals in 2002/3 (Table 6.2). However, leaf harvest intervals had no significant effects ($p > 0.05$) on pumpkin growth duration in 2002/3.
In 2003/4, leaf harvest intensity had no effects on pumpkin primary branching (Table 6.3). However, pumpkin vine length significantly decreased ($p < 0.001$) with increasing harvest intensity, from 5.1m obtained at the two-leaf intensity to 4.4 at six-leaf intensity.

Table 6.1: Effects of leaf harvests and seasons on cob length and grain yield in maize, and pumpkin leaf size over the 2002/3 and 2003/4 seasons.

Treatments	2002/3	2003/4	(2002/3 &2003/4)	
	Cob length (cm)	**Cob length (cm)**	**Grain yield (kg ha^{-1})**	**Pumpkin Leaf size (cm^2)**
Harvest interval				
5 days	14.18	17.10	7775	242.20 c
10 days	14.21	17.04	8564	283.70 b
15 days	14.78	17.09	8336	300.30 a
Significance	ns	ns	ns	***
Harvest Intensity				
2 leaves	14.56	17.26 a	8094	294.50 a
4 leaves	14.60	17.45 a	8579	275.50 b
6 leaves	14.01	16.52 b	8001	261.20 c
Significance	ns	**	ns	***
$LSD_{0.05}$	-	0.592	-	12.90
Control[¤]	**(15.50)**	**(17.10)**	**(8798)**	**(390.30)**
CV (%)	8.60	4.10	15.00	11.50

Means with different letters in a column are significantly different; **= p<0.01 *** = p < 0.001; ns =not significant; $LSD_{0.05}$ = Least Significant Difference at p = 0.05; CV= coefficient of variation. [¤]The control (farmer's practice sole crop) only serves as a dummy variable in this table.

In 2002/3 (Table 6.4), the number of primary branches per vine was reduced by intercropping ($p < 0.001$) and by more intense leaf harvests ($p < 0.05$), but was not affected by leaf harvest interval in 2002/3. The number of primary branches per vine was reduced by more than 50 % from 10.75 in sole cropping to 4.53 in intercropping in 2002/3. It was also reduced from 9.12 obtained by harvesting two leaves per growing tip to the least value of 6.75 by harvesting six leaves per growing tip.

Table 6.2: Effects of harvest interval on pumpkin vine length and growth duration in the 2002/3 season.

Harvest interval	Vine length (m)	Growth duration (days)
5 days	2.63 b	92.40
10 days	2.80 b	90.70
15 days	3.18 a	97.50
Significance	*	ns
$LSD_{0.05}$	0.37	-
Control[¤]	**(3.95)**	**(126.00)**
CV (%)	22.00	10.90

Means with different letters in a column are significantly different; * = $p < 0.05$; ns =not significant; $LSD_{0.05}$ = Least Significant Difference at p = 0.05; CV= coefficient of variation. [¤]The control (farmer's practice sole crop) only serves as a dummy variable in this table.

Table 6.3: Effects of harvest intensity on branching and vine length in pumpkin in the 2003/4 season.

Harvest intensity	Primary branches $vine^{-1}$	Vine length (m)
2 leaves	8.77	5.12 a
4 leaves	8.48	4.83 b
6 leaves	7.98	4.38 c
Significance	ns	***
$LSD_{0.05}$	-	0.28
Control[¤]	**(3.95)**	**(7.18)**
CV (%)	22.00	10.90

Means with different letters in a column are significantly different; *** = $p < 0.001$; ns =not significant; $LSD_{0.05}$ = Least Significant Difference at p = 0.05; CV= coefficient of variation. [¤]The control (farmer's practice sole crop) only serves as a dummy variable in this table.

Similarly, pumpkin dry leaf yield was significantly reduced ($p < 0.001$) by intercropping to 13 % of the yields obtained in pure stands in both the 2002/3 and 2003/4 seasons. However, it was not affected by both leaf harvest interval and leaf harvest intensity in both seasons. Analysis of the sole crops data showed that harvesting four leaves per tip at five-day intervals significantly increased leaf yields by 98 % in 2002/3 and 153 % in 2003/4 compared to farmers' practice control (Analysis shown in Appendix 6.2.9)

The interaction between the effects of cropping system and harvest intensity had significant ($p < 0.01$) effects on pumpkin crop growth duration in 2002/3 (Figure 6.1A). Intercropping shortened ($p < 0.001$) pumpkin growth duration to 119 days from 170 days recorded in the pure stands. Pumpkin crop growth duration was reduced to 91 days at six-leaf harvest intensities from 111 days obtained at four-leaf harvest intensities in pure stands, whilst it was not affected by leaf harvest intensity in intercropping.

Table 6.4: Effects of cropping system and leaf harvests on leaf yield and branching in pumpkin in the 2002/3 and 2003/4 seasons.

Treatments		2002/3		2003/4
		Primary branches vine^{-1}	**Dry leaf yield (kg ha^{-1})**	**Dry leaf yield(kgha^{-1})**
Cropping system	**Intercropping**	4.53 b	15.10 b	20.00 b
	Sole cropping	10.75 a	114.40 a	150.40
	Significance	***	***	***
	$LSD_{0.05}$	1.529	16.49	21.67
Harvest interval	**5 days**	7.21	74.40	98.40
	10 days	7.62	65.60	85.60
	15 days	8.08	54.40	71.70
	Significance	ns	ns	ns
	$LSD_{0.05}$	-	-	-
Harvest intensity	**2 leaves**	9.12 a	54.20	71.00
	4 leaves	7.04 b	77.20	101.90
	6 leaves	6.75 b	63.00	82.90
	Significance	*	ns	ns
	$LSD_{0.05}$	5.907	-	-
	Control¤	**(15.00)**	**(95.70)**	**(98.80)**
	% CV	10.90	53.80	53.70

Means with different letters in a column are significantly different; * = $p < 0.05$, *** = $p < 0.001$; ns =not significant; $LSD_{0.05}$ = Least Significant Difference at p = 0.05; CV= coefficient of variation. ¤The control (farmer's practice sole crop) only serves as a dummy variable in this table.

Pumpkin vine length was also significantly ($p < 0.05$) influenced by the interaction between the effects of cropping system and harvest intensity in 2002/3 (Figure 6.1B). Pumpkin vine length significantly decreased with increasing leaf harvest intensity in sole cropping, whilst it was not affected by leaf harvest intensities in intercropping. For instance, it was reduced to 3.1 m by six-leaf harvest intensities from 4.2 m obtained at two-leaf harvest intensities in sole cropping, whilst it was not affected by leaf harvest intensities in intercropping.

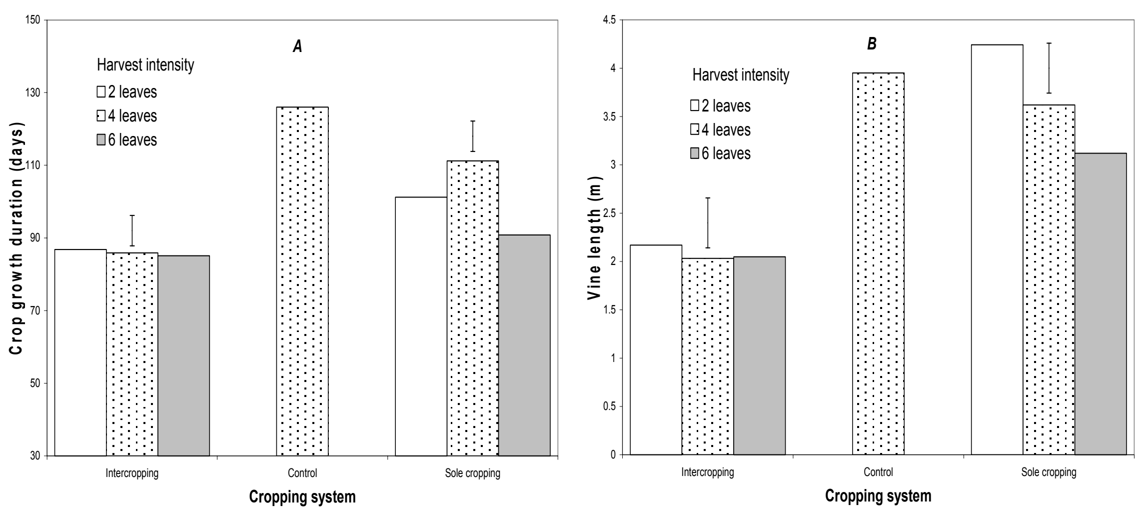

Figure 6.1: **Effects of cropping system and leaf harvest intensity on A) pumpkin growth duration and B) pumpkin vine length in 2002/3. Bars on the graphs represent $LSD_{0.05}$ values. The control (farmer's practice sole crop) only serves as a dummy variable in this figure.**

The number of female flowers per vine was significantly ($p < 0.05$) influenced by the interaction of the effects of season, cropping system and harvest interval (Figures 6.2A and 6.2B). The parameter was reduced by intercropping in both seasons. In 2002/3 in sole cropping, the number of female flowers per vine decreased with increasing leaf harvest interval, with no differences between 10- and 15-day intervals. However, in intercropping, 10-day harvest intervals increased the number of female flowers per vine and there were no differences between five and 15-day harvest intervals. On the contrary, in 2003/4 (Figure 6.2B), the number of female flowers per vine was not affected by leaf harvest intervals in intercropping, whilst it increased at with increasing length of harvest interval in pure stands.

Similarly, primary branching in pumpkin was significantly affected ($p < 0.001$) by the interaction between the effects of cropping system and harvest interval in 2003/4 (Figure 6.2C). The number of primary branches per vine was significantly reduced by more frequent harvests, with no difference between 10- and 15-day intervals in sole cropping. However, it was not affected by harvest interval in intercropping.

Furthermore, the interaction between the effects of cropping system and harvest interval was also significant ($p < 0.001$) for pumpkin vine length in 2003/4 (Figure 6.2D). Pumpkin vine length was not affected by leaf harvest interval in intercropping whilst it progressively and significantly increased with increasing harvest intervals in sole cropping.

Whilst intercropping reduced pumpkin growth and leaf yields it was, however advantageous over sole cropping, shown by LER values that were greater than unity (Table 6.5). The highest LER values (1.18) were recorded at 15-day intervals and at 6-leaf harvest intensities, whilst the least were recorded at five-day leaf harvest intervals and at two-leaf harvest intensities in 2002/3. Similarly, in 2003/4, LER values increased with increases in length of harvest interval. However, in 2003/4, the highest LER was recorded by harvesting four leaves per growing tip per occasion.

Table 6.5: Effects of leaf harvest interval and intensity on the productivity of maize - pumpkin intercrops in the 2002/3 and 2003/4 seasons.

		2002/3			2003/4		
		Partial LER		LER	Partial LER		LER
		Maize	Pumpkin		Maize	Pumpkin	
Harvest Interval	**5 days**	0.92	0.18	1.10	0.92	0.22	1.14
	10 days	0.98	0.15	1.13	0.98	0.18	1.17
	15 days	1.01	0.16	1.18	0.95	0.22	1.18
Harvest Intensity	**2 leaves**	0.95	0.13	1.08	0.95	0.15	1.10
	4 leaves	0.99	0.16	1.15	1.00	0.20	1.20
	6 leaves	0.97	0.21	1.18	0.91	0.27	1.18

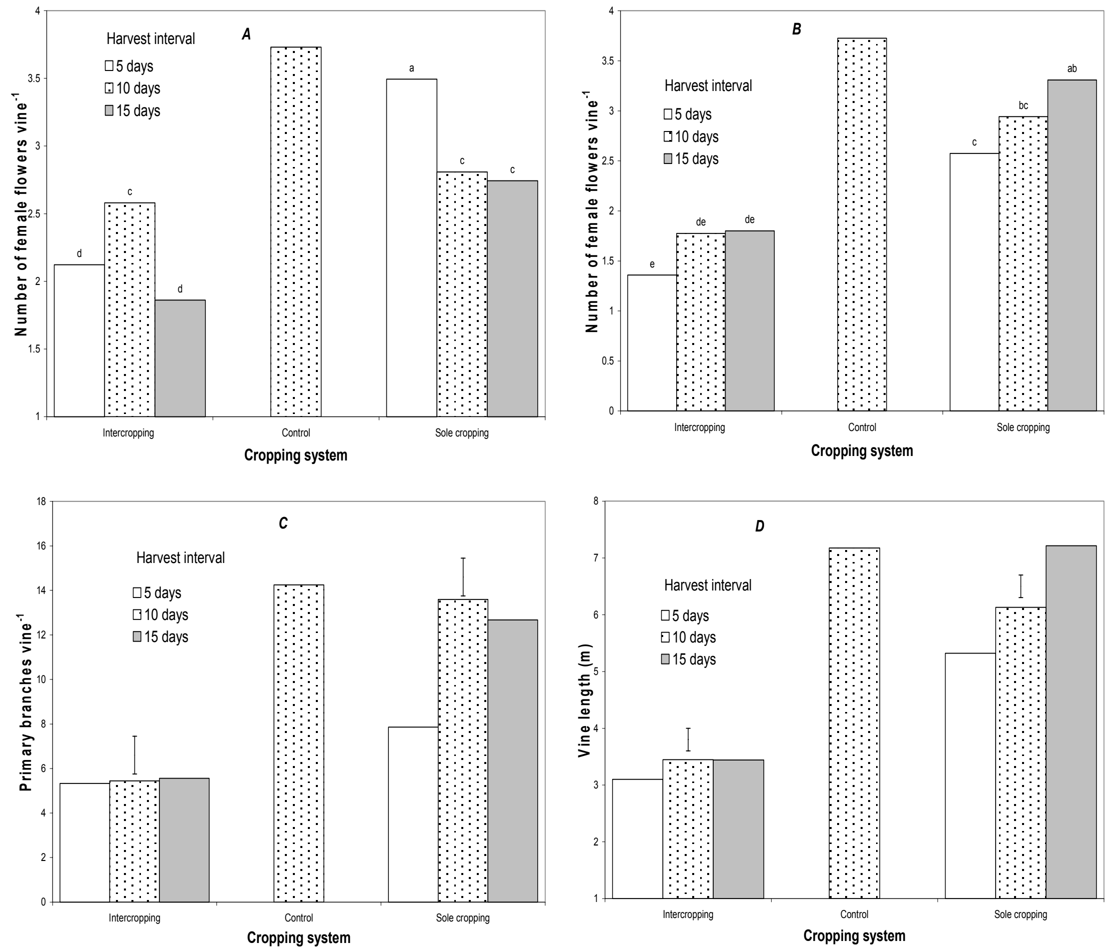

Figure 6.2: Effects of the interaction between cropping system and leaf harvest interval on various pumpkin characteristics; the number of female flowers vine^{-1} in A) 2002/3 and B) 2003/4, C) Number of primary branches per vine in 2003/4 and D) vine length in 2003/4. Lower case letters on Figures 6.2 A and 6.2 B show mean separation using the Duncan's Multiple Range Test. Bars on Figures 6.2 C and 6.2 D indicate $LSD_{0.05}$ values. The control (farmer's practice sole crop) only serves as a dummy variable in this figure.

6.4 Discussion

Maize has a height advantage over the prostate pumpkin crop such that in companion cropping, the interception of light by maize seems not to be affected by the underlying pumpkin crop. Whilst there is competition for various growth resources in intercrops, it has been found that light interception plays an important role in the competitive processes in intercrops (Gautier, Varlet-Grancher, Gastal and Moulia*,* 1995). The reduction of maize cob length due to leaf harvesting in the pumpkin component in one season, however, indicates that maize growth was somehow affected by intercropping, though not sufficient to cause a reduction in the resultant grain yields. Since leaf harvest intervals and intensities in component pumpkin had no significant effects on maize grain yield as shown by maize partial LER values close to unity, it means that farmers do not lose their main crop yield when they intercrop and implement the leaf harvest practices used in this study. Unlike Nyeko *et al.* (2004), who recorded yield increases in one component following defoliation of the other, this result suggests that partial defoliation of a less competitive component will not benefit the more competitive. It might be worth investigating whether the suppressed pumpkin will benefit from the partial defoliation of the dominant maize, similar to results obtained in leaf stripping of maize in maize-bean intercrops (Mashingaidze, 2004).

On the other hand, general growth of the underlying pumpkin crop was reduced by intercropping, as indicated by the reduction in the harvested leaf size, growth duration and vine length. Shading, which was evident, but not scientifically determined in this study, has been shown to reduce growth of the underlying crop (Ofori and Stern, 1987) due to reduced photosynthetically active radiation (PAR, 400 – 700 nm wavelength) reaching the under storey (Gautier *et al.*, 1995).

Light has also been found to be critical for leaf area development, with low light levels having been shown to reduce leaf area expansion rates and the resultant leaf sizes (Board, 2000). On the same note, leaf area is critical for light interception and growth. The generally poor growth and smaller leaf sizes of partially shaded pumpkin in intercropping compared to the almost fully-illuminated pure stands are thus explained. Similarly, Mashingaidze *et al.* (2000) recorded reduced pumpkin vine extension in a maize-pumpkin intercrop, suggesting that pumpkin is very sensitive to shading by tall crops such as maize in intercropping. Leaf size has implications on the acceptability of the vegetable, especially for marketing purposes. For instance larger leaves may be preferred to smaller leaves.

The reduced growth duration of intercropped pumpkin partly explains the low leaf yields in intercropping compared to pure stands. Short duration of pumpkin in the intercrops can be ascribed to competition for growth resources including light. Inadequate capture of resources and interception of light due to shading increases the rate of senescence of leaves, the source of assimilates, thereby shortening the duration of the crop (Fageria, 1992). A short growth duration of the pumpkin crop means that relish in the form of pumpkin leaves will only be available during a short period of time during the summer season. This also means reduced benefit to the farmer as both leaf yields and harvesting period will be reduced. Therefore, such a scenario will only temporarily solve the problem of the unavailability of relish.

Apart from reduced plant size and yield-related attributes in intercropping, low pumpkin yields and low partial LER values were also a result of the low density in intercrops. At 11.7 % of the maize population, intercropped pumpkin was 55.56 % of the sole pumpkin population. The highest leaf yield in intercrops was only 27 % of the sole crop yield, emphasizing the fact that growth was lower in intercrops compared to sole crops.

The low leaf yields in intercropping had a masking effect on the responses of pumpkin to leaf harvest intervals and frequencies, especially compared to the control. This is responsible for the numerous cropping system-related interactions and fairly high coefficients of variation for leaf yield in this study. Analysis of the yield data as a non-factorial experiment revealed that pumpkin dry leaf yields at all the harvest intervals and intensities in the pure stands were higher than in the control, by an average of 126 % over the 2002/3 and 2003/4 seasons. Therefore, there is a need for controls in both pure stands and intercropping.

Pumpkin partial LER values show that the effects of leaf harvest intensities are more critical and more obvious than the effects of leaf harvest intervals. The results clearly showed that leaf yields and pumpkin partial LER values can be increased by more intense harvests, whilst the trend was not clear for leaf harvest intervals. This can be explained by the fact that the contribution of more intense harvests to total harvested biomass are straight forward, whilst effects of leaf harvest intervals are dependent on re-growth.

With shorter harvest intervals the resultant leaves were numerous and small whilst with less intense or less frequent harvests the resultant leaves were fewer in number but larger in size, resulting in a compensatory effect in terms of biomass. It has been observed, that after partial defoliation, there is compensatory photosynthesis to maintain similar biomass as before the treatment (Eaton and Ergle, 1954). However, it has been observed that re-growth and leaf harvests employed in pumpkin depend on nutrition and initial vigour of growth (Ndoro, 2004). From another perspective, the absence of significant differences in leaf yields across the leaf harvest intensities and intervals could be related to timing of the beginning leaf harvests. Yang and Midmore (2004) indicated that there are critical times for inducing responses to various levels of partial defoliation.

Short harvest intervals probably meant that there was not much time for re-growth of residual leaf area before the subsequent harvest. In partial defoliation experiments, it has been observed, that consecutive partial defoliation reduces the final biomass due to depletion of carbon reserves (Vanderklein and Reich, 1999). However, with long (15-day) harvest intervals, it meant leaves were allowed to grow probably up to full size before being harvested. This explains the decrease in leaf size with increasing leaf harvest severity. In another leafy vegetable, *Solanum nigrum,* Chweya (1997) recorded two-week harvest intervals reduced the number of shoots, but resulted in higher leaf yields than weekly harvests. Harvesting smaller leaves may also be more arduous compared to harvesting larger leaves. Therefore, any activities that reduce leaf size are likely to be less popular with farmers and consumers. However, there are no existing standards or acceptable leaf sizes for pumpkin to compare with. The reduced leaf size also means that the available photosynthesizing leaf area per plant is reduced hence, a reduction in overall growth due to source limitation (Vanden Heuvel and Davenport, 2005).

Probably this also explains the reduced vine length and growth duration with more intense and more frequent harvests. Similarly, reduced leaf area per plant due to partial defoliation was shown to reduce vine growth in grapevines and was ascribed to a reduced supply of assimilates (Petrie *et al*., 2003), though with increased single leaf photosynthesis. Therefore, it implies that compensatory photosynthesis might not necessarily translate to compensatory growth. For this study, it would have been worth measuring the rates of photosynthesis after each leaf harvest.

In most cases, branching in pumpkin is closely related to vine length, and therefore the reduction in primary branching in intercropped pumpkin in this study could have been a result of the reduced vine length in the intercrop. This reduction in vine extension could also have veiled the effects of leaf harvest intensities on pumpkin branching in intercropping. Marume (1999) also found no effects of pinching on pumpkin branching. Branching in pumpkin contributes immensely to the leaf and fruit yields as the branches also bear fruits and harvestable leaves. Therefore, any process that reduces vine length and branching may also have similar effects on the number of leaves harvestable per vine and therefore, leaf yield.

The reduced number of female flowers per vine could have been a result of mechanical stress caused by leaf harvesting. Leaf picking is a form of stress on the subject plants. It has been observed that under stressful conditions, pumpkin produces fewer female flowers per vine (Nonnecke, 1989). A reduction in the number of female flowers per plant reduces the potential of the equally important fruit yield of the pumpkin crop. Though there are some preferences over landraces, farmers usually grow pumpkin for both fruit and leaf yields. In Zimbabwe, one pumpkin landrace is grown for its leaves only (Ndoro, 2004).

In this study, the absence of pumpkin fruits on vines due to fruit fly damage could have confounded the response of pumpkin to leaf harvest intervals and intensities. The presence of fruits could have made pumpkin more aggressive in the intercrop due to higher sink strength. Leaf harvesting is also known to influence fruit growth and therefore, it could have been rewarding to note how fruit growth would respond to the leaf harvests employed herein. Elsewhere, more intense leaf pruning was reported to increase fruit abortion in sweet pepper (Marcelis, Heuvelink, Baan Hofman-Eijer, Den Bakker and Xue, 2004).

6.5 Conclusions

- In intercropping, pumpkin was already suppressed and was less responsive to leaf harvesting intensities, whereas the normal growth in sole cropping resulted in marked responses.

- Intercropping, five-day leaf harvest intervals and six-leaf harvest intensities reduced pumpkin growth duration, by 5.8 %, 26.8 % and 30.2% respectively and leaf size by 48.6 %, 38 % and 24.5 % respectively compared to the current farmer practice in sole crops (available leaves at 12-day intervals).
- Harvesting four leaves per growing tip at five-day harvest intervals increased leaf yields of sole crop pumpkin by 126 % of yields obtained in the current practice.
- However, these leaf harvest intervals and intensities had no significant effects on vine length, duration, branching and branching of pumpkin intercropped with maize at 11.4 % of the maize population.
- Leaf harvest intervals of 5-15 days and leaf harvest intensities of 2-6 leaves per growing tip per occasion in the pumpkin component had no effects on maize grain yield in maize – pumpkin intercrops.
- Intercropping maize and pumpkin proved beneficial as there was up to 20 % advantage over sole cropping as shown by the LER values.

6.6 Recommendations

- In pumpkin intercropped at 11.7 % of maize, farmers should harvest six leaves per growing tip at 10-day intervals for high leaf yields without reducing maize grain yields.
- Farmers are recommended to adopt harvesting four leaves per growing tip at five-day intervals in pumpkin pure stands, for higher leaf yields compared to the current 12-day harvest intervals.
- Leaf harvest practices employed in this study must be evaluated by by farmers for suitability of leaf sizes and storage quality.

CHAPTER 7

7.0 EFFECTS OF LEAF HARVEST INTERVALS AND INTENSITIES ON GROWTH AND LEAF YIELDS OF MUSTARD RAPE

7.1 Introduction

The frequent all-year consumption, adaptability to summer production (Chigumira-Ngwerume, 1998) and high nutritional value make mustard rape a reliable source of nourishment for most smallholder households in Zimbabwe. However, the suppression of mustard rape in intercrops unveiled in the preceding chapters, calls for a need to optimize leaf yields in intercrops to meet consumers' needs, possibly through employing optimal leaf harvest practices.

Establishment of appropriate leaf harvest intensities and intervals is critical in improving the productivity of mustard rape in both intercropping and sole cropping systems. In Zimbabwe, farmers apply various leaf harvest intervals and intensities depending on the production system. In a fully subsistence system leaf harvesting is less intense and less frequent than in a more-or-less commercial one, where there may be a need to meet a huge demand for mustard rape leaves. This variation explains the inconsistencies in leaf harvest intensities recorded in literature. For instance, Schippers (2002) reports that mustard rape leaves are harvested weekly, whilst Ndoro (2004) reports that mostly one or two leaves are harvested per plant. The available information does not clearly state the number of leaves harvested per plant and the frequency of harvesting.

There appears to be no records of studies on the effects of leaf harvest intensities on growth and leaf yields in mustard rape in sole cropping and on component crops in intercropping situations in Zimbabwe. Partial defoliation of mustard rape through leaf picking for vegetable leaf is likely to have effects on growth of the subject crop. The response to partial defoliation, which is likely to influence the resultant vegetable leaf yields, is affected by the intensity and the timing.

Some studies reported that lightly defoliated plants may increase sufficiently in biomass to end up larger in mass than non-defoliated controls (e.g. Harris, 1974;

McNaughton, 1983). However, others recorded reduced plant growth and yield with more severe defoliation than with less severe defoliation (Petrie *et al.,* 2003). For instance, an increase in growth was recorded with more intense partial defoliation in pure stands of mustard rape (Khan and Lone, 2005), whilst Tayo and Morgan (1979), correlated poor growth and low seed yield to shortage of carbon assimilates resulting from leaf removal in rapeseed (*Brassica napus*). In Ethiopian kale (*B.carinata)*, which is closely related to mustard rape, more frequent and intense plucking of leaves has been shown to prolong the vegetative phase and hence increase the leaf yields (Schippers, 2002).

However, the studies mentioned above have been mainly pure stands. Since mustard rape is usually found in intercrops in summer there is a need for investigating the effects of leaf harvest intervals and intensities under intercrop situations. In intercropping, the effects of leaf harvests (partial defoliation) also influence growth of the other component crop apart from the subject crop, through modification of competition. For instance, in an intercrop situation, maize yields were increased by partial defoliation and subsequent weakening of the component *Alnus acuminate* (Nyeko *et al.,* 2004). In the study, *Alnus acuminate*, a perennial tree, was the main component. Similarly, partial defoliation of maize was shown to increase growth of the minor bean component (Mashingaidze, 2004). However, the effects of partial defoliation of the minor component still remain obscure.

In mustard rape intercrops in Zimbabwe, the nurturing of volunteer mustard rape plants that emerge at various times of the season also suggests differential response of both component crops, due to presumable differences in intensity of competition.

Therefore, there is a need to determine leaf harvest intervals and intensities that give high mustard rape leaf yields with the least yield losses in the associated maize component crop. This report presents results on the effects of varying leaf harvest intensities and frequencies in summer-grown mustard rape in maize intercrops and pure stands. Two mustard rape populations and two planting dates relative to the main crop were also evaluated.

The objectives of the study were:

i) To investigate the effects of leaf harvest intervals and intensities on the growth and vegetable leaf yields of mustard rape in maize intercrops and pure stands.

ii) To evaluate double cropping, and leaf harvest intervals and intensities on mustard rape leaf yields and grain yield of the component maize crop.

The objectives were formulated from the following hypotheses:

i) More frequent and more intense leaf harvests increase growth and leaf yields in mustard rape due to increases in the number of leaves harvested per plant and compensatory growth in mustard rape compared to the current leaf harvest practice.

ii) Double cropping of mustard rape, and more frequent and more intense leaf harvests in mustard rape increase the leaf yields, but reduce grain yield of the component maize crop due to increased competition in intercrops.

7.2 Materials and Methods

Two experiments were conducted over two rainy seasons: 2002/3 and 2003/4 at the University Farm. The characteristics of the site are described in Section 3.4 of the General Materials and Methods. The first experiment, which will be referred to as Experiment 1 in this report, was designed as a 2 x 2 x 3 x 3 factorial experiment laid out as a randomized complete block design with four blocks. The factors in the experiment were two mustard rape planting dates as described in Section 3.5 of the General Materials and Methods, two cropping systems (sole cropping and intercropping with maize), three leaf harvest intensities (one, two or three leaves harvested per plant) and three harvest intervals of 5, 10 or 15 days. The controls used in this experiment were a maize sole crop and also, a mustard rape sole crop harvested on average after every 12 days (whenever harvestable leaves were present) to simulate farmers' practice.

The second experiment, which is referred to as Experiment 2 in this report, was similar to Experiment 1 in design, except that in Experiment 1 intercropping treatments, mustard rape was planted 1.4 m apart to achieve a population of 11.7 %

of the maize population, whilst it was planted at 0.6 m to achieve a population of 41.18 % of the maize population in Experiment 2. In both experiments, mustard rape was planted into every row of maize. Experiment 2 which was designed after observing that mustard rape populations used in the Experiment 1 were too low, was carried out only in the 2003/4 season.

Both maize and mustard rape crop cultivars and their spacing are described in Section 3.4 of the General Materials and Methods. Mustard rape was direct seeded at the first planting, whilst its three-week old seedlings were transplanted into the maize rows at the second planting.

All plots measured 4.5 m wide x 5 m long in both Experiments 1 and 2. Basal fertilizer (6 % N, 17 % P_2O_5, 5 % K_2O and 10 % S) was applied to all plots at planting at a rate of 300 kg ha^{-1}, and 250 kg ha^{-1} of lime ammonium nitrate (28 % N) was applied as top dressing at five weeks after emergence (WAE) of maize in the maize plots. The experiments were weeded at three, six and nine WAE of maize.

The maize net plot comprised of the innermost three of the five rows minus two guard plants at each end of the rows. For mustard rape, in intercropping the net plot comprised of mustard rape associated the maize net plot while in sole cropping the net plot was defined by the innermost three rows of the seven mustard rape rows minus two guard plants at each end of the rows. Leaf harvests were started at three weeks after transplanting for mustard rape introduced at 10 WAE of maize whilst for the direct seeded crop leaf harvests started at three WAE and ran until after flowering when there were no more harvestable leaves on plants in the respective plots. Grain and leaf yields were from the plants within the net plot.

Immediately after each leaf harvest, harvested leaf area for each plot was determined using a LI-3100 leaf area meter (LI-COR, Lincoln, USA). The average harvested leaf size for each harvest was calculated by dividing total leaf area per plot per harvest by the number of leaves. These harvest averages were then used to calculate the average leaf size for each plot for the season. There was no equipment available to measure light interception in the field. After leaf area measurement, the harvested leaves were then oven-dried at 60°C for 48 hours to obtain dry weight. Mustard rape plant height for each plot was determined by averaging out plant height for seven randomly selected plants in the net plot.

For maize, moisture content was determined using a moisture meter (NJF 1210 Moisture Tester, N.J. Fromet & Co. Ltd. Stamford, England), and grain yield from the net plot and 1000 seed weight were standardized to 12.5 % moisture content as described in Section 3.6 of the General Material and Methods. For mustard rape leaf yields, the farmer practice sole crop was the one used as the control for calculating the mustard rape partial land equivalent ratio (LER) values as described in Section 3.6 of the General Materials and Methods. Data for Experiments 1 and 2 were analyzed separately. All data were subjected to analysis of variance (ANOVA) using Genstat Statistical Package (Lawes Agricultural Trust, 2002) after checking for normality. For more than 12 means, mean separation was done using the Duncan's Multiple Range Test (DMRT) of MSTAT C (ver 2.10). Combined analyses over the 2002/3 and 2003/4 seasons for Experiment 1 data were only done after variances were found to be homogenous in the test for homogeneity of variances.

7.3 Results

Test for homogeneity of variances showed that maize characteristics could not be combined over the 2002/3 and 2003/4 seasons. In both the 2002/3 and 2003/4 seasons, maize grain yield was not affected by both leaf harvest intervals and intensities in the component mustard rape crop (Table 7.1). Maize 1000 grain weight was significantly reduced ($p < 0.05$) by 15-day leaf harvest intervals as compared to five- and 10-day intervals and by one and two-leaf harvest intensities as compared to three-leaf harvest intensities ($p < 0.001$) in the component mustard rape in Experiment 1 in 2002/3. However, it was not affected by leaf harvest intensity or interval in the component mustard rape in both Experiments 1 and 2 in 2003/4.

The first planting of mustard rape in Experiment 1 failed due to poor rainfall at the beginning of the 2002/3 season and therefore, no records were taken. Length of the vegetative phase (shown by the number of days to flowering) and plant height were the mustard rape attributes eligible for combined analysis over the two seasons based on tests for homogeneity. Over the 2002/3 and 2003/4 seasons the length of the vegetative phase in the second planting of mustard rape was significantly ($p < 0.001$) reduced to 39 days by 3-leaf harvest intensities from 41 days obtained by 1-leaf harvest intensities (Table 7.2). Mustard rape dry leaf yield of the second planting in Experiment 2 was not affected by leaf harvest intensities in 2003/4. The data however, had a relatively high coefficient of variation (49.5 %).

Table 7.2: Effects of leaf harvest intensity on length of vegetative phase and dry leaf yield of mustard rape in Experiment 1 (second planting) and Experiment 2 (both planting times) over the 2002/3 and 2003/4 seasons.

Leaf harvest intensity	Experiment 1 2002/3 & 2003/4	Experiment 2 (2003/4)
	LVP§ (days)	Dry leaf yield (kg ha^{-1})
1 leaf	40.50 a	237.00
2 leaves	39.58 b	255.00
3 leaves	38.57 c	288.00
Significance	***	ns
$LSD_{0.05}$	0.707	-
Control¤(current practice)	**(47.88)**	**(210.58)**
CV (%)	4.50	49.50

§LVP = length of the vegetative phase. Means with the same letter in a column are not significantly different. *** = $p < 0.001$. ns = not significant. CV = coefficient of variation. $LSD_{0.05}$ = Least Significant Difference at $p = 0.05$. ¤The control (current harvesting practice) only serves as a dummy variable

Length of the vegetative phase in mustard rape was significantly ($p < 0.001$) influenced by the interaction between effects of cropping system and harvest interval in Experiment 1 (Figures 7.1A and 7.1B). Length of the vegetative phase was static at about 33 days from emergence in intercropping, whilst it increased with increasing length of harvest interval in sole cropping in 2002/3. However, it increased with increasing length of harvest interval in both cropping systems in 2003/4. Overall, mustard rape vegetative phase was shorter in intercropping compared to pure stands.

Table 7.1

Similar to length of vegetative phase, dry leaf yield in the second planting of mustard rape was also significantly ($p < 0.001$) influenced by the interaction between effects of cropping system and harvest interval both the 2002/3 and 2003/4 seasons in Experiment 1(Figures 7.1C and 7.1D). In both seasons, mustard rape leaf yield was not affected by harvest intervals in intercropping, whilst it decreased with increasing length of harvest interval in pure stands. Intercropping reduced mustard rape dry leaf yield by 1565 % and 1910 % in 2002/3 and 2003/4 respectively.

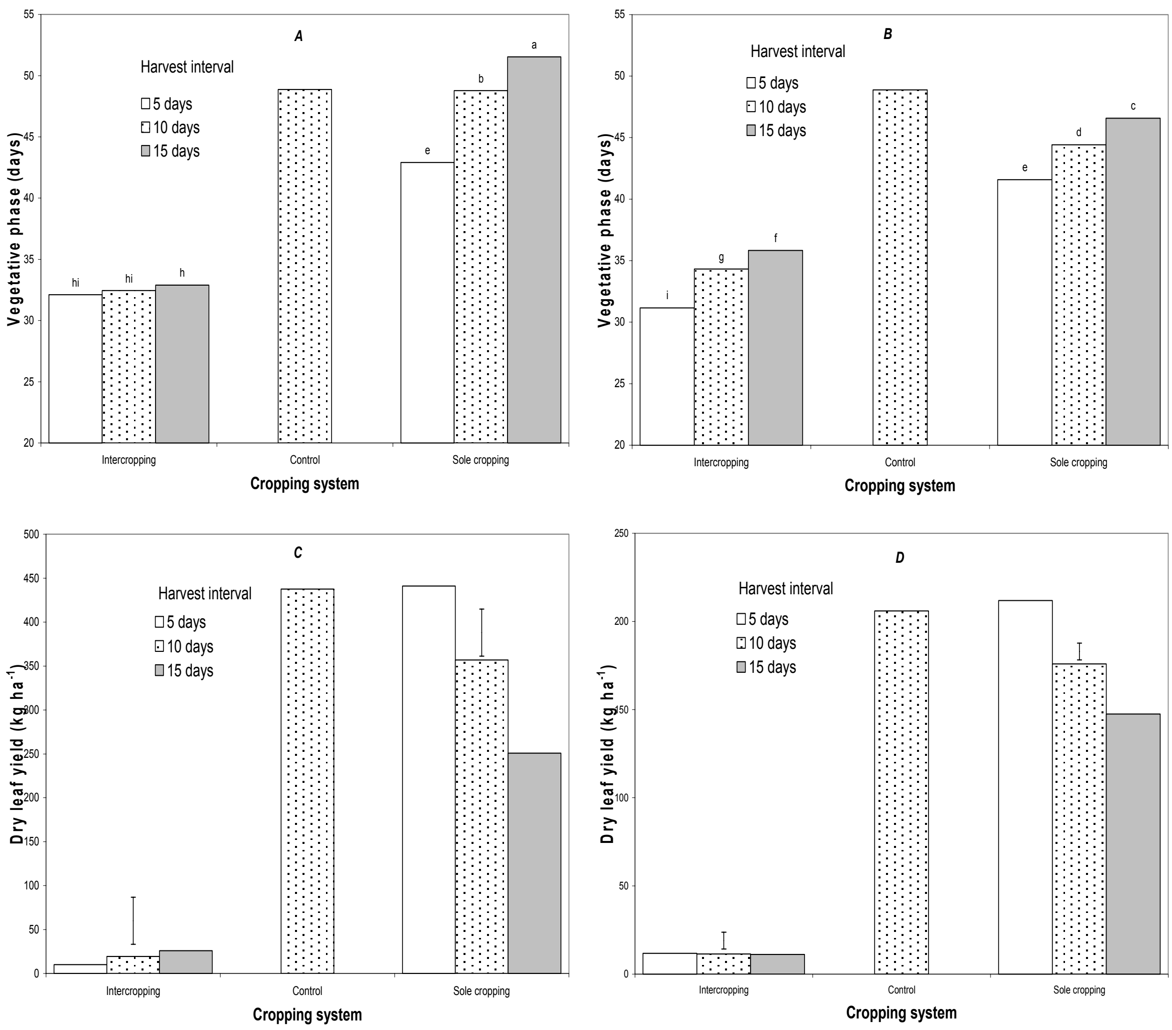

Figure 7.1: Effects of the interaction between cropping system and leaf harvest interval on various attributes of mustard rape in the second planting in Experiment 1: length of the vegetative phase, in 2002/3 and B) in 2003/4, and dry leaf yield C) in 2002/3 and D) in 2003/4. Lower case letters on Figures 7.1A and 7.1B show mean separation using the Duncan's Multiple Range Test (DMRT). Bars on Figures 7.1C and 7.1D represent $LSD_{0.05}$ values. The control (farmer's practice sole crop) only serves as a dummy variable in this figure.

The interaction between effects of cropping system and leaf harvest intensity was also significant ($p < 0.001$) on mustard rape harvested leaf size in 2002/3 and dry leaf yield in 2003/4 in the second planting of mustard rape in Experiment 1 (Figures 7.2A and 7.2B). Both parameters were not affected by leaf harvest intensities in intercropping. However, in sole cropping, on one hand, mustard rape leaf size at three-leaf harvest intensity was reduced to 64 % of the leaf size at one-leaf harvest intensity. On the other hand, dry leaf yield increased with increasing leaf harvest intensity.

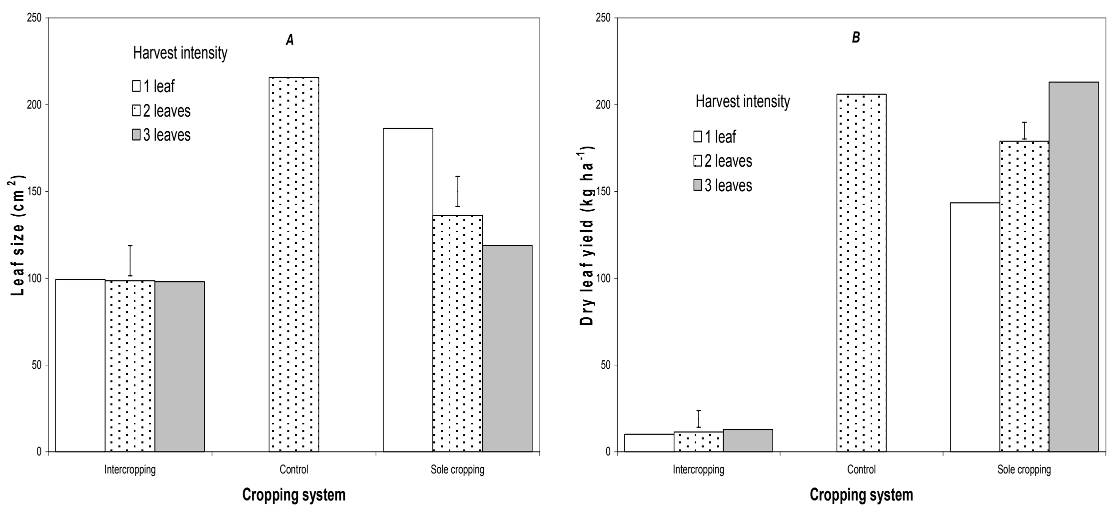

Figure 7.2: Effects of the interaction between cropping system and harvest intensity in the second planting of mustard rape in Experiment 1 on: A) leaf size in 2002/3 and B) dry leaf yield in 2003/4. Bars on the graphs represent $LSD_{0.05}$ values.
The control (farmer's practice sole crop) only serves as a dummy variable in this figure.

The interaction between planting time and leaf harvest intensity was significant ($p < 0.001$) on mustard rape harvested leaf size in both Experiments 1 and 2 in 2003/4 (Figures 7.3A and 7.3B). At both planting times leaf size decreased with more intense leaf harvests in both experiments. However, the differences in leaf size between harvest intensities were larger in the first compared to the second planting. In both experiments, leaf size was larger in the control compared to any of the harvest intensities at both planting times.

The interaction of the effects of time of planting, cropping system and harvest interval had significant effects ($p < 0.001$) on the length of the vegetative phase of mustard rape in Experiment 2 in 2003/4. In both sole cropping and intercropping, length of the vegetative phase increased with increases in length of harvest interval at both planting times. However, in intercropping length of the vegetative phase was shorter in the second planting, whilst in sole cropping there were no differences due to planting time differences at 15-day intervals, and also at 10-day intervals (Figures 7.4A and 7.4B).

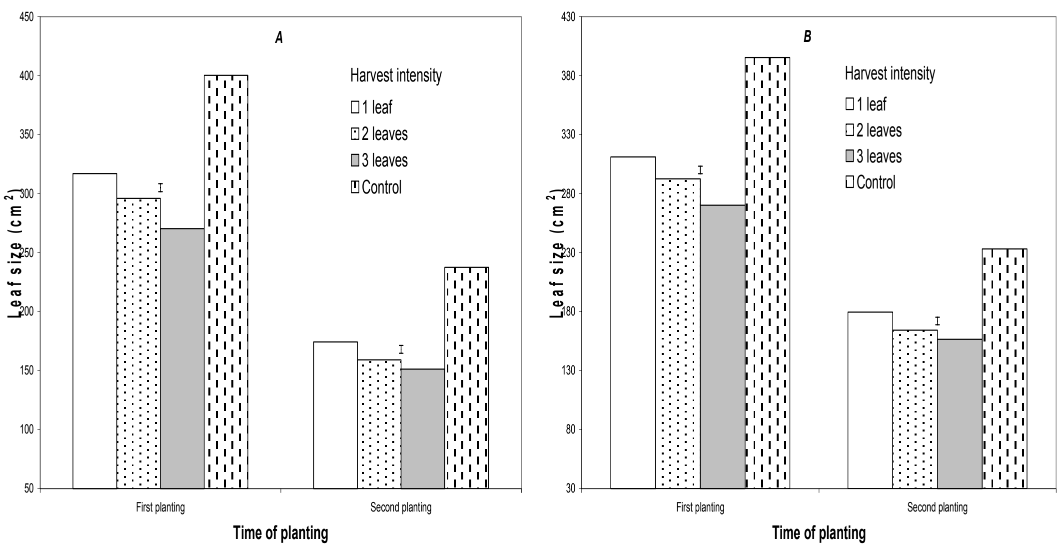

Figure 7.3: Effects of the interaction between time of planting and harvest intensity on mustard rape leaf size in 2003/4: A) in Experiment 1 and B) in Experiment 2. Bars on the graphs represent $LSD_{0.05}$ values. The control (farmer's practice sole crop) only serves as a dummy variable in this figure.

The interaction between the effects of planting time and harvest interval also had significant effects ($p < 0.001$) on mustard rape harvested leaf size in Experiment 2 (Figure 7.4C). At both planting times, mustard rape leaf size increased with increasing length of leaf harvest intervals. However, larger differences in leaf size between harvest intervals were in the first planting. For instance, in the first planting leaf size increased from 244 cm^2 at 5-day intervals to 332 cm^2 at 15-day intervals, whilst a corresponding increase in the second planting was from 157 cm^2 to 177 cm^2.

Similar to leaf size, the number of leaves harvested per plant in Experiment 2 was also significantly ($p < 0.001$) affected by the interaction between the effects of planting time and harvest interval (Figure 7.4D). Unlike leaf size, the number of leaves harvested per plant decreased with increasing length of harvest interval at both the first and the second planting times. However, in the first planting the number of leaves harvested decreased from 8 leaves at 5-day intervals to 6 at 15-day intervals whilst in the second planting the corresponding reduction was from 9 leaves to 5 leaves.

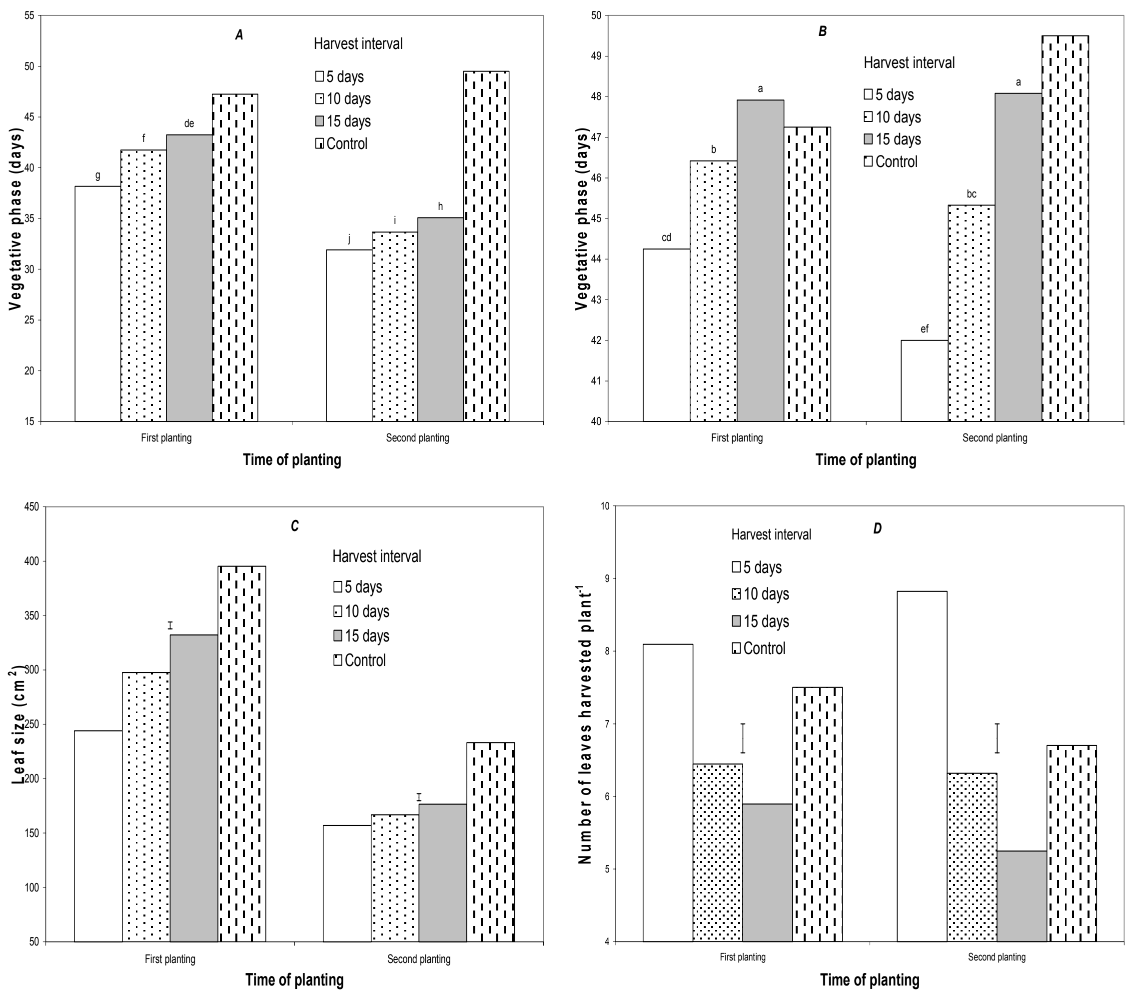

Figure 7.4: Effects of the interaction between time of planting and leaf harvest interval on mustard rape characteristics in Experiment 2 in 2003/4: A) length of the vegetative phase in intercropping, B) length of the vegetative phase sole cropping, C) leaf size and D) leaf number per plant. Lower case letters on Figures 7.4A and 7.4B show mean separation using the Duncan's Multiple Range Test (DMRT). Bars on Figures 7.4C and 7.4D represent LSD values. The control (farmer's practice sole crop) only serves as a dummy variable in this figure.

Mustard rape dry leaf yield was significantly ($p < 0.001$) influenced by the interaction between the effects of cropping system and planting time in Experiment 2. It was reduced by intercropping to 38.38 % of the pure stand yield in the second planting, whereas the corresponding reduction in the first planting was to 28.24 % (Figure 7.5A). The interaction between cropping system and planting time also had significant ($p < 0.05$) effects on mustard rape leaf size in Experiment 2. In intercropping, leaf size in the second planting was reduced by nearly 50 % to 120.57 cm^2 from 240.28 cm^2 obtained in the first planting, whereas in sole cropping the corresponding reduction was 38 % to 212.88 cm^2 from 342.24 cm^2 (Figure 7.5B). Both dry leaf yield and leaf size in mustard rape were higher in the first compared to the second planting in both intercropping and sole cropping.

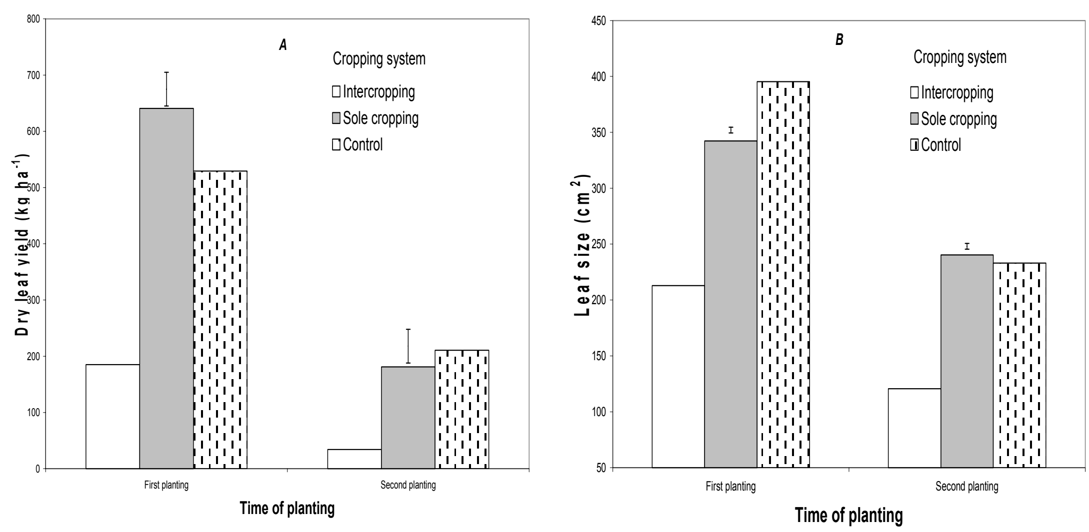

Figure 7.5: Effects of the interaction between cropping system and time of planting on: A) dry leaf yield and B) leaf size of mustard rape in Experiment 2 in 2003/4. Bars on the graphs represent LSD values. The control (farmer's practice sole crop) only serves as a dummy variable in this figure.

In Experiment 1, there was no simple trend for the maize partial LER which was around unity. However, the partial LER of the second planting of mustard rape increased with increasing length of harvest interval and also with increasing intensity of harvest in both 2002/3 and 2003/4. Similarly, the intercropping advantage, LER, increased with increasing harvest intensity and length of harvest interval in 2002/3. The advantage of intercropping over sole cropping ranged from 0.3 % to 9.2 % in 2002/3 and from 8.1 % to 27.3 % in 2003/4 (Table 7.3). The highest LER values (1.09 in 2002/3 and 1.27 in 2003/4) were both obtained by harvesting three leaves per plant per occasion in the second planting of mustard rape in Experiment 1.

Table 7.3. Effects of leaf harvests in the second planting of mustard rape on the productivity of maize-mustard rape intercrops in Experiment 1 in the 2002/3 and 2003/4 seasons.

Treatment	2002/3 season			2003/4 season		
	Partial LER		LER	Partial LER		LER
	Maize	MRape		Maize	MRape	
Harvest interval						
Five days	1.020	0.025	1.045	1.13	0.058	1.184
Ten days	1.030	0.042	1.072	1.05	0.055	1.100
Fifteen days	0.950	0.057	1.007	1.12	0.055	1.172
Harvest intensity						
One leaf	0.996	0.033	1.029	1.05	0.050	1.101
Two leaves	0.963	0.041	1.003	1.03	0.056	1.081
Three leaves	1.042	0.050	1.092	1.21	0.063	1.273

MRape = Mustard rape

In both Experiments 1 and 2, mustard rape partial LER values were lower in the second planting compared to the first planting in 2003/4 (Table 7.4). In the second planting, LER values were reduced to 1.09 and 1.19 from 1.17 and 1.38 in the first planting in Experiments 1 and 2 respectively in 2003/4. Also, in both experiments, mustard rape partial LER values increased with increasing harvest intervals and increasing leaf harvest intensity. However, there was no straight forward trend in the LER values. LER values were higher in Experiment 2 than in Experiment 1. Overall, all the intercrops in this study recorded LER values greater than unity. However, mustard rape partial LER and LER values for Experiment 1 are very low, especially where there is the second planting of mustard rape only.

Table 7.4. Effects of planting time and leaf harvests on the productivity of maize – mustard rape intercrops in Experiments 1 and 2 in 2003/4.

Treatment	Experiment 1			Experiment 2		
	Partial LER		LER	Partial LER		LER
	Maize	MRape		Maize	MRape	
Planting time						
First Planting	1.034	0.136	1.170	1.021	0.324	1.384
Second planting	1.034	0.056	1.090	1.021	0.164	1.185
Harvest interval						
Five days	1.055	0.089	1.144	1.042	0.251	1.292
Ten days	0.996	0.096	1.091	0.966	0.262	1.258
Fifteen days	1.052	0.103	1.155	1.027	0.277	1.303
Harvest intensity						
One leaf	1.014	0.086	1.100	1.027	0.248	1.271
Two leaves	0.994	0.092	1.086	1.045	0.266	1.299
Three leaves	1.095	0.110	1.205	0.992	0.296	1.283

MRape = Mustard rape.

7.4 Discussion

The reduction of all mustard rape leaf yield-related attributes in intercropping at both planting times in both Experiments 1 and 2 can be ascribed to competition with maize for growth resources, such as water, mineral nutrients and light. The severe reduction of mustard rape growth in the second planting suggests that the competition was more intense for the second planting than the first planting of mustard rape. Also, since the second planting of mustard rape was not introduced with a basal fertilizer application, it means the crop might not have had adequate nutrition to grown, even in pure stands as shown by low yields in the pure stands as well.

In addition, the tall maize crop, which had already reached its full canopy at 10 WAE, probably shaded the underlying mustard rape crop to levels that retard growth. The extent of shading was however, not determined in this experiment. Introducing mustard rape into maize at 10 WAE meant that maize already had establishment and height advantages over mustard rape and thus maize was the dominant component while mustard rape was the dominated component. Competition for light and other growth resources due to increased plant densities, even in mustard rape sole cropping has been shown to reduce plant growth, leaf size and therefore leaf yields (Schippers, 2002).

It seems that in intercropping mustard rape was so dominated by maize that it responded to the pressure of intercropping only, thereby confounding the effects of the leaf harvest treatments on intercropped mustard rape, especially introduced at 10 WAE of maize. In intercropping, a dominant component shows a response similar to that in sole cropping whereas the dominated component may display a response quite different from that in sole cropping (Saka *et al*, 1993). The performance of the two crops in intercropping is thus explained. Simultaneous planting of mustard rape and maize probably reduced levels shading as the maize canopy was not yet compact to effectively shade mustard rape during the first few weeks of growth. This resulted in higher leaf yields compared to yields in the second planting of mustard rape. Elsewhere, in haricot bean-maize intercrops, Fininsa (1997) also noted that introducing haricot bean 30 days after planting maize significantly reduced haricot bean yields and plant growth in general as compared to simultaneous planting.

Early planting of crops takes advantage of abundant sunshine early in the season, which however, disappears as cloud cover incidence increases as the rainy season progresses. Cloud cover affects the quality of light reaching the crop. Light quality has been shown to have an effect on leaf area expansion in other crops. For instance, leaf area expansion rates and subsequent leaf sizes were reduced due to shading in soybean (Board, 2000) and maize (Iqbal and Chauhan, 2003). Leaf size in turn, has an effect on accumulation of dry matter and therefore crop yields. This explains the reduced leaf size and consequently leaf yields of mustard rape due to planting at 10 WAE of maize. Similar results were also reported by Abel (1976), in sole cropping of safflower, where smaller, earlier flowering plants with low yields were obtained as a result of a 30 day delay in planting.

Low mustard rape leaf yields recorded in intercropping are partly a result of early flowering. Since no further harvestable leaves are produced after flowering in mustard rape, the extent of yield reduction depends on the extent of shortening of the vegetative phase. This explains the low leaf yields obtained in both intercrops and sole crops where the vegetative phase was reduced.

However, it should also be noted that mustard rape intercropped at 11.7 % and 41.18 % of the maize population was only equivalent to about 7.1 % and 23.53 % of the pure mustard rape stand density respectively. Therefore the reduction in mustard rape leaf yields in intercrops was also, a result of lower densities compared to pure stands. Similarly, Willey and Osiru (1972), recorded bean and maize yield reduction when plant population was lowered in intercropping.

Apart from the harvestable leaf yields, the yield components of mustard rape, defined by leaf size and the number of leaves produced per plant were also significantly reduced in intercropping. Reduction of these plant characters emphasize that the low leaf yields obtained in intercropping were a result of stunted growth rather than the low population effect alone. Therefore the reduction of yields in intercropped mustard rape seems three-pronged. Firstly, the low populations compared to sole crops, poor competitive ability (including for light) resulting in stunted growth and thirdly, early flowering.

It seems that frequent and intense leaf harvests reduced mustard rape’s competitive ability resulting in gains in maize grain size. Though the change in grain size was not linked to a change in grain yield, it has an effect on the selling price of maize. Grain size in maize is an important quality aspect used for grading maize. Small grain is of low grade and therefore fetches low prices on the market, which are disadvantageous to the farmer. However, the results suggest that grain size is not always reduced by more intense leaf harvests in component mustard rape.

Leaf harvesting is tantamount to plant injury, and therefore constitutes a form of stress whose magnitude depends on the intensity of harvest. Stressful conditions tend to reduce length of the vegetative phase in mustard rape. Khan (2003) obtained increased ethylene evolution with more intense partial defoliation of mustard rape.

Ethylene is usually produced by vegetatively growing plants under stressful environments. Shorter harvest intervals or more intense leaf harvests constituted a more severe harvest and therefore, could have exerted more stress resulting in a shorter vegetative phase than a longer harvest interval or less intense leaf harvest. This is, however, contrary to the observed trend in Ethiopian kale where more frequent harvesting prolonged the vegetative phase (Schippers 2002). In mustard rape, harvestable leaves are produced before flowering. Shortening of the vegetative phase in mustard rape reduces leaf yields as explained earlier. In intercropping, the less-than-three-day differences in flowering may not be significant to the farmers.

Severe leaf harvesting restricts vertical growth and for that reason it has been used as height control tool in greenhouse vegetable plants (Schnelle, McCraw and Dole, unpublished).The extent of vertical growth restriction depends on the intensity of harvesting. Therefore, the reduction of mustard rape plant height with more severe leaf harvests in this study is thus explained.

The total number of leaves harvested per plant was increased by harvesting three leaves per plant per occasion. This result means that a considerable proportion of 'harvestable' leaves might not be harvested when less intense harvests are employed. In partial defoliation experiments more intense defoliation has been shown to stimulate growth in cotton (Eaton and Ergle, 1954). However, this does not seem to apply to this study as the leaves harvested at three-leaf harvest intensities were smaller than those harvested at one-leaf harvest intensities. At more intense harvests and shorter harvest intervals, under-developed leaves, small in size were harvested.

The evidence that one-leaf harvest intensities significantly increased size of the leaves harvested also further indicates that greater leaf harvest intensities and shorter intervals were limiting full leaf development. This scenario explains the high leaf yields and the small leaf sizes obtained by harvesting three leaves per plant per occasion. The leaves harvested in this experiment are just harvestable biomass whose quality and acceptability to consumers in not known. The leaves were quite variable in dimensions. There may be a need however, to test for the acceptability and marketability of the leaves harvested at the different harvest intensities to consumers before making solid recommendations on leaf harvest intensities. The reduction in leaf size may however, not desirable to farmers, especially those who produce mustard rape for the market as leaves of 15-30 cm long are preferred for marketing (Duke, 1983).

Though intercropping drastically reduced mustard rape yields, still it emerged advantageous to intercrop maize and mustard rape, as the land equivalent ratio values were greater than unity for all the leaf harvest treatments in intercrops in this study. However, it is also worth noting that the yield advantage realized in intercropping with the second planting of mustard rape in this study was mainly a consequence of the fact that maize yields were not significantly reduced by intercropping.

7.5 Conclusions

- Leaf harvest intervals of 5-15 days and leaf harvest intensities of 1-3 leaves per plant per occasion in intercropped mustard rape had no significant effects on the component maize grain yield.
- Leaf harvest intervals of 5-15 days and leaf harvest intensities of 1-3 leaves per plant per occasion in intercropped mustard rape did not seem to have significantly different effects on mustard rape leaf size, length of vegetative phase and leaf yield, especially when mustard rape is planted at 10 WAE of maize.
- Mustard rape leaf yields in pure stands and simultaneously planted with maize, can be increased by harvesting three leaves at five day intervals, compared to the current practice of 12-day harvest intervals.
- More intense and more frequent leaf harvests in mustard rape reduced the vegetative growth phase compared to the current farmer’s practice, and therefore the time during which the much needed relish will be available. Mustard rape leaf size was also reduced by more frequent leaf harvests.
- Intercropping mustard rape with maize, especially introducing mustard rape at 10 WAE of maize, reduced mustard rape growth and leaf yields compared to sole cropping and simultaneous planting with maize.

- Nonetheless, it still emerged advantageous to intercrop maize and mustard rape. Farmers can even increase the benefits of intercropping by increasing mustard rape to 41.18 % of the maize population without any significant loss in maize yield while similar response of mustard rape to leaf harvest intensities is maintained.
- The highest yield advantages of intercropping are realized by harvesting three leaves per plant in mustard rape or through harvesting at 15-day intervals as shown by LER values.
- Double cropping of mustard rape in a maize intercrop also gives farmers the advantage of having relish available throughout much of the summer season.

7.6 Recommendations

- Farmers may abandon the current leaf harvest practice of 12-day intervals and adopt harvesting 3 leaves per plant at 5-day intervals for higher leaf yields, only if the leaf size is acceptable for their needs.
- Farmers should take advantage of the high leaf yields of shorter harvest intervals and more intense harvest through processing and preservation as the high yielding crop lasts for a shorter time.
- There is a need for maintaining high mustard rape leaf yields without reducing the much needed long vegetative growth phase and leaf size, possibly through appropriate application and management nitrogen.

CHAPTER 8

8.0 EFFECTS OF NITROGEN FERTILIZATION AND TIME OF HARVESTING ON LEAF NITRATE CONTENT AND TASTE IN MUSTARD RAPE

8.1 Introduction

From the foregoing review, it is clear that mustard rape can be raised with minimum input requirements in intercrops. However, unlike in winter when mustard rape is grown in pure stands, fertilizer management is not clear-cut in summer in intercrops as mustard rape derives its nutrition from fertilizers that are applied to the main crops. This becomes particularly critical as certain fertilizer levels are claimed to cause bitterness. Bitterness in mustard rape is caused by a glucosinolate sinigrin naturally found in some plants of the *Brassica* species (Rem and Espig, 1991); it is claimed to increase with increases in nitrogen fertilization. However, mustard rape's vegetative growth is also very responsive to nitrogen fertilization.

This often leaves farmers caught up in a 'yield dilemma' between quality and quantity of the most preferred leafy vegetable in Zimbabwe. The mustard rape yield dilemma is likely to present a challenge especially in maize – mustard rape intercrops which receive fairly high nitrogen fertilizer levels. Nitrogen is central to plant growth due to its presence in nucleic acids, enzymes, chlorophyll, proteins and hormones. However, its excessive supply is often damaging to the environment (Food and Fertilizer Technical Centre (FFTC), 1997) as well as to crop quality, especially in vegetables (Stopes, Woodward, Forde and Vogtmann, 1989).

Elsewhere, nitrogen management in cropping systems has been eased by the measurement of leaf chlorophyll levels using a hand-held chlorophyll meter which gives unit less relative measurement of chlorophyll. The instrument has simplified nitrogen management through effecting "plant response fertilization" (Westcott and Wraith, 2003), in which fertilizer is applied only when it has gone below threshold levels in the plant tissue. Also, there is no lag time between sampling and outcome of results. The hand-held chlorophyll meter has been successfully used to predict nitrogen status, and therefore nitrogen fertilizer requirements in various grass crops such as rice (Turner and Jund, 1991), maize (Piekielek and Fox 1992), wheat (Follet, Follet and Halvorson, 1992) and very few broad leaved crops including cotton (Wood, Tracy, Reeves and Edminsten, 1992) and tobacco (Mackown and Sutton, 1998). Hand-held chlorophyll meters, have therefore contributed to the reduction of excessive nitrogen fertilizer application in cropping systems.

Nitrate is the form through which most plants take up nitrogen from the soil and the form in which excessive nitrates not incorporated into organic compounds by the plant remain stored in the plant leaves. It is the most critical form of nitrogen in pasture plants and leafy vegetables because of its potential toxicity to livestock and humans (Tremblay, Scharf, Weier, Laurence and Owen, 2001). Nitrates themselves are relatively non-toxic, but upon ingestion they are reduced to nitrites. The nitrites oxidize normal haemoglobin to metahaemoglobin which has no capacity to transport oxygen in the blood. In the human body, nitrates can also be converted to nitrosamines which are carcinogenic. Vitamin C is however, believed to be a strong inhibitor of formation of the nitrosamines (Mirvish, Wallcave, Eagan and Schbic, 1972) and therefore, its intake should be monitored.

Whilst research with other crop plants has shown diurnal variations in leaf nitrate metabolism and content, it has also been observed that as a result of their busy daily schedules, smallholder farmers usually harvest mustard rape early in the morning before most of their daily chores or late afternoon after their daily chores. Possibly, there might be some differences in the taste of leaves harvested at the two times during the day. Higher plant nitrate uptake during the day compared to night has been recorded in tobacco (Matt *et al*., 2001) and other plants. Diurnal variations in tissue nitrate metabolism and content have been attributed to the activity of nitrate reductase (NR) enzyme whose activity increases with exposure to light. Reduced activity of NR results in a decrease in the conversion of nitrate to organic molecules resulting in accumulation of nitrate in the leaves. For instance, leaf nitrate levels in tobacco were shown to decrease during the light period and to recover during the dark period (Matt *et al*., 2001). Therefore, time of harvesting mustard rape leaves during the day, through its effect on leaf nitrate levels might have the potential to forestall the bitterness claim in mustard rape.

Taste cannot be measured objectively and there is considerable variation among consumers as to which tastes are acceptable, therefore there is a need for taste panels. There is no record of the use of taste panels in the evaluation of leafy vegetables in Zimbabwe. Taste panel findings could be used in designing production systems for mustard rape, especially when they are used complimentarily with biochemical assays. The aim of this study was therefore to establish whether taste in mustard rape leaves is related to nitrogen fertilizer application levels, tissue nitrate levels and time of harvesting. The objectives of this study were thus:

i) To determine the effects of nitrogen fertilizer rates used in maize on the taste quality, growth and leaf yields of the component mustard rape.
ii) To establish whether mustard rape leaf taste is related to leaf nitrate content and time of harvesting during the day.

The objectives were based on following hypotheses:

i) High rates of nitrogen fertilizer increase leaf yields and bitterness in mustard rape.
ii) Mustard rape leaves harvested in the morning are more bitter than those harvested at sunset due to higher leaf nitrate content.

8.2 Materials and Methods

The study was carried out on red fersiallitic clay soils at the Crop Science Department, University of Zimbabwe campus. This site lies on the latitude 17° 48' South and longitude 31° 00' East. The study was conducted over two cropping periods on tractor-disced land. The first crop was planted in February 2004 and the second in August 2004 and in this report these are referred to as Season 1 and Season 2 respectively.

The experiment was laid out as a 4 x 2 factorial experiment. The first factor was nitrogen side dressing at three weeks after emergence (WAE) of mustard rape with four levels (0 (control), 34.5, 69 and 103.5 kg N ha^{-1}). The second factor was harvesting time with two leaf harvesting times during the day (in the morning (7-8 am) and at sunset (5-6 pm)). The treatment combinations were arranged in a randomized complete block design with three blocks.

Mustard rape (cv 'Tsunga', Prime Seeds) was direct seeded into furrows made using hoes in plots measuring 2 m long and 3 m wide. Planting stations were spaced at 0.5 m between rows and 0.3 m within the rows. Compound 'D' fertilizer, (6 % N, 17 % P_2O_5, 5 % K_2O, 10 % S) was banded in furrows in all plots at a rate of 300 kg ha^{-1} at planting. Plants were thinned out to one plant per station at 2 WAE. Nitrogen side dress treatments were applied in the respective plots at three WAE. Nitrogen was applied in the form of NH_4NO_3 (34.5% N), which was banded beside the rows. The rates of basal fertilizer and nitrogen side dress were adopted from the smallholders' rates used for fertilization of maize, which is usually intercropped with mustard rape.

Chlorophyll readings were taken using a hand-held chlorophyll meter (SPAD meter) (MINOLTA SPAD 502, Minolta, Japan) at one-week intervals starting from three WAE up to the maturity of the crop (nine WAE). The SPAD meter gives unitless values referred to as SPAD values. SPAD values were recorded by inserting fully expanded tender mustard rape leaves in the meter and pressing the 'record' button on the meter. SPAD readings were taken weekly from 10 leaves per plot and averaged out to give a reading for each plot for the respective week.

Total leaf nitrogen content analysis was carried out at five and seven WAE in both seasons. However, leaf nitrate content analysis was only carried out at 5 WAE in Season 2. Soon after harvesting, leaf samples harvested at the respective times were dried in a forced-air oven at 70ºC for 48 hours. For total nitrogen and nitrate analysis samples were then ground to a fine powder.

Nitrogen content analysis was done using the improved Kjehdahl Method (Horwitz, 1975). From each sample 0.2 g were digested in 5 ml of concentrated H_2SO_4 with 0.1 g Se catalyst at 70ºC for 30 minutes. After the appearance of a pale green colour, the digestion was stopped and the samples were allowed to cool. Fifty (50) ml of 50% NaOH was introduced in each sample and the mixture was distilled. Distillate was collected in Boric acid with indicator mixtures. Each sample was then titrated with 0.01M H_2SO_4. The titre value was equivalent to the percentage total nitrogen in the sample. Nitrate content was determined using the sodium-salicylate method (Caltado, Haroon, Schrader and Youngs, 1975).

Vitamin C content was assessed at five and seven WAE in Season 1, and only at five WAE in Season 2. The analysis was done using the reduction of dichlorophenolindophenol (DCPIP) (Horwitz, 1975). Two grammes of leaf sample from each treatment were macerated in 50 ml of distilled water using a kitchen blender. Twenty-five milliliters (25 ml) of the resultant solution was mixed with 20ml of 5% metaphosphoric acid. After a thorough shaking, the mixture was left for 20 minutes. Distilled water was added to make up to 50 ml. Solids were removed by filtering through Whatman's number one filter paper. The filtrate was then titrated against 1 ml of standardized DCPIP, until a distinct pink colour persisted for at least 15 seconds.

Ordinary leaf harvesting was done at five day intervals from four to eight WAE of mustard rape. The net plot comprised the inner four mustard rape rows, and two guard plants were left out at each end of the rows. Expanded leaves were harvested using the traditional criterion of tenderness. After each harvest, leaf area was measured using a LI-3100 leaf area meter (LI-COR Inc., Lincoln, Nebraska) and then the leaves were oven-dried at 70°C for 48 hours. At each harvest, an average leaf size was estimated from a random sample of 10 leaves from each plot. The average leaf size for each plot was then calculated from the weekly averages. Leaf dry weight and plant phenology data for all plots were also recorded. At flowering, average plant height for each plot was determined from measuring 10 random plants from each plot. All numerical data were subjected to analysis of variance using Genstat Statistical Package (Lawes Agricultural Trust, 2002) after testing for normality. Data that were not normal were transformed to normality, and if normality was not achieved non-parametric tests were performed on the data. Data for Season 1 and Season 2 were only combined after testing for homogeneity of variances.

Taste panels were conducted for each nitrogen level and each harvesting time at five WAE. For the sunset harvesting time, samples were harvested and immediately put in a freezer over night to 'fix' the nitrate levels and then cooked the following day at the same time with those that were harvested in the morning. Samples were each cooked separately in different pots by boiling for 20 minutes, after which salt and cooking oil were added. Taste panels were done with willing students and staff of the University of Zimbabwe. Using university-affiliated panelists reduced the likelihood of rejection and suspicion that might otherwise be found in the general public.

Participants were asked to taste the eight samples one by one and to rinse their mouths after tasting each sample. Samples were labeled with numbers to hide their identity. The samples which were tasted without any accompaniment were also tasted in different orders for different tasters. After tasting the samples, the tasters were asked to complete a short questionnaire (Appendix 3). In Season 1, taste panels comprised 18 assessors, 55.6 % male and 44.4 % female, whilst in Season 2, 25 assessors, 68 % male and 32 % female formed the taste panel. Panelists' perceptions were analyzed using the SPSS (SPSS Inc., 1997).

8.3 Results

Tests for homogeneity of variances showed that leaf size and dry leaf yield could not be combined over Seasons 1 and 2. Leaf size and dry leaf yield of mustard rape were not affected by harvesting time in both Seasons 1 and 2 (Table 8.1).

Table 8.1: Effects of leaf harvesting time on mustard rape leaf size and dry leaf yield in Seasons 1 and 2.

	Season 1		Season 2	
Harvesting time	**Leaf size (cm^2)**	**DLY ($kg\ ha^{-1}$)**	**Leaf size (cm^2)**	**DLY ($kg\ ha^{-1}$)**
Morning	320.00	1317.00	322.40	1022.00
Sunset	322.00	1307.00	326.50	1046.00
Significance	ns	ns	ns	ns
$LSD_{(0.05)}$	-	-	-	-
CV (%)	18.60	27.50	9.10	12.30

DLY = Dry leaf yield, Means with different letters in a column are significantly different. *** = p<0.001, ns = not significant, CV = Coefficient of variation. $LSD_{(0.05)}$= Least Significant Difference at $p < 0.05$

However, the two parameters were significantly ($p < 0.001$) affected by nitrogen side dress rate in both Seasons 1 and 2, increasing with increasing with rate (Figure 8.1). Mustard rape leaf yield was higher in Season 1 compared to Season 2.

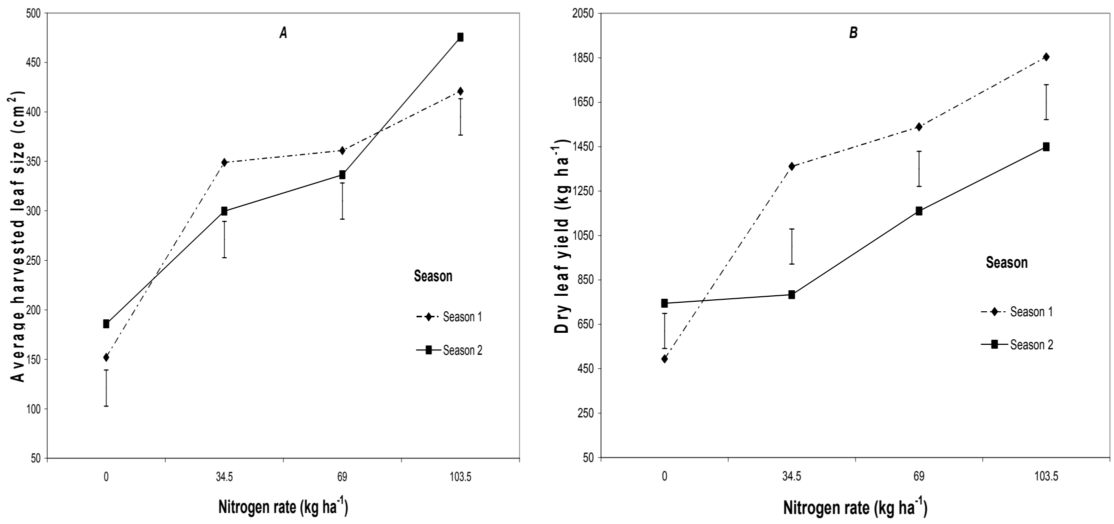

Figure 8.1: Effects of nitrogen side dress rate on A) leaf size and B) dry leaf yield in mustard rape in Seasons 1 and 2. The bars on the graphs represent LSD $_{(0.05)}$ bars

Leaf nitrogen content was significantly affected ($p < 0.001$) by both harvesting time and nitrogen side dress rate at 5 WAE in Season 1 (Table 8.2). It was higher (5.01 %) in leaves harvested in the morning compared to those harvested at sunset (4.57 %). The parameter also increased with increasing nitrogen side dress rate from 3.94 % in the control to 5.15 % in 69 kg N ha^{-1}. Vitamin C content was not affected by nitrogen side dress rate at seven WAE in Season 1 and at five WAE in Season 2.

Leaves harvested in the morning at five WAE had 0.433 % and 0.08 % higher ($p < 0.05$) nitrogen and nitrate respectively than those harvested at sunset in Season 2. Both parameters also increased with increasing nitrogen side dress rate. There were no differences ($p > 0.05$) in both leaf nitrogen and leaf nitrate content between the control and 34.5 kg N ha^{-1} in Season 2. Leaf nitrate content at seven WAE was neither affected by harvesting time nor by nitrogen side dress rate in Season 2. Over Seasons 1 and 2, leaf nitrogen content at 7 WAE significantly ($p < 0.001$) increased with increasing nitrogen side dress rate.

Table 8.2

Mustard rape leaf nitrogen content at seven WAE was significantly affected ($p < 0.05$) by the interaction between season and leaf harvesting time (Figure 8.2A). In Season 1 there were no differences in leaf nitrogen content between leaves harvested in the morning and at sunset. However, leaf nitrogen content was higher (4.31 %) in leaves harvested in the morning compared to those harvested at sunset (3.74 %).

Tests for normality of data showed that mustard rape plant height data for the two seasons and vitamin C at five WAE in Season 1 data could not be subjected to analysis of variance even after transformation. Therefore, Friedman's non-parametric test was performed on the data. Mustard rape vitamin C content at five WAE was not affected by nitrogen side dress rate in Season 1 (Figure 8.2B). Mustard rape generally increased with increasing nitrogen side dress in both Seasons 1 and 2 (Figures 8.2C and 8.2D). Plant height was not affected by harvesting time at each nitrogen side dress level in Season 1, whilst it was lower at the morning harvesting in the control in Season 2.

Tests for homogeneity of variances showed that SPAD values data could be combined over Seasons 1 and 2. SPAD values were higher in Season 2 compared to Season 1, except at seven and nine WAE where converse results were obtained (Figure 8.3A). At three WAE there were no differences in SPAD values across the nitrogen side dress rates (Figure 8.3B). Generally, the SPAD values increased with increasing nitrogen side dressing rate, though at different rates of increase each week. At all nitrogen side dressing levels, SPAD values increased with time in WAE. The SPAD values reached a peak at five and six WAE before starting to decline at seven WAE. Throughout the season, SPAD values were higher at higher nitrogen rates.

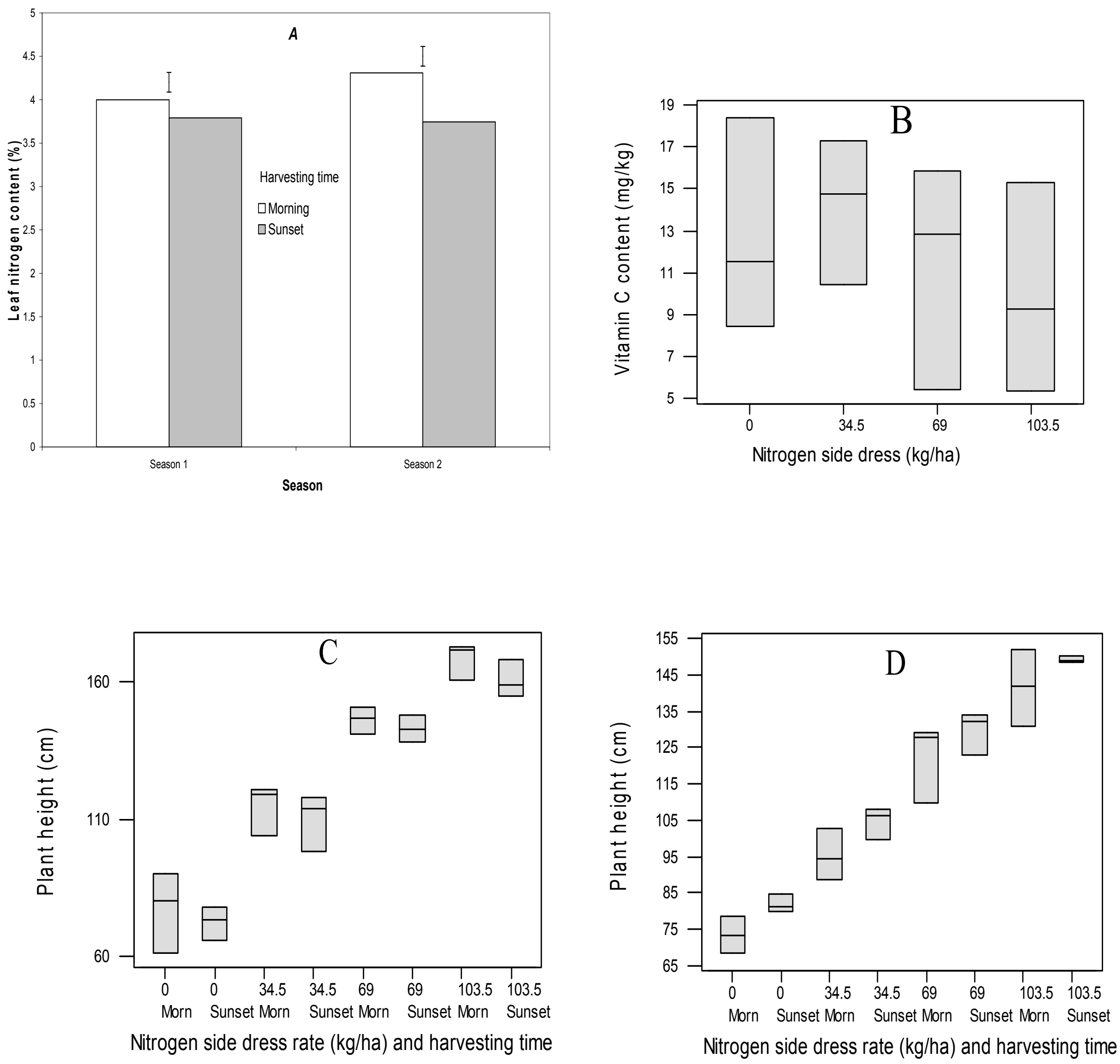

Figure 8.2: Effects of seasons, nitrogen side dress rate and leaf harvesting time on mustard rape plant characteristics; A) Leaf harvesting time and seasons on % leaf nitrogen at 7 WAE. B) Vitamin C content at five WAE in Season 1 and C & D) plant height in Season 1 and Season 2 respectively. Bars on Figure 8.2A represent $LSD_{0.05}$ values. On Figures 8.2B, 8.2C & 8.2D, lower and upper parts of the rectangles give the estimated 25th and 75th percentiles respectively and the middle lines indicate the median values

The detection of off-flavours was higher in the samples harvested at sunset in both seasons. The panelists however, could only describe as ‘medicinal’ the off-flavour in the samples. Differences in taste detected were not much for the times of harvesting (Table 8.3). No major differences were recorded in the appearance of samples after preparation due to harvesting time. For both harvesting times, most of the samples fell in the ‘acceptable’ category in both seasons.

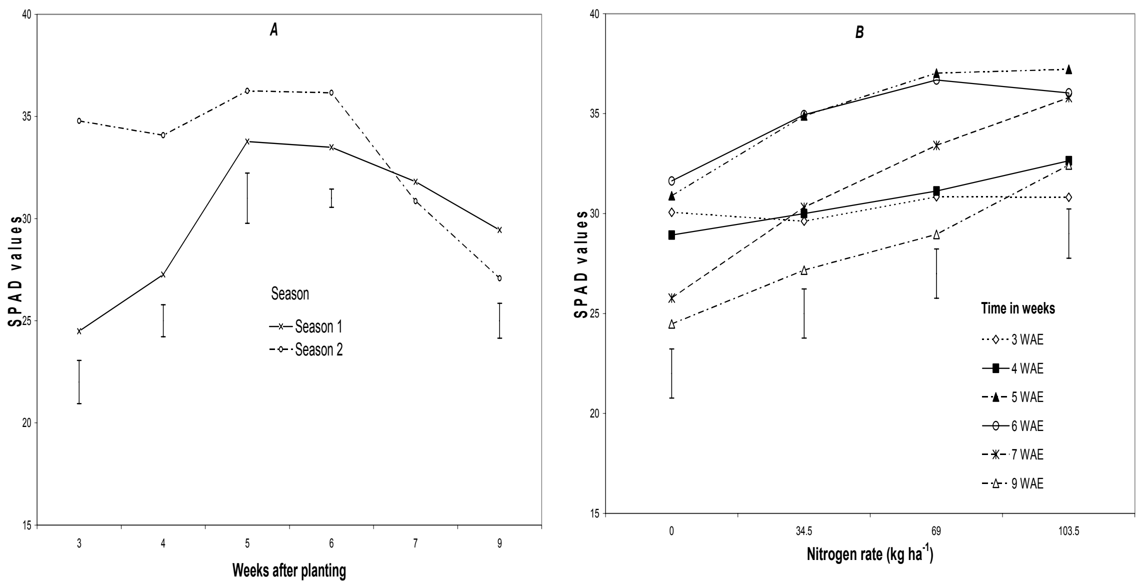

Figure 8.3: Effects of A) season and B) nitrogen side dress rate on SPAD values during mustard rape growth. Bars on the graphs represent $LSD_{0.05}$ values

Table 8.3: Effects of leaf harvesting time on taste attributes of mustard rape in Seasons 1 and 2 (figures are percentage of taste panelists).

Parameter		Season 1 (*n = 72*)		Season 2 (*n = 100*)	
		Time of harvesting		**Time of harvesting**	
		Morning	**Sunset**	**Morning**	**Sunset**
Taste	Mild	19.40	13.89	20.00	16.00
	Bitter	33.33	22.22	33.00	26.00
	Very bitter	47.27	63.89	47.00	58.00
	Total	**100**	**100**	**100**	**100**
Appearance after cooking	Appealing	25.00	16.67	20.00	16.00
	Acceptable	41.67	72.22	71.00	77.00
	Gross	33.33	11.11	9.00	7.00
	Total	**100**	**100**	**100**	**100**
Presence of off-flavours	Yes	44.44	50.00	34.00	49.00
	No	55.56	50.00	66.00	51.00
	Total	**100**	**100**	**100**	**100**

Generally an increasing percentage of panelists recorded increasing bitterness and decreased mild taste with increasing nitrogen side dress rate in both seasons. All levels of bitterness were recorded for each rate of nitrogen side dress (Table 8.4).

There was a significant ($p < 0.01$) correlation between nitrogen side dress level and taste (R = 0.503) in Season 2. Meanwhile, leaves got more appealing and less gross with increasing nitrogen side dress rate in both seasons. There was a significant negative correlation between nitrogen level and appearance after preparation (R= -0.259: $p < 0.01$) in Season 2. The presence of off-flavours increased with increasing nitrogen side dress rate in Season 1, whilst to the contrary, it decreased with increasing nitrogen side dress in Season 2.

Table 8.4

8.4 Discussion

Part of Season 1 (February to June 2004) received a considerable amount of rainfall as it falls within the ending of the rainy season. Season 2 was predominantly the dry season in which the crop was grown under irrigation, with a little rain marking the start of the rainy season. A higher proportion of leaf total nitrogen at 7 WAE was probably leached by rains in Season 1 resulting in lower nitrate for plant uptake and thus the lower leaf nitrogen and SPAD values in Season 1 compared to Season 2 may be explained.

Increases in plant height and dry leaf yield with increasing nitrogen side dress rate in the experiment may be attributed to a good supply of nitrogen. Nitrogen promotes rapid leaf area development and this increases leaf size and therefore, dry matter accumulation due to good capture of radiation. Several other plants have been shown to respond to nitrogen application through vigorous vegetative growth (e.g. van Delden, Lotz, Bastiaans, Frnakel, Smid, Groeneveld and Kropff, 2002), and this is attributable to an increase in leaf area.

Nitrogen content is related to both nitrogen in the sap and nitrogen that has already been incorporated into organic compounds such as chlorophyll and photosynthetic proteins (Tremblay *et al*., 2001). This explains the increasing leaf nitrogen content and SPAD values with increasing nitrogen side dress rate. Therefore an increase in leaf nitrogen means an increase in the capture of light and its subsequent conversion to dry matter. The nitrogen fertilizer rates used in this study are representative of the level used in maize, which is one of the main component crops for mustard rape intercropping. These results imply that with increases in nitrogen fertilization farmers may get high leaf yields of a relatively large and marketable leaf size as leaf size is one of the important aspects of marketability of leafy vegetables. The high yields obtained with increasing nitrogen side dress were contributed by increases in individual leaf size and the number of leaves per plant.

The significant differences in various plant growth parameters between 103.5 kg N ha^{-1} and all the other treatments suggest that mustard rape could still be responsive to nitrogen supply beyond the 103.5 kg N ha^{-1} rate. The rates of fertilizer used in the current study still fall below the optimum rates of 700 – 1000 kg per hectare usually used in mustard rape sole crops. Rathore and Manohar (1989), obtained linear increase in mustard seed yields with increase nitrogen side dress from 30-120 kg N ha^{-1}. Linear increases were also obtained up to 180 kg N ha^{-1} by Singh *et al* (1997), however, with a negative correlation between N and oil content.

Leaf harvesting time had no significant effects on mustard rape growth parameters probably due the fact that there were no differences in the amount of time the plants were exposed to illumination. Also, there were no differences in leaf area exposed to sunlight. For instance, between harvests, existing plant leaf area was exposed to almost the same number of hours, irrespective of the time of harvesting.

The slightly higher leaf nitrate in the morning harvest compared to the sunset harvest implies that farmers who harvest in the morning, especially a few days after nitrogen topdressing may consume slightly more nitrates than those who harvest at sunset. However, farmers just harvest by tradition and are often oblivious of the repercussions of their harvest practice on nitrate content. Light has been shown to stimulate the assimilation of nitrates and reduce their levels in leaves of various plants such as *Nicotiana tabacum* and *N. plumbaginifolia* (Lejay, Quilleré, Roux, Tillard, Cliquet, Meyer, Morot-Gaudry and Gojon, 1997: Matt *et al.,* 2001).

The decrease in nitrate content with time in this experiment implies that mustard leaf harvesting may be delayed when there are concerns of high nitrate content, as results showed that at 7 WAE there were no differences in leaf nitrate content between the highly fertilized crop and the non-fertilized one. This is in pursuance with Brown, Marshal, and Smith (1993), who highlighted that nitrate is generally higher in young plants in their early vegetative phase as compared to more mature plants. The high nitrate levels in aerial parts of the plants indicate that the plants were receiving an adequate supply of nitrogen.

The nitrate levels obtained in this experiment are generally higher than the maximum acceptable for leafy vegetables in Europe. For instance, maximum acceptable nitrate contents in the Netherlands are 0.003 % and 0.0035 % and the European Commission 0.0035 % and 0.0025 % for lettuce and spinach respectively (Tremblay *et al.,* 2001). However, there are no references for leaf mustard rape.

Other sources of nitrate need to be determined for comparison with acceptable daily intake (ADI) of nitrate. FAO and WHO established ADI of nitrate as 0-3.7 NO_3 mg / kg of body weight (JECFA, 1995).

Similarly, the nitrogen levels in this study are fairly high. Foliar nitrogen content for most plants is usually below 2 %. The results suggest that mustard rape extracted high levels of nitrate from the soil, even above its requirements, shown by increases with increasing rates of nitrogen side dressing. Mustard rape takes up large amounts of minerals from the soil and for that peculiarity it has been used in the phytoextraction of heavy metals such as lead from contaminated soil (Soil Quality Institute, 2000).

SPAD readings were no different across the treatments at three WAE because the nitrogen side dress treatments were not carried out yet; hence the plants had an almost equal amount of nitrogen and chlorophyll. In this experiment, the fact that SPAD readings were not always significantly different across all the nitrogen side dress levels suggests that SPAD readings may not always be responsive of nitrogen side dress rates. Similarly, Westcott and Wraith (2003) found that SPAD readings did not respond to luxury nitrogen consumption in peppermint. The plants were senescing and therefore chlorophyll and nitrogen levels were decreasing at about nine WAE. The differences in SPAD readings amongst the nitrogen side dress levels at nine WAE suggest that higher nitrogen side dress rates help maintain chlorophyll levels in plants. The higher SPAD values in Season 2 may have been a result of the amounts of higher quality of light that enhance chlorophyll development received at the beginning of Season 2, compared to the overcast conditions at beginning of Season 1.

Seasonal differences in vitamin C content could be a result of the different storage periods of the samples before analysis was done. Season 2 samples were kept in the refrigerator for a longer time than Season 1 samples and this may explain the very low vitamin C content. Vitamin C is a strong inhibitor of the formation of the carcinogenic *N*-nitrosamine compounds (Mirvish *et al.,* 1972). Therefore, lack of changes in Vitamin C content despite increases in nitrogen fertilization suggests that the risk of nitrosamine formation is not necessarily increased at high rates of nitrogen. However, on the contrary, Tremblay *et al.* (2001) indicated that vitamin C content decreases with increasing nitrate levels.

Samples, which were recorded as mild by some, were recorded as very bitter by others. This inconsistency may be attributed to the poor appreciation of mustard rape by some panelists and also by tasting a relatively high number of samples. A limited number of samples can be tasted before the palate is saturated and therefore, taste panels should be supported by chemical assays (Crowther, Collin, Smith, Tomsett, O'Connor and Jones, 2005). This also shows that results from taste panels, especially from untrained panelists are very subjective and therefore can only serve as a general guideline. If quality control is required, then trained assessors should be used, for instance in wine, tea and cheese tasting. Electronic tasters have been developed and successfully used in pharmaceuticals to eliminate subjective bias of taste panels as well as eliminate safety concerns (Murray, Dang and Bergstrom, 2004).

The increasing percentages of panelists recording bitterness with increasing levels of nitrogen side dress can be attributed to an increase in levels of free nitrogenous compounds in the leaves as supported by leaf nitrate analysis. Similarly, Brussels sprouts have been found to get more bitter with increasing nitrogen fertilization (Tremblay *et al*, 2001). Mustard rape contains a glucoside, sinigrin, which imparts bitterness and pungency (Rathore, 2001; Rem and Espig, 1991). The presence of such severe flavours may impair accuracy and consistency of judgement in taste panels (Crowther *et al*., 2005) and this could be responsible for the bitter taste recorded in the control. There was no assessment of the accuracy and consistency of panelists because there is no classification of mustard rape based on taste in Zimbabwe. Classification helps in the provision of a reference, which is used to assess the accuracy of judgement of taste panelists (Crowther *et al*., 2005).

The improvement of appearance after preparation with increasing amounts of nitrogen side dressing can be ascribed to the luxuriant growth of the heavily fertilized plants, resulting in succulence and better cooking quality than the control. Some panelists even indicated that leaves from the control were tough and a bit fibrous. According to Tremblay *et al* (2001) and Foth (1984), nitrogen imparts a good colour to the leaves and improves the cooking quality of some leafy vegetables, because leaves will be very susceptible to mechanical injury. Samples harvested at sunset were not cooked immediately, but were put in a freezer over night, and this may have caused the lack of much difference in taste with those that were harvested the following day in the morning as some physiological processes could have continued in leaves in the refrigerator. There were no major differences in appearance after preparation of the samples harvested during the different times, probably due to the fact that time of harvesting did not affect growth and tenderness of the plants, leaving only the nitrogen level to determine the cooking quality.

8.5 Conclusions

- Increasing nitrogen side dressing to 103.5 kg N ha^{-1} increased dry leaf yields of mustard rape up to 375 % of the yield of non-top dressed crop but also slightly increased the levels of nitrates and bitterness.
- Harvesting mustard rape at sunset, after exposure to sunlight reduces the amount of free nitrates consumed by consumers compared to that harvested in the morning. However, this only applied to a recently top dressed mustard rape crop as the disparity disappeared at four weeks after top dressing.
- The slight differences in nitrate content between morning and sunset leaf harvests that existed in the then recently top dressed mustard rape, was not significantly detected in taste by taste panelists.
- SPAD readings cannot be reliably used to predict the nitrogen status of mustard rape, without concurrent chemical analysis as large differences in nitrogen content are required to reflect significantly different SPAD readings.

8.6 Recommendations

- Nitrogen side dress can be increased up to 103.5 kg ha^{-1} to increase mustard rape leaf yield without a perceptible deterioration in taste quality if leaves are harvested after an exposure to light.

- From a health point of view, the nitrate consumed in mustard rape top dressed at rates used in maize needs to be reduced for it is above WHO recommendations of less than 0.004 % nitrate.
- There is however, a need for more taste panels, with diverse panelists. Cost-benefit analysis for nitrogen fertilization and the monetary returns from the increased fertilizer levels is also necessary.

CHAPTER 9

9.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

9.1 General Discussion

The large height and large biomass of maize could have been responsible for the suppression of both pumpkin and mustard rape, through limiting light levels reaching the under storey crop in maize intercrops. Intercropping with maize also reduced duration and leaf sizes of the vegetables through partial shading which often reduces the content of photosynthetic pigments and compounds (Pons and Pearcy, 1994: Vos and van der Putten, 2001). Simulating partial shading in intercrops, Pons and Pearcy (1994) recorded lower rate of leaf appearance and ultimate leaf size in partially shaded plants compared to those in full light. The reduced leaf size of intercropped vegetables could also explain poor growth in intercrops, probably due to source limitation. Similarly, Wahua (1985), also recorded decreases in morphological parameters such as number of branches, number of leaves and leaf area per plant in melon intercropped with maize.

Maize has a C_4 carbon assimilation pathway, and typically has a rapid initial growth rate which resulted in a rapid height advantage over pumpkin or mustard rape. In intercrops with short-statured crops such as beans, maize has also been reported to be a dominant component through its morpho-physiological advantage including an extensive root system (Ofori and Stern, 1987). The extensive root system advantage becomes particularly important under rainfed conditions where water is in limited supply. Therefore, in the current studies, it also means maize also had a competitive advantage to limited water and nutrient supplies over the vegetables, especially on-farm, where there was no supplementary irrigation. It is claimed that competition below ground is more intense, hence more critical than above ground competition in agricultural fields (Wilson, 1988).

Mustard rape introduced at 10 WAE of maize was shaded and suffered the height disadvantage as explained in the first paragraph of this chapter. However, there was no additional fertilizer application in the second planting of mustard rape intercrops, and this could also have reduced the growth and yield of mustard rape apart from the shading effects. It has also been reported that initial size of component crops is important in modifying competition dynamics in intercrops, to the advantage of the larger sized crop (Taofinga, Paolini and Snaydon, 1993). Similarly, biological yield of mustard rape (*B. juncea*) was also lowered by late sowing in chick pea-based intercropping (Singh and Rathi, 2003), even with proper fertilizer application. The initial size is very important where components are of almost similar height such as groundnut and mustard rape in the current studies. However, mustard rape planted simultaneously with maize or groundnut benefited from less shading by the then under-developed maize or groundnut canopy. This explains the larger leaf size and leaf yield of mustard rape planted simultaneously with maize or groundnut compared to the second planting, and also in groundnut intercrops compared to maize intercrops. Consequently, mustard rape leaf yields obtained in intercropping at 10 WAE of maize, especially at 11.4 % of the maize population, are unlikely to meet the household demands for relish. Therefore, for improving leaf yields in intercrop situations, both pumpkin and mustard rape must be planted simultaneously with the main crops so that they benefit from less shading at the beginning of the season.

Overall, the competitive advantage of maize resulted in maize dominating the vegetables in intercrops. Typical of a dominant component in an intercrop, maize showed a response similar to the sole crop whilst the dominated components performed lower than their sole crops. The dominance of maize is indicated by the high maize partial land equivalent ratio (LER) values close to unity and the low vegetable partial LER values, especially densities were higher than pure stands. For instance, in 35.3 % maize-pumpkin intercrops, pumpkin density was higher compared to pure pumpkin stands. However, lower leaf yields obtained in the former, emphasizing the domination effects. On the contrary, there is scope for increasing mustard rape population beyond 35.3 % of the maize population without any effects on maize yields as shown in Experiment 2 of Chapter 7.

Possible domination of the vegetables by maize in maize intercrops could have resulted in the observed lack of responses in growth parameters such as plant height or vine length and leaf size to population effects, which were however, recorded in groundnut intercrops. In maize intercrops, the absence of differences in pumpkin and mustard rape growth parameters such as leaf size and growth duration within intercrop populations in maize intercrops suggests that there was only interspecific competition between maize and the vegetables and not within the intercropped vegetables. However, in groundnut intercrops, intercropping pumpkin at 1.84 % reduced pumpkin leaf size to 83 % of the size in the 0.46 % groundnut-pumpkin intercrops, showing the population effects. Generally, in an intercrop, one would expect plant size to decrease at higher densities due to intraspecific competition (Francis, 1989). However, in maize intercrops in the current studies, it seems that the vegetables were so dominated by maize that they could not grow to levels where they would initiate competition amongst themselves under the maize canopy.

Unlike maize, the short height of groundnut allowed more illumination of the vegetables, resulting in less depression of vegetable growth in groundnut intercrops. This is evident through the differential decreases in growth attributes such as leaf size, growth duration and vine length or plant height observed in Chapters 4 and 5. However, the short stature of groundnut also allowed vigorous growth of pumpkin resulting in reduction of groundnut seed yield due to competition for growth resources. Shading of the short groundnut plants by pumpkin leaves was evident especially in the 1.84 % groundnut-pumpkin intercrop where the worst reduction in groundnut seed yield was recorded. The sensitivity of groundnut to intense shading is the main reason why it is not included in conventional intercrops (Tungani *et al.,* 2002).

Whilst intercropping with reduced vegetable plant growth irrespective of population, increases in leaf yields with increasing populations suggest that high vegetable populations can be used to counter the effects of reduced plant growth to maintain high leaf yields as well as increase weed suppression in intercrops. The increases in leaf yield with increasing populations emphasize the importance of increasing populations for increased yields in intercrops (Trenbath, 1976). This means that to achieve the goal of relish availability in sufficient quantities, higher vegetable population levels of up to 35.3 % for pumpkin and beyond 35.3 % for mustard rape, in maize intercrops must be adopted.

In the maize intercropping experiments (Chapters 4, 6 and 7), the yield advantage of intercropping over sole cropping, especially with low mustard rape populations or mustard rape planted at 10 WAE of maize, was mainly a consequence of the stability of maize yields in intercropping. The relatively large maize partial LER values around unity explain this. However, vegetable partial LER values for pumpkin and the first planting of mustard rape were also substantial. The results suggest that intercropping will still be attractive to smallholder farmers in Zimbabwe whose main aim is ensuring stability of the main crop yield in intercrops.

Intercropping maize or groundnut, especially with pumpkin, also has the advantage of suppressing weeds. Canopy density, which presumably increased with increasing plant densities at high intercrop populations, smothered weeds better than maize or groundnut pure stands. The differences in canopy densities explain the different weed suppression effects between pumpkin and mustard rape in intercropping with either maize or groundnut. Pumpkin grows horizontally and has large flat leaves that cover wider ground area compared to the erect mustard rape with fewer and smaller leaves. It seems therefore, that the important factor in weed suppression is canopy development and not intercropping *per se.* Weed suppression in a cropping system where there is no allelopathy, is linked to leaf area index. Olasantan (2007) obtained reduced weed density in yam-pumpkin intercrops as a result of 58-68% increase in the leaf area index. Extensive canopy development in pumpkin pure stands, as indicated by larger leaves and longer vines, was more suppressive to weeds than intercrop canopies, though a 35.3 % maize - pumpkin intercrop had a higher pumpkin density than pumpkin sole cropping.

Under canopy shading, weed biomass is reduced through reduced carboxylase enzymes' activity, chlorophyll content and therefore, photosynthetic and growth rates (Bridgemohan, 1995), whilst density is reduced by low germination (Gautier *et al*, 1995) as most weed seeds require light for germination. Therefore, it means that with higher canopy density as observed in pumpkin intercrops and pumpkin pure stands, the few weeds that germinate have retarded growth and are eventually suppressed to death as they will be starved of assimilates. This explains the low weed density and weed biomass where canopy development was extensive.

The more suppressive effect of intercropping with pumpkin to weeds compared with maize sole cropping suggests that with high populations, intercropping can be an effective option in weed management. However, results and observations from the current studies indicate that intercropping alone will not completely eliminate weeds. Nonetheless, intercropping pumpkin within the same row as maize is recommended for two reasons: i) it allows farmers to use ox-drawn cultivators early in the season before the pumpkin vines spread thereby reducing the drudgery of weeding, and ii) it reduces the frequency of weeding later in the season when the pumpkin vines spread and smother weeds. Therefore, intercropping with pumpkin will alleviate weed problems such as delayed weeding (Mangosho, Mabasa, Jasi and Makanganise, 1999) and field abandonment due to excessive weed pressure which are prevalent in the smallholder farming sector.

Whilst leaf harvest management modified pumpkin and mustard rape leaf yields, it constitutes a form of stress on the plants, whose magnitude depends on the intensity and interval of harvesting. Frequent and intense harvests could have been stressful on the subject plants. Typical of stressed plants, more frequently and more intensely harvested plants showed reduced overall growth, leaf size and growth duration. On one hand, the results demonstrate that the high yields obtained by more intense and frequent harvesting in both mustard rape and pumpkin, will only be available for a short time, therefore farmers should resort to preservation methods to capitalize on the high leaf yields. On the other hand, the advantage of higher leaf yields could be misleading if the small leaves obtained under frequent and intense harvests are less preferable for marketing and consumption.

The reduction of leaf size, vine length and duration of vegetables with more severe harvesting in both mustard rape and pumpkin in both intercrops and pure stands suggest that there was no compensatory growth. In the presence of compensatory growth, an increase in growth parameters such as leaf size, duration and vine length would be expected. This suggests that the concept of compensatory growth observed in trees and pure stands (e.g. McNaughton, 1983: Nowak and Caldwell, 1984: Hoogesteger and Karlsson, 1992) might not apply to repeated defoliation and intercrop situations. It seems, the concept of compensatory growth following partial defoliation might only apply to situations where resources are not limiting, unlike in an intercrop where light, water and nutrients might be limiting as result of competition. Importantly, the history of defoliation is also critical. Repeated defoliation was reported to cause a depletion of plant carbon reserves and consequently the final biomass in trees (Vanderklein and Reich, 1999).

Severely harvested plants may also exceed the threshold of loss of leaf area and this often results in the plants dying. This might partly explain the early senescence of more intensely and more frequently harvested vegetables in the current studies.

The absence of responsive increases in maize yield after more intense or more frequent leaf harvesting in pumpkin or mustard rape can be attributed to the fact that the vegetables had no significant effects on the maize crop yield and therefore, maize did not benefit from their weakening. The results mean that partial defoliation of a less competitive minor component does not benefit the main component in an intercrop. This is contrary to results by Nyeko *et al.* (2004), who recorded increases in growth of the minor component following partial defoliation the main component. However, this means that leaf harvest intensities and intervals implemented in the current intercrop studies can be implemented without any effects on the maize component.

The leaf harvest techniques employed herein are a new technology and therefore, these exploratory studies were only carried out at research station level. They need co-development with farmers on the farmers' field to optimize them, especially with the local farmer's landraces, before adoption. The pumpkin and mustard rape cultivars used in the current studies might not be adapted to shading in intercrops. Therefore, the use of local landraces adapted to intercropping could have improved evaluation of the leaf harvesting practices employed herein. In addition, the increase in phenolics associated with more severe partial defoliation (Khan, 2003), might also influence taste of the vegetables. Hence, it will be worthwhile to study taste and fertilizer responses to the leaf harvests in the current studies as part of the optimization of vegetable production systems.

The rates of nitrogen fertilizer used in the studies represent those used in maize cropping. The results indicate that whilst farmers increase nitrogen fertilizer levels for higher grain yields in maize, the component mustard rape also responds positively through increased leaf yields. However, there is a risk of high nitrate levels in the mustard rape leaves following application of nitrogen side dressing. The low nitrate levels at the sunset harvest are immaterial as they are still above the WHO limits (JECFA, 1995) and are not easily perceptible in taste. Therefore, high rates of nitrogen side dressing in maize - mustard rape intercrops produce high leaf yields, but of objectionable quality, with reference to nitrate levels and taste. It is worth noting that the nitrogen side dressing rate study was carried in pure stands of mustard rape. The results suggest that leaf nitrate level could be even higher in the intercrops due to reduced nitrate reductase activity as a result of partial shading that is inherent in intercrops.

Similar to leaf harvest management, the on-station exploratory nitrogen fertilizer management and taste panel studies also need further research under varying conditions in the farmers' fields. The effects of the increased mustard rape leaf size and biomass with increases in nitrogen side dress levels on weed dynamics also need further research. Elsewhere, high nitrogen fertilization and the resultant high biomass in wheat and potato were effective in smothering weeds (van Delden *et al*, 2002).

Failure of mustard rape in CRA indicates that mustard rape intercropping is drought-sensitive and emphasizes the need for on-farm testing of technologies. The availability of irrigation facilities for supplementary irrigation during the dry spells within the seasons at University Farm facilitated the growth of mustard rape which completely failed in CRA due to drought. This accentuates the fact that recurrent droughts are the major militating factor against the intercropping of mustard rape with field crops (Schippers, 2002).

Whilst it had adequate water supply, the University Farm however, had a high incidence of the fruit fly, probably due to the presence of many other fruit fly host trees such as peach and plum within the vicinity of the experimental plots. Also, the University Farm was characterized by high incidence of mildew diseases due to high rainfall. The two factors led to extensive pumpkin fruit drop and early senescence of pumpkin vines in both seasons. Disease pressure and the absence of fruits could have confounded the responses of pumpkin to populations and leaf harvest practices employed herein. Increases in sink demand per unit of foliage may stimulate photosynthesis and growth by reducing starch or foliage sugar accumulation (Lavigne, Little and Major, 2001). However in cucumbers, leaf dry matter increased with reduced sink demand as a result of fruit pruning (Marcelis, 1991). Therefore, the absence of fruits in the current studies could have promoted vegetative leaf growth thereby inflating the leaf yields. In fruit trees, fruit yield and development was reported to be limited by available leaf area following partial defoliation (Yuan *et al.*, 2005).

Furthermore, restricting the creeping of pumpkin within the respective plots could also have confounded pumpkin responses to the experimental factors. It has been noted that the roots at the nodes are very essential in the growth of pumpkin as these can support growth beyond them with very little contribution from the main root system.

Generally, the current studies revealed that intercropping pumpkin and mustard rape with maize or groundnut assure relish availability and populations of up to 35.3 %, especially of pumpkin, increase leaf yields and augment weed management. Though intercropping reduced duration of availability, double cropping of mustard rape in groundnut and maize intercrops can be adopted as a counter measure. However, the high rates of nitrogen side dressing used in maize reduce the quality of mustard rape, particularly taste and nitrate content.

9.2 Conclusions and Recommendations

- Intercropping pumpkin with maize and groundnut with mustard rape is recommended as mustard rape grows well with less shading in groundnut intercrops whilst pumpkin reduces groundnut seed yield.
- Increasing pumpkin and mustard rape populations to 35.3 % in maize intercrops increased vegetable leaf yields and weed suppression, especially pumpkin intercrops, without any effects on maize grain yield. However,

increasing pumpkin population to 0.94 % in groundnut intercrops reduced groundnut seed yield by up to 45 %.

- Harvesting six leaves per shoot tip at 10 day intervals is recommended in pumpkin and harvesting three leaves at 5-day intervals in mustard rape, as opposed to 12-day intervals practiced by farmers. However, these intervals and intensities reduce leaf size and plant height or vine length.
- Double cropping of mustard rape considerably supplements relish availability within a season without affecting groundnut or maize grain yields, but for high leaf yields with a single planting in intercrops, mustard rape must be planted simultaneously with either maize or groundnut. A second planting of mustard rape at 11 WAE of groundnut or 10 WAE of maize, should only be used as a supplement to the crop simultaneously planted with groundnut.
- Nitrogen side dress rates of up to 103.5 kg N ha^{-1} increase mustard rape leaf yields without marked impairment of taste quality, but exposes consumers to nitrate levels beyond the WHO allowable intake of 0.004 %.
- The intercropping systems studied herein need to be optimized with respect to crop quality and yields of the vegetables before implementation. For improving the performance of mustard rape and pumpkin cropping systems, the following questions must be addressed:
    i. Do further increases in mustard rape intercrop populations beyond those used in the current studies improve leaf yields without effects on maize yields?
    ii. Do leaf harvest intensities and intervals improve leaf vegetable quality aspects such as taste, texture, cooking quality and palatability?
    iii. Do leaf harvest intervals and intensities modify weed suppression and pumpkin fruit yield in intercrops?
    iv. Does partial shading provided by intercrops have any effects on nitrogen metabolism, taste and nitrate levels in mustard rape leaves?

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APPENDICES

Appendix 1: Characteristics of the Natural Regions of Zimbabwe

Natural Region	Characteristics.[1]
I (abt 1.56%)	≥ 1050 mm of rainfall per annum with some rain in all months of the year. Relatively low temperatures.
II (abt 18.68 %)	700-1050 mm of rainfall per annum usually confined to summer. Intensive crop and livestock production. Crops may be affected by short rainy periods or dry spells during the season.
III (abt 17.43 %)	500-700 mm of rainfall per annum with relatively high temperatures and infrequent heavy falls of rain. Subject to seasonal droughts and fairly severe mid-season dry spells.
IV (abt 33.03 %)	450-600 mm of rainfall per annum and subject to frequent seasonal droughts.
V (abt 26.2 %)	< 500 mm of rainfall per annum. Very erratic rainfall. Topography and soils are also very poor.

Adopted from Vincent and Thomas (1961).

Appendix 2: Characteristics of soils found in the study areas

Appendix 2.1: Typical characteristics of soils in the paraferrallitic group*:
☼S/C value not greater than 6
☼E/C value not greater than 12
At least 5% weatherable minerals present in the system and the clay mineralogy is dominated by Kandites (1:1 clay minerals).

Apendix 2.2: Typical characteristics of fersiallitic soils*
S/C values 6-30
E/C values 12-35
Small amounts of 2:1 lattice clays
* Source: Nyamapfene (1991).

[1] N.B. Figures in parentheses show percentage of total area. The remaining 3.1 % of land area is not suitable for any arable agriculture activity. ☼ S/C = Total exchangeable bases (TEB) per 100g of clay; E/C = Cation exchange capacity per 100g of clay

Appendix 3: Taste Panels Questionnaire

The Department of Crop Science at the University of Zimbabwe is carrying out research on improving the productivity of traditional vegetables. The samples of mustard rape (tsunga in Shona) in this experiment received various levels of nitrogen side dress and were harvested at different times of the day. The researcher needs to establish how nitrogen fertilization and time of harvesting are related to the taste of leaves. Participants are required to complete the short questionnaire on their perceptions of mustard rape and their responses will be useful in making recommendations.

1 Particulars of participants
1.1 Name……………………………………1.2 Gender: 1. male 2. female
1.3 Age 1. 20-29 years 2. 30-39 years 3. 40 years and above

2. Tasting
2.1 Sample number……….. 2.2 Date……………………..
Participants are required to taste all the eight samples supplied before completing the questionnaire. One sample must be tasted at a time and participants are reminded to rinse their mouths with water between samples. The response they give below should be solely theirs.

2.2 Please encircle the phrase that best describes the taste of the sample with the above number (in 2.1).
1 mild
2 bitter
3 very bitter

2.2 How would you describe the appearance of the sample?
1 appealing
2 acceptable
3 gross

2.3 Did the sample have an off-flavour?
1 yes
2 no
If your response in 2.3 is yes, can you describe the off-flavour?
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

THANK YOU FOR VOLUNTEERING FOR THIS TASTE PANEL!

Appendix 4: Analysis of Variance (ANOVA) for the effects of pumpkin and mustard rape intercropping and sole cropping in maize-based cropping systems

Appendix 4.1: ANOVA for the effects of cropping system on maize characteristics in 2002/3 and 2003/4 at UZF

Appendix 4.1.1: ANOVA for the effects of cropping system on maize grain yield in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	22436937.	7478979.	19.61	
Block.*Units* stratum					
Cropping system	6	1846590.	307765.	0.81	0.578
Residual	18	6864782.	381377.		
Total	27	31148309.			

Appendix 4.1.2: ANOVA for the effects of cropping system on maize grain yield in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1428035.	476012.	0.31	
BLOCK.*Units* stratum					
Cropping system	6	3694892.	615815.	0.40	0.870
Residual	18	27820923.	1545607.		
Total	27	32943850.			

Appendix 4.2: ANOVA for the effects of cropping system on mustard rape characteristics in maize-based cropping systems at UZF in 2002/3 and 2003/4

Appendix 4.2.1: ANOVA for the effects of cropping system on mustard rape leaf size in the second planting over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
Year	1	9489.6	9489.6	76.59	<.001
Residual	6	743.4	123.9	0.41	
Block.year.*Units* stratum					
Cropping system	3	195414.3	65138.1	214.54	<.001
Year.Cropping system	3	1337.7	445.9	1.47	0.257
Residual	18	5465.1	303.6		
Total	31	212450.1			

Appendix 4.2.2: ANOVA for the effects of cropping system on mustard rape length of vegetative phase in the second planting in the 2002/3 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6.688	2.229	1.05	
Block.*Units* stratum					
Cropping system	3	619.688	206.562	97.52	<.001
Residual	9	19.062	2.118		
Total	15	645.438			

Appendix 4.2.3: ANOVA for the effects of cropping system on the number of leaves harvested per plant in the second planting of mustard rape in the 2002/3 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4.500	1.500	0.64	
Block.*Units* stratum					
Cropping system	3	66.500	22.167	9.50	0.004
Residual	9	21.000	2.333		
Total	15	92.000			

Appendix 4.2.4: ANOVA for the effects of cropping system on plant height in the second planting of mustard rape in the 2002/3 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	58.05	19.35	1.46	
Block.*Units* stratum					
Cropping system	3	9201.55	3067.18	231.21	<.001
Residual	9	119.39	13.27		
Total	15	9378.98			

Appendix 4.2.5: ANOVA for the effects of cropping system on mustard rape length of vegetative phase in the second planting in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	20.75	6.92	0.62	
BLOCK.*Units* stratum					
Cropping system	3	398.75	132.92	11.93	0.002
Residual	9	100.25	11.14		
Total	15	519.75			

Appendix 4.2.6: ANOVA for the effects of cropping system on number of leaves harvested per plant in the second planting of mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.27500	0.09167	1.23	
BLOCK.*Units* stratum					
Cropping system	3	8.70500	2.90167	38.98	<.001
Residual	9	0.67000	0.07444		
Total	15	9.65000			

Appendix 4.2.7: ANOVA for the effects of cropping system on plant height in the second planting of mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	30.31	10.10	0.23	
BLOCK.*Units* stratum					
Cropping system	3	8419.76	2806.59	62.86	<.001
Residual	9	401.85	44.65		
Total	15	8851.93			

Appendix 4.2.8: ANOVA for the effects of cropping system and planting time on harvested leaf size in mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1460.5	486.8	2.14	
BLOCK.*Units* stratum					
Planting Time (P Time)	1	412795.2	412795.2	1814.23	<.001
Cropping sys	3	79231.2	26410.4	116.07	<.001
P Time.Cropping system	3	38408.6	12802.9	56.27	<.001
Residual	21	4778.2	227.5		
Total	31	536673.6			

Appendix 4.2.9: ANOVA for the effects of cropping system and planting time on length of the vegetative period in mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	74.094	24.698	2.71	
BLOCK.*Units* stratum					
Planting Time (PTime)	1	520.031	520.031	56.98	<.001
Cropping sys	3	355.594	118.531	12.99	<.001
P Time.Cropping system	3	91.844	30.615	3.35	0.038
Residual	21	191.656	9.126		
Total	31	1233.219			

Appendix 4.2.10: ANOVA for the effects of cropping system and planting time on dry leaf yield in mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2513.6	837.9	0.86	
BLOCK.*Units* stratum					
Planting Time (PTime)	1	47676.4	47676.4	49.06	<.001
Cropping sys	3	232214.8	77404.9	79.65	<.001
P Time. Cropping system	3	33567.2	11189.1	11.51	<.001
Residual	21	20407.2	971.8		
Total	31	336379.2			

Appendix 4.2.11: ANOVA for the effects of cropping system and planting time on the number of leaves harvested per plant in mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.4734	0.1578	1.41	
BLOCK.*Units* stratum					
Planting Time (PTime)	1	49.2528	49.2528	440.31	<.001
Cropping system	3	6.8259	2.2753	20.34	<.001
P Time. Cropping system	3	2.4409	0.8136	7.27	0.002
Residual	21	2.3491	0.1119		
Total	31	61.3422			

Appendix 4.3: ANOVA for the effects of cropping system on pumpkin characteristics in maize-based cropping systems at UZF in 2002/3 and 2003/4

Appendix 4.3.1: ANOVA for the effects of cropping system on harvested leaf size in pumpkin at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1122.	374.	0.35	
BLOCK.*Units* stratum					
Cropping system	3	86673.	28891.	27.20	<.001
Residual	9	9560.	1062.		
Total	15	97355.			

Appendix 4.3.2: ANOVA for the effects of cropping system on pumpkin growth duration at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1040.7	346.9	0.90	
BLOCK.*Units* stratum					
Cropping system	3	10850.2	3616.7	9.33	0.004
Residual	9	3488.1	387.6		
Total	15	15378.9			

Appendix 4.3.3: ANOVA for the effects of cropping system on pumpkin dry leaf yield at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	444.9	148.3	1.15	
BLOCK.*Units* stratum					
Cropping system	3	5241.2	1747.1	13.50	0.001
Residual	9	1164.7	129.4		
Total	15	6850.8			

Appendix 4.3.4: ANOVA for the effects of cropping system on pumpkin harvested leaf size at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2225.	742.	0.35	
BLOCK.*Units* stratum					
Cropping system	3	171936.	57312.	27.20	<.001
Residual	9	18965.	2107.		
Total	15	193126.			

Appendix 4.3.5: ANOVA for the effects of cropping system on pumpkin growth duration at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	173.25	57.75	1.63	
BLOCK.*Units* stratum					
Cropping system	3	8597.25	2865.75	80.79	<.001
Residual	9	319.25	35.47		
Total	15	9089.75			

Appendix 4.3.6: ANOVA for the effects of cropping system on pumpkin dry leaf yield at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2035.	678.	0.40	
BLOCK.*Units* stratum					
Cropping system	3	938684.	312895.	185.65	<.001
Residual	9	15169.	1685.		
Total	15	955888.			

Appendix 4.3.7: ANOVA for the effects of season and cropping system on the number of leaves harvested per plant in pumpkin over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
Year	1	102.388	102.388	18.64	0.005
Residual	6	32.957	5.493	2.58	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	3	1302.660	434.220	203.95	<.001
Year. Cr Sys	3	31.730	10.577	4.97	0.011
Residual	18	38.323	2.129		
Total	31	1508.057			

Appendix 4.3.8: ANOVA for the effects of season and cropping system on vine length in pumpkin over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.YEAR stratum					
YEAR	1	10.9746	10.9746	21.20	0.004
Residual	6	3.1062	0.5177	2.07	
BLOCK.YEAR.*Units* stratum					
Cropping system (Cr Sys)	3	154.9901	51.6634	206.40	<.001
YEAR. Cr Sys	3	10.6938	3.5646	14.24	<.001
Residual	18	4.5056	0.2503		
Total	31	184.2704			

Appendix 4.4: ANOVA for the effects of cropping system on maize characteristics on-farm

Appendix 4.4.1: ANOVA for the effects of cropping system on maize grain yield across the four on-farm sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.site stratum					
Site	3	53497023.	17832341.	85.57	<.001
Residual	12	2500675.	208390.	0.50	
Block.site.*Units* stratum					
Cropping system (Cr Sys)	3	2428348.	809449.	1.94	0.141
Site. Cr Sys	9	7307593.	811955.	1.95	0.076
Residual	36	15021722.	417270.		
Total	63	80755361.			

Appendix 4.5: ANOVA for the effects of cropping system on pumpkin characteristics in maize-based cropping systems on-farm

Appendix 4.5.1: ANOVA for the effects of cropping system and site on pumpkin growth duration on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	3	3060.17	1020.06	20.64	<.001
Residual	12	593.19	49.43	1.89	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	1277.80	425.93	16.26	<.001
Site. Cr Sys	9	457.89	50.88	1.94	0.077
Residual	36	943.06	26.20		
Total	63	6332.11			

Appendix 4.5.2: ANOVA for the effects of cropping system and site on number of primary branches in pumpkin on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	3	759.170	253.057	38.78	<.001
Residual	12	78.311	6.526	0.77	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	239.757	79.919	9.40	<.001
Site. Cr Sys	9	121.808	13.534	1.59	0.155
Residual	36	305.914	8.498		
Total	63	1504.960			

Appendix 4.5.3: ANOVA for the effects of cropping system and site on the number of leaves harvested per vine in pumpkin on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	3	1549.78	516.59	31.83	<.001
Residual	12	194.73	16.23	1.08	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	715.23	238.41	15.80	<.001
SITE. Cr Sys	9	445.94	49.55	3.28	0.005
Residual	36	543.29	15.09		
Total	63	3448.98			

Appendix 4.5.4: ANOVA for the effects of cropping system and site on average harvested leaf size in pumpkin on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.site stratum					
Site	3	247306.4	82435.5	40.06	<.001
Residual	12	24696.3	2058.0	2.76	
Block.site.*Units* stratum					
Cropping system (Cr Sys)	3	168801.2	56267.1	75.50	<.001
SITE. Cr Sys	9	17101.5	1900.2	2.55	0.022
Residual	36	26830.7	745.3		
Total	63	484736.0			

Appendix 4.5.5: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Chinyudze in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	34.34	11.45	1.09	
Block.*Units* stratum					
Cropping system	3	840.62	280.21	26.60	<.001
Residual	9	94.82	10.54		
Total	15	969.78			

Appendix 4.5.6: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Chinyudze in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2583.0	861.0	1.27	
Block.*Units* stratum					
Cropping system	3	47955.6	15985.2	23.49	<.001
Residual	9	6124.4	680.5		
Total	15	56663.0			

Appendix 4.5.7: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Bingaguru in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	61.89	20.63	1.51	
BLOCK.*Units* stratum					
Cropping system	3	2759.30	919.77	67.39	<.001
Residual	9	122.84	13.65		
Total	15	2944.03			

Appendix 4.5.8: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Gowakowa in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	477.36	159.12	3.58	
BLOCK.*Units* stratum					
Cropping system	3	25696.50	8565.50	192.94	<.001
Residual	9	399.55	44.39		
Total	15	26573.41			

Appendix 4.5.9: ANOVA for the effects of cropping system on pumpkin fruit yield at Chinyudze in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	594800.	198267.	0.58	
BLOCK.*Units* stratum					
Cropping system	3	50702568.	16900856.	49.47	<.001
Residual	9	3074908.	341656.		
Total	15	54372276.			

Appendix 4.5.10: ANOVA for the effects of cropping system on pumpkin fruit yield at Bingaguru in 2003/4

Source	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	659728	219909	0.26	0.849
BLOCK.*Units* stratum					
Cropping system	3	41947957	13982652	16.83	<.001
Residual	9	7476814	830757		
Total	15	50084499			

Appendix 4.5.11: ANOVA for the effects of cropping system on pumpkin fruit yield at Gowakowa in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	115517151.	38505717.	11.65	
BLOCK.*Units* stratum					
Cropping system	3	258951165.	86317055.	26.11	<.001
Residual	9	29751538.	3305726.		
Total	15	404219853.			

Appendix 4.6: ANOVA for the effects of cropping system on weed density and weed biomass in maize-based cropping systems at UZF and on-farm

Appendix 4.6.1: ANOVA for the effects of cropping system and site on weed biomass at maize physiological maturity on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.site stratum					
site	3	24804.5	8268.2	16.32	<.001
Residual	12	6078.4	506.5	4.47	
BLOCK.site.*Units* stratum					
Cropping system (Cr Sys)	4	18615.9	4654.0	41.07	<.001
site. Cr Sys	12	5761.9	480.2	4.24	<.001
Residual	48	5439.7	113.3		
Total	79	60700.5			

Appendix 4.6.2: ANOVA for the effects of cropping system on weed density (Square root transformed) at six WAE of maize at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	12.792	4.264	3.09	
Block.*Units* stratum					
Cropping system	4	25.816	6.454	4.67	0.017
Residual	12	16.580	1.382		
Total	19	55.188			

Appendix 4.6.3: ANOVA for the effects of cropping system on weed biomass at six WAE of maize at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1010.2	336.7	1.05	
Block.*Units* stratum					
Cropping system	4	5544.1	1386.0	4.32	0.021
Residual	12	3846.6	320.6		
Total	19	10400.9			

Appendix 4.6.4: ANOVA for the effects of cropping system on weed density (Square root transformed) at 10 WAE of maize at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	11.6032	3.8677	6.24	
Block.*Units* stratum					
Cropping system	4	52.1315	13.0329	21.03	<.001
Residual	12	7.4380	0.6198		
Total	19	71.1728			

Appendix 4.6.5: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at 10 WAE of maize at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	33.671	11.224	6.17	
Block.*Units* stratum					
Cropping system	4	138.096	34.524	18.97	<.001
Residual	12	21.838	1.820		
Total	19	193.605			

Appendix 4.6.6: ANOVA for the effects of cropping system on weed density at maize physiological maturity at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	718.91	239.64	8.62	
Block.*Units* stratum					
Cropping system	4	4584.95	1146.24	41.25	<.001
Residual	12	333.45	27.79		
Total	19	5637.31			

Appendix 4.6.7: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at six WAE of maize at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.019540	0.006513	1.00	
BLOCK.*Units* stratum					
Cropping system	4	0.222025	0.055506	8.53	0.002
Residual	12	0.078073	0.006506		
Total	19	0.319638			

Appendix 4.6.8: ANOVA for the effects of cropping system on weed biomass at six WAE of maize at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	4440.6	1480.2	5.71	
BLOCK.*Units* stratum					
Cropping system	4	15648.6	3912.1	15.10	<.001
Residual	12	3108.7	259.1		
Total	19	23197.9			

Appendix 4.6.9: ANOVA for the effects of cropping system on weed density at 10 WAE of maize at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	7335.2	2445.1	5.67	
BLOCK.*Units* stratum					
Cropping system	4	12418.1	3104.5	7.20	0.003
Residual	12	5176.8	431.4		
Total	19	24930.0			

Appendix 4.6.10: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 10 WAE of maize at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.08711	0.02904	1.53	
BLOCK.*Units* stratum					
Cropping system	4	1.55148	0.38787	20.37	<.001
Residual	12	0.22848	0.01904		
Total	19	1.86707			

Appendix 4.6.11: ANOVA for the effects of cropping system on weed density at maize physiological maturity at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	6830.7	2276.9	5.94	
BLOCK.*Units* stratum					
Cropping system	4	13296.0	3324.0	8.67	0.002
Residual	12	4599.7	383.3		
Total	19	24726.3			

Appendix 4.6.12: ANOVA for the effects of cropping system on weed density (Square root transformed) at six WAE of maize at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	51.851	17.284	3.94	
BLOCK.*Units* stratum					
Cropping system	4	153.850	38.462	8.77	0.002
Residual	12	52.629	4.386		
Total	19	258.329			

Appendix 4.6.13: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at six WAE of maize at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.41266	0.13755	13.70	
BLOCK.*Units* stratum					
Cropping system	4	0.94277	0.23569	23.47	<.001
Residual	12	0.12051	0.01004		
Total	19	1.47595			

Appendix 4.6.14: ANOVA for the effects of cropping system on weed density at 10 WAE of maize at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1166.6	388.9	0.89	
BLOCK.*Units* stratum					
Cropping system	4	44876.0	11219.0	25.56	<.001
Residual	12	5267.3	438.9		
Total	19	51309.9			

Appendix 4.6.15: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at 10 WAE of maize at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	8.3469	2.7823	8.23	
BLOCK.*Units* stratum					
Cropping system	4	27.4236	6.8559	20.28	<.001
Residual	12	4.0572	0.3381		
Total	19	39.8277			

Appendix 4.6.16: ANOVA for the effects of cropping system on weed density at physiological maturity of maize at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	10025.0	3341.7	6.22	
BLOCK.*Units* stratum					
Cropping system	4	35818.6	8954.6	16.68	<.001
Residual	12	6441.8	536.8		
Total	19	52285.4			

Appendix 4.6.17: ANOVA for the effects of cropping system on weed density (Square root transformed) at six WAE of maize at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	11.2502	3.7501	25.09	
BLOCK.*Units* stratum					
Cropping system	4	28.1687	7.0422	47.11	<.001
Residual	12	1.7939	0.1495		
Total	19	41.2128			

Appendix 4.6.18: ANOVA for the effects of cropping system on weed biomass at six WAE of maize at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	20661.	6887.	3.39	
BLOCK.*Units* stratum					
Cropping system	4	92124.	23031.	11.32	<.001
Residual	12	24407.	2034.		
Total	19	137192.			

Appendix 4.6.19: ANOVA for the effects of cropping system on weed density at 10 WAE of maize at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	4703.20	1567.73	19.95	
BLOCK.*Units* stratum					
Cropping system	4	9322.94	2330.74	29.67	<.001
Residual	12	942.80	78.57		
Total	19	14968.94			

Appendix 4.6.20: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 10 WAE of maize at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.055029	0.018343	12.75	
BLOCK.*Units* stratum					
Cropping system	4	0.439342	0.109835	76.36	<.001
Residual	12	0.017260	0.001438		
Total	19	0.511631			

Appendix 4.6.21: ANOVA for the effects of cropping system on weed density at physiological maturity of maize at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	3541.4	1180.5	11.25	
BLOCK.*Units* stratum					
Cropping system	4	8430.4	2107.6	20.08	<.001
Residual	12	1259.2	104.9		
Total	19	13231.1			

Appendix 4.6.22: ANOVA for the effects of cropping system on weed density at six WAE of maize at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	57255.	19085.	11.14	
Block.*Units* stratum					
Cropping system	8	253180.	31648.	18.47	<.001
Residual	24	41130.	1714.		
Total	35	351565.			

Appendix 4.6.23: ANOVA for the effects of cropping system on weed biomass (Log_{10} (x+10) transformed) at six WAE of maize at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.69861	0.56620	7.58	
Block.*Units* stratum					
Cropping system	8	11.45660	1.43208	19.17	<.001
Residual	24	1.79299	0.07471		
Total	35	14.94820			

Appendix 4.6.24: ANOVA for the effects of cropping system on weed density at 10 WAE of maize at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	35046.	11682.	2.17	
Block.*Units* stratum					
Cropping system	8	159605.	19951.	3.71	0.006
Residual	24	129016.	5376.		
Total	35	323667.			

Appendix 4.6.25: ANOVA for the effects of cropping system on weed biomass at 10 WAE of maize at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1869.29	623.10	10.94	
Block.*Units* stratum					
Cropping system	8	3020.26	377.53	6.63	<.001
Residual	24	1366.59	56.94		
Total	35	6256.14			

Appendix 4.6.26: ANOVA for the effects of cropping system on weed density (Square root transformed) at physiological maturity of maize at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	18.544	6.181	4.50	
Block.*Units* stratum					
Cropping system	8	73.544	9.193	6.70	<.001
Residual	24	32.949	1.373		
Total	35	125.036			

Appendix 4.6.27: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at physiological maturity of maize at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	39.169	13.056	9.12	
Block.*Units* stratum					
Cropping system	8	92.579	11.572	8.08	<.001
Residual	24	34.372	1.432		
Total	35	166.120			

Appendix 4.6.28: ANOVA for the effects of cropping system on weed density at six WAE of maize at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	4243.3	1414.4	3.63	
BLOCK.*Units* stratum					
Cropping system	8	48852.3	6106.5	15.65	<.001
Residual	24	9364.1	390.2		
Total	35	62459.7			

Appendix 4.6.29: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at six WAE of maize at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	6.290954	2.096985	542.18	
BLOCK.*Units* stratum					
Cropping system	8	1.949297	0.243662	63.00	<.001
Residual	24	0.092824	0.003868		
Total	35	8.333075			

Appendix 4.6.30: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at 10 WAE of maize at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1.091480	0.363827	41.45	
BLOCK.*Units* stratum					
Cropping system	8	1.292032	0.161504	18.40	<.001
Residual	24	0.210635	0.008776		
Total	35	2.594147			

Appendix 4.6.31: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 10 WAE of maize at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.267445	0.089148	19.63	
BLOCK.*Units* stratum					
Cropping system	8	1.915067	0.239383	52.71	<.001
Residual	24	0.108991	0.004541		
Total	35	2.291502			

Appendix 4.6.32: ANOVA for the effects of cropping system on weed density (Square root transformed) at physiological maturity of maize at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	38.2828	12.7609	14.52	
BLOCK.*Units* stratum					
Cropping system	8	120.4721	15.0590	17.14	<.001
Residual	24	21.0890	0.8787		
Total	35	179.8439			

Appendix 4.6.33: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at physiological maturity of maize at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.60030	0.20010	12.91	
BLOCK.*Units* stratum					
Cropping system	8	2.13407	0.26676	17.21	<.001
Residual	24	0.37193	0.01550		
Total	35	3.10630			

Appendix 5: ANOVA for the effects of pumpkin and mustard rape intercropping and sole cropping in groundnut-based cropping systems

Appendix 5.1: ANOVA for the effects cropping system on groundnut characteristics in 2002/3 and 2003/4 at UZF

Appendix 5.1.1: ANOVA for the effects cropping system on 1000 seed weight in groundnut in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1761.5	587.2	2.62	
Block.*Units* stratum					
Cropping system	6	4317.2	719.5	3.22	0.025
Residual	18	4028.5	223.8		
Total	27	10107.2			

Appendix 5.1.2: ANOVA for the effects cropping system on the number of pods per plant in groundnut in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	28.26	9.42	0.28	
Block.*Units* stratum					
Cropping system	6	512.07	85.35	2.57	0.056
Residual	18	596.98	33.17		
Total	27	1137.31			

Appendix 5.1.3: ANOVA for the effects cropping system on 1000 seed weight in groundnut in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2155.8	718.6	0.73	
BLOCK.*Units* stratum					
Cropping system	6	1614.6	269.1	0.27	0.943
Residual	18	17798.1	988.8		
Total	27	21568.5			

Appendix 5.1.4: ANOVA for the effects cropping system on the number of pods per plant in groundnut in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6.842	2.281	0.49	
Block.*Units* stratum					
Cropping system	6	76.968	12.828	2.74	0.045
Residual	18	84.373	4.687		
Total	27	168.182			

Appendix 5.1.5: ANOVA for the effects cropping system and season on groundnut seed yield over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
Year	1	1444633.	1444633.	0.98	0.361
Residual	6	8873484.	1478914.	20.03	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	6	1225827.	204305.	2.77	0.026
Year. Cr Sys	6	1527595.	254599.	3.45	0.009
Residual	36	2657893.	73830.		
Total	55	15729433.			

Appendix 5.2: ANOVA for the effects cropping system on pumpkin characteristics in groundnut-based cropping systems in 2002/3 and 2003/4 at UZF

Appendix 5.2.1: ANOVA for the effects cropping system and season on pumpkin vine length over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
year	1	15.111	15.111	11.58	0.014
Residual	6	7.833	1.305	0.57	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	3	47.303	15.768	6.92	0.003
year. Cr Sys	3	21.817	7.272	3.19	0.049
Residual	18	40.994	2.277		
Total	31	133.058			

Appendix 5.2.2: ANOVA for the effects cropping system and season on pumpkin growth duration over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
year	1	1526.28	1526.28	13.47	0.010
Residual	6	679.69	113.28	4.81	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	3	902.34	300.78	12.78	<.001
year. Cr Sys	3	65.84	21.95	0.93	0.445
Residual	18	423.56	23.53		
Total	31	3597.72			

Appendix 5.2.3: ANOVA for the effects cropping system and season on average harvested leaf size in pumpkin over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
year	1	118390.	118390.	80.57	<.001
Residual	6	8816.	1469.	0.47	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	3	204485.	68162.	21.71	<.001
year. Cr Sys	3	14683.	4894.	1.56	0.234
Residual	18	56509.	3139.		
Total	31	402883.			

Appendix 5.2.4: ANOVA for the effects cropping system and season on dry leaf yield of pumpkin over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
year	1	138831.	138831.	61.63	<.001
Residual	6	13517.	2253.	1.37	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	3	569873.	189958.	115.90	<.001
year. Cr Sys	3	1174.	391.	0.24	0.868
Residual	18	29500.	1639.		
Total	31	752895.			

Appendix 5.3: ANOVA for the effects cropping system on mustard rape characteristics in groundnut-based cropping systems in 2002/3 and 2003/4 at UZF

Appendix 5.3.1: ANOVA for the effects cropping system and season on length of the vegetative period in the second planting of mustard rape over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.Year stratum					
Year	1	54.34	54.34	6.25	0.047
Residual	6	52.17	8.69	0.85	
BLOCK.Year.*Units* stratum					
Cropping system (Cr Sys)	3	1084.02	361.34	35.44	<.001
Year. Cr Sys	3	0.60	0.20	0.02	0.996
Residual	18	183.50	10.19		
Total	31	1374.62			

Appendix 5.3.2: ANOVA for the effects cropping system and season on dry leaf yield in the second planting of mustard rape over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.Year stratum					
Year	1	964.5	964.5	10.79	0.017
Residual	6	536.5	89.4	0.44	
BLOCK.Year.*Units* stratum					
Cropping system (Cr Sys)	3	402596.1	134198.7	655.56	<.001
Year. Cr Sys	3	921.0	307.0	1.50	0.249
Residual	18	3684.7	204.7		
Total	31	408702.7			

Appendix 5.3.3: ANOVA for the effects cropping system and planting time on average harvested leaf size in mustard rape in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	15383.	5128.	2.84	
BLOCK.*Units* stratum					
Planting time (PT)	1	191367.	191367.	105.93	<.001
Cropping system (Cr Sys)	3	13463.	4488.	2.48	0.089
PT. Cr Sys	3	20191.	6730.	3.73	0.027
Residual	21	37938.	1807.		
Total	31	278342.			

Appendix 5.3.4: ANOVA for the effects cropping system and planting time on mustard rape dry leaf yield in the 2003/4 season at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	6395.	2132.	2.04	
BLOCK.*Units* stratum					
Planting time (PT)	1	1231873.	1231873.	1176.68	<.001
Cropping system (Cr Sys)	3	639410.	213137.	203.59	<.001
PT. Cr Sys	3	56600.	18867.	18.02	<.001
Residual	21	21985.	1047.		
Total	31	1956263.			

Appendix 5.4: ANOVA for the effects of cropping system on groundnut characteristics on-farm

Appendix 5.4.1: ANOVA for the effects of site and cropping system on groundnut 1000 seed weight in 2002/3 on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	2	2817.64	1408.82	13.82	0.006
Residual	6	611.60	101.93	1.72	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	149.54	49.85	0.84	0.490
SITE. Cr Sys	6	525.75	87.63	1.47	0.242
Residual	18	1069.61	59.42		
Total	35	5174.14			

Appendix 5.4.2: ANOVA for the effects of site and cropping system on number of pods per plant in groundnut in 2002/3 on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	2	10.042	5.021	0.85	0.472
Residual	6	35.328	5.888	0.78	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	45.418	15.139	2.02	0.147
SITE. Cr Sys	6	38.002	6.334	0.84	0.552
Residual	18	135.025	7.501		
Total	35	263.816			

Appendix 5.4.3: ANOVA for the effects of site and cropping system on groundnut 1000 seed weight in 2003/4 on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	2	934.6	467.3	0.67	0.548
Residual	6	4214.2	702.4	5.61	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	9037.5	3012.5	24.08	<.001
SITE. Cr Sys	6	2283.8	380.6	3.04	0.031
Residual	18	2252.1	125.1		
Total	35	18722.1			

Appendix 5.4.4: ANOVA for the effects of site and cropping system on number of pods per plant in groundnut in 2003/4 on-farm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.SITE stratum					
SITE	2	2218.59	1109.29	56.25	<.001
Residual	6	118.33	19.72	1.15	
BLOCK.SITE.*Units* stratum					
Cropping system (Cr Sys)	3	384.06	128.02	7.48	0.002
SITE. Cr Sys	6	364.52	60.75	3.55	0.017
Residual	18	308.09	17.12		
Total	35	3393.59			

Appendix 5.4.5: ANOVA for the effects of cropping system on groundnut seed yield at Chinyudze in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	20549.	10275.	2.23	
BLOCK.*Units* stratum					
Cropping system	3	212867.	70956.	15.38	0.003
Residual	6	27689.	4615.		
Total	11	261106.			

Appendix 5.4.6: ANOVA for the effects of cropping system on groundnut seed yield at Gowakowa in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	6405.6	3202.8	5.35	
BLOCK.*Units* stratum					
Cropping system	3	22226.8	7408.9	12.39	0.006
Residual	6	3589.2	598.2		
Total	11	32221.6			

Appendix 5.4.7: ANOVA for the effects of cropping system on groundnut seed yield at Bingaguru in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	2798.58	1399.29	14.66	
BLOCK.*Units* stratum					
Cropping system	3	21827.71	7275.90	76.25	<.001
Residual	6	572.53	95.42		
Total	11	25198.81			

Appendix 5.4.8: ANOVA for the effects of cropping system on groundnut seed yield at Chinyudze in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	4692.3	2346.1	4.41	
BLOCK.*Units* stratum					
Cropping system	3	43578.1	14526.0	27.27	<.001
Residual	6	3195.6	532.6		
Total	11	51466.0			

Appendix 5.4.9: ANOVA for the effects of cropping system on groundnut seed yield at Gowakowa in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	153088.	76544.	6.77	
BLOCK.*Units* stratum					
Cropping system	3	323840.	107947.	9.55	0.011
Residual	6	67805.	11301.		
Total	11	544733.			

Appendix 5.4.10: ANOVA for the effects of cropping system on groundnut seed yield at Bingaguru in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1570.5	785.2	2.14	
Block.*Units* stratum					
Cropping system	3	7069.3	2356.4	6.43	0.027
Residual	6	2200.2	366.7		
Total	11	10840.0			

Appendix 5.5: ANOVA for the effects of cropping system on pumpkin characteristics in groundnut-based cropping systems on-farm

Appendix 5.5.1: ANOVA for the effects of cropping system on average harvested leaf size in pumpkin at Chinyudze in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	188.7	94.4	0.30	
BLOCK.*Units* stratum					
Cropping system	3	25594.8	8531.6	26.86	<.001
Residual	6	1905.9	317.7		
Total	11	27689.4			

Appendix 5.5.2 ANOVA for the effects of cropping system on pumpkin dry leaf yield at Chinyudze in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	4.772	2.386	0.78	
BLOCK.*Units* stratum					
Cropping system	3	4269.092	1423.031	463.65	<.001
Residual	6	18.415	3.069		
Total	11	4292.279			

Appendix 5.5.3: ANOVA for the effects of cropping system on average harvested leaf size in pumpkin at Gowakowa in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1181.08	590.54	6.40	
BLOCK.*Units* stratum					
Cropping system	3	25169.20	8389.73	90.95	<.001
Residual	6	553.46	92.24		
Total	11	26903.74			

Appendix 5.5.4: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Gowakowa in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	114.99	57.49	1.82	
BLOCK.*Units* stratum					
Cropping system	3	7187.39	2395.80	76.02	<.001
Residual	6	189.09	31.51		
Total	11	7491.47			

Appendix 5.5.5: ANOVA for the effects of cropping system on average harvested leaf size in pumpkin at Bingaguru in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	330.	165.	0.10	
BLOCK.*Units* stratum					
Cropping system	3	13453.	4484.	2.83	0.129
Residual	6	9507.	1584.		
Total	11	23290.			

Appendix 5.5.6: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Bingaguru in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	3.87	1.94	0.17	
BLOCK.*Units* stratum					
Cropping system	3	2114.49	704.83	60.54	<.001
Residual	6	69.85	11.64		
Total	11	2188.22			

Appendix 5.5.7: ANOVA for the effects of cropping system on average harvested leaf size in pumpkin at Chinyudze in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1717.2	858.6	2.26	
BLOCK.*Units* stratum					
Cropping system	3	4828.5	1609.5	4.23	0.063
Residual	6	2280.8	380.1		
Total	11	8826.5			

Appendix 5.5.8: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Chinyudze in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	381.5	190.8	0.36	
BLOCK.*Units* stratum					
Cropping system	3	14892.5	4964.2	9.46	0.011
Residual	6	3149.2	524.9		
Total	11	18423.3			

Appendix 5.5.9: ANOVA for the effects of cropping system on pumpkin fruit yield at Chinyudze in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1517364.	505788.	2.76	
BLOCK.*Units* stratum					
Cropping system	3	77662362.	25887454.	141.25	<.001
Residual	9	1649438.	183271.		
Total	15	80829164.			

Appendix 5.5.10: ANOVA for the effects of cropping system on average harvested leaf size in pumpkin at Gowakowa in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	906.5	453.2	3.44	
BLOCK.*Units* stratum					
Cropping system	3	31962.0	10654.0	80.93	<.001
Residual	6	789.9	131.6		
Total	11	33658.3			

Appendix 5.5.11: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Gowakowa in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	706.8	353.4	0.63	
BLOCK.*Units* stratum					
Cropping system	3	33508.6	11169.5	19.86	0.002
Residual	6	3374.8	562.5		
Total	11	37590.2			

Appendix 5.5.12: ANOVA for the effects of cropping system on pumpkin fruit yield at Gowakowa in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	29589925.	9863308.	0.36	
BLOCK.*Units* stratum					
Cropping system	3	126052388.	42017463.	1.52	0.275
Residual	9	248854642.	27650516.		
Total	15	404496955.			

Appendix 5.5.13: ANOVA for the effects of cropping system on average harvested leaf size in pumpkin at Bingaguru in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1557.9	778.9	5.98	
BLOCK.*Units* stratum					
Cropping system	3	8404.8	2801.6	21.49	0.001
Residual	6	782.1	130.3		
Total	11	10744.7			

Appendix 5.5.14: ANOVA for the effects of cropping system on pumpkin dry leaf yield at Bingaguru in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	24.0	12.0	0.10	
BLOCK.*Units* stratum					
Cropping system	3	8181.9	2727.3	22.14	0.001
Residual	6	739.1	123.2		
Total	11	8945.0			

Appendix 5.5.15: ANOVA for the effects of cropping system on pumpkin fruit yield at Bingaguru in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2649333.	883111.	1.94	
BLOCK.*Units* stratum					
Cropping system	3	27289329.	9096443.	19.94	<.001
Residual	9	4104920.	456102.		
Total	15	34043582.			

Appendix 5.6: ANOVA for the effects of cropping system on weed density and weed biomass in groundnut-based cropping systems at UZF and on-farm

Appendix 5.6.1: ANOVA for the effects of cropping system on weed density at seven WAE of groundnut at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	77193.	25731.	15.06	
Block.*Units* stratum					
Cropping system	8	102509.	12814.	7.50	<.001
Residual	24	41017.	1709.		
Total	35	220719.			

Appendix 5.6.2: ANOVA for the effects of cropping system on weed biomass at seven WAE of groundnut at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	20790.3	6930.1	27.97	
Block.*Units* stratum					
Cropping system	8	23751.4	2968.9	11.98	<.001
Residual	24	5947.1	247.8		
Total	35	50488.8			

Appendix 5.6.3: ANOVA for the effects of cropping system on weed density at 11 WAE of groundnut at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	13557.	4519.	2.14	
Block.*Units* stratum					
Cropping system	8	34084.	4260.	2.02	0.088
Residual	24	50728.	2114.		
Total	35	98369.			

Appendix 5.6.4: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 11 WAE of groundnut at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.26725	0.42242	36.00	
Block.*Units* stratum					
Cropping system	8	1.06071	0.13259	11.30	<.001
Residual	24	0.28160	0.01173		
Total	35	2.60956			

Appendix 5.6.5: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at physiological maturity of groundnut at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.23277	0.07759	4.25	
Block.*Units* stratum					
Cropping system	8	0.73996	0.09249	5.07	<.001
Residual	24	0.43821	0.01826		
Total	35	1.41094			

Appendix 5.6.6: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at physiological maturity of groundnut at UZF in 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.10684	0.03561	1.12	
Block.*Units* stratum					
Cropping system	8	1.71463	0.21433	6.73	<.001
Residual	24	0.76447	0.03185		
Total	35	2.58594			

Appendix 5.6.7: ANOVA for the effects of cropping system on weed density (Square root transformed) at seven WAE of groundnut at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	125.392	41.797	24.12	
BLOCK.*Units* stratum					
Cropping system	8	98.501	12.313	7.11	<.001
Residual	24	41.581	1.733		
Total	35	265.474			

Appendix 5.6.8: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at seven WAE of groundnut at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	3.698	1.233	0.76	
BLOCK.*Units* stratum					
Cropping system	8	93.944	11.743	7.21	<.001
Residual	24	39.115	1.630		
Total	35	136.758			

Appendix 5.6.9: ANOVA for the effects of cropping system on weed density at 11 WAE of groundnut at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	18242.	6081.	2.14	
BLOCK.*Units* stratum					
Cropping system	8	45863.	5733.	2.02	0.088
Residual	24	68260.	2844.		
Total	35	132365.			

Appendix 5.6.10: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed)at 11 WAE of groundnut at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1.26725	0.42242	36.00	
BLOCK.*Units* stratum					
Cropping system	8	1.06071	0.13259	11.30	<.001
Residual	24	0.28160	0.01173		
Total	35	2.60956			

Appendix 5.6.11: ANOVA for the effects of cropping system on weed density (Square root transformed) at physiological maturity of groundnut at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	55.606	18.535	15.18	
BLOCK.*Units* stratum					
Cropping system	8	148.987	18.623	15.25	<.001
Residual	24	29.305	1.221		
Total	35	233.898			

Appendix 5.6.12: ANOVA for the effects of cropping system on weed biomass at physiological maturity of groundnut at UZF in 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	662.7	220.9	2.06	
BLOCK.*Units* stratum					
Cropping system	8	8818.9	1102.4	10.29	<.001
Residual	24	2570.8	107.1		
Total	35	12052.4			

Appendix 5.6.13: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at seven WAE of groundnut at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.09521	0.04760	2.46	
BLOCK.*Units* stratum					
Cropping system	4	0.13487	0.03372	1.75	0.233
Residual	8	0.15456	0.01932		
Total	14	0.38464			

Appendix 5.6.14: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at seven WAE of groundnut at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	2.205	1.102	0.68	
BLOCK.*Units* stratum					
Cropping system	4	27.234	6.809	4.19	0.040
Residual	8	12.991	1.624		
Total	14	42.430			

Appendix 5.6.15: ANOVA for the effects of cropping system on weed density (Square root transformed) at 11 WAE of groundnut at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	9.2157	4.6078	5.79	
BLOCK.*Units* stratum					
Cropping system	4	33.4790	8.3698	10.52	0.003
Residual	8	6.3651	0.7956		
Total	14	49.0598			

Appendix 4.6.16: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 11 WAE of groundnut at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.00889	0.00445	0.30	
BLOCK.*Units* stratum					
Cropping system	4	1.05706	0.26426	17.59	<.001
Residual	8	0.12018	0.01502		
Total	14	1.18613			

Appendix 4.6.17: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at groundnut physiological maturity at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.42953	0.21476	16.72	
BLOCK.*Units* stratum					
Cropping system	4	0.50450	0.12612	9.82	0.004
Residual	8	0.10277	0.01285		
Total	14	1.03679			

Appendix 4.6.18: ANOVA for the effects of cropping system on weed biomass at groundnut physiological maturity at Chinyudze 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	300.592	150.296	17.76	
BLOCK.*Units* stratum					
Cropping system	4	262.587	65.647	7.76	0.007
Residual	8	67.701	8.463		
Total	14	630.880			

Appendix 5.6.19: ANOVA for the effects of cropping system on weed density (Square root transformed) at seven WAE of groundnut at Bingaguru 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1.6910	0.8455	0.97	
BLOCK.*Units* stratum					
Cropping system	4	80.8011	20.2003	23.16	<.001
Residual	8	6.9789	0.8724		
Total	14	89.4710			

Appendix 5.6.20: ANOVA for the effects of cropping system on weed biomass at seven WAE of groundnut at Bingaguru 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	342.55	171.27	5.14	
BLOCK.*Units* stratum					
Cropping system	4	5266.84	1316.71	39.49	<.001
Residual	8	266.75	33.34		
Total	14	5876.15			

Appendix 5.6.21: ANOVA for the effects of cropping system on weed density at 11 WAE of groundnut at Bingaguru 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1254.4	627.2	3.92	
BLOCK.*Units* stratum					
Cropping system	4	13008.7	3252.2	20.34	<.001
Residual	8	1278.9	159.9		
Total	14	15542.0			

Appendix 4.6.22: ANOVA for the effects of cropping system on weed biomass at 11 WAE of groundnut at Bingaguru 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1812.4	906.2	3.61	
BLOCK.*Units* stratum					
Cropping system	4	18668.5	4667.1	18.59	<.001
Residual	8	2008.3	251.0		
Total	14	22489.1			

Appendix 4.6.23: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at groundnut physiological maturity at Bingaguru 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.004485	0.002242	0.81	
BLOCK.*Units* stratum					
Cropping system	4	0.241236	0.060309	21.75	<.001
Residual	8	0.022181	0.002773		
Total	14	0.267902			

Appendix 4.6.24: ANOVA for the effects of cropping system on weed biomass (Log$_{10}$ transformed) at groundnut physiological maturity at Bingaguru 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.34461	0.17230	3.35	
BLOCK.*Units* stratum					
Cropping system	4	2.12721	0.53180	10.35	0.003
Residual	8	0.41102	0.05138		
Total	14	2.88283			

Appendix 5.6.25: ANOVA for the effects of cropping system on weed density (Log$_{10}$ transformed) at seven WAE of groundnut at Gowakowa 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.168753	0.084377	16.18	
BLOCK.*Units* stratum					
Cropping system	4	0.098644	0.024661	4.73	0.030
Residual	8	0.041730	0.005216		
Total	14	0.309127			

Appendix 5.6.26: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at seven WAE of groundnut at Gowakowa 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	23.9420	11.9710	16.47	
BLOCK.*Units* stratum					
Cropping system	4	31.2837	7.8209	10.76	0.003
Residual	8	5.8132	0.7267		
Total	14	61.0389			

Appendix 5.6.27: ANOVA for the effects of cropping system on weed density (Log$_{10}$ transformed) at 11 WAE of groundnut at Gowakowa 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.00316	0.00158	0.05	
BLOCK.*Units* stratum					
Cropping system	4	0.16303	0.04076	1.24	0.369
Residual	8	0.26401	0.03300		
Total	14	0.43021			

Appendix 5.6.28: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at 11 WAE of groundnut at Gowakowa 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	2.245	1.122	0.50	
BLOCK.*Units* stratum					
Cropping system	4	33.251	8.313	3.70	0.055
Residual	8	17.983	2.248		
Total	14	53.478			

Appendix 5.6.29: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at physiological maturity of groundnut at Gowakowa 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.18651	0.09326	1.47	
BLOCK.*Units* stratum					
Cropping system	4	0.24852	0.06213	0.98	0.469
Residual	8	0.50660	0.06333		
Total	14	0.94164			

Appendix 5.6.30: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at physiological maturity of groundnut at Gowakowa 2002/3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	10.1491	5.0745	12.10	
BLOCK.*Units* stratum					
Cropping system	4	24.4345	6.1086	14.57	<.001
Residual	8	3.3545	0.4193		
Total	14	37.9381			

Appendix 5.6.31: ANOVA for the effects of cropping system on weed density (Square root transformed) at seven WAE of groundnut at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	28.867	14.434	4.80	
BLOCK.*Units* stratum					
Cropping system	4	29.882	7.470	2.48	0.127
Residual	8	24.060	3.007		
Total	14	82.809			

Appendix 5.6.32: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at seven WAE of groundnut at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	21.2074	10.6037	12.22	
BLOCK.*Units* stratum					
Cropping system	4	62.5844	15.6461	18.03	<.001
Residual	8	6.9417	0.8677		
Total	14	90.7335			

Appendix 5.6.33: ANOVA for the effects of cropping system on weed density (Square root transformed) at 11 WAE of groundnut at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	9.6391	4.8196	7.76	
BLOCK.*Units* stratum					
Cropping system	4	12.7413	3.1853	5.13	0.024
Residual	8	4.9703	0.6213		
Total	14	27.3507			

Appendix 5.6.34: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 11 WAE of groundnut at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.469536	0.234768	54.47	
BLOCK.*Units* stratum					
Cropping system	4	0.258006	0.064502	14.97	<.001
Residual	8	0.034478	0.004310		
Total	14	0.762020			

Appendix 5.6.35: ANOVA for the effects of cropping system on weed density at physiological maturity of groundnut at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	3932.0	1966.0	6.37	
BLOCK.*Units* stratum					
Cropping system	4	5716.2	1429.0	4.63	0.031
Residual	8	2467.5	308.4		
Total	14	12115.7			

Appendix 5.6.36: ANOVA for the effects of cropping system on weed biomass at physiological maturity of groundnut at Bingaguru 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	14356.32	7178.16	95.72	
BLOCK.*Units* stratum					
Cropping system	4	4088.34	1022.09	13.63	0.001
Residual	8	599.90	74.99		
Total	14	19044.56			

Appendix 5.6.37: ANOVA for the effects of cropping system on weed density (Square root transformed) at seven WAE of groundnut at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	25.160	12.580	3.88	
BLOCK.*Units* stratum					
Cropping system	4	84.593	21.148	6.52	0.012
Residual	8	25.932	3.241		
Total	14	135.685			

Appendix 5.6.38: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at seven WAE of groundnut at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.151449	0.075724	58.24	
BLOCK.*Units* stratum					
Cropping system	4	0.494762	0.123690	95.13	<.001
Residual	8	0.010402	0.001300		
Total	14	0.656612			

Appendix 5.6.39: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at 11 WAE of groundnut at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.029455	0.014727	2.75	
BLOCK.*Units* stratum					
Cropping system	4	0.265425	0.066356	12.37	0.002
Residual	8	0.042913	0.005364		
Total	14	0.337793			

Appendix 5.6.40: ANOVA for the effects of cropping system on weed biomass (Log_{10} transformed) at 11 WAE of groundnut at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.22197	0.11099	10.24	
BLOCK.*Units* stratum					
Cropping system	4	0.60525	0.15131	13.97	0.001
Residual	8	0.08668	0.01083		
Total	14	0.91390			

Appendix 5.6.41: ANOVA for the effects of cropping system on weed density (Log_{10} transformed) at physiological maturity of groundnut at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.029455	0.014727	2.75	
BLOCK.*Units* stratum					
Cropping system	4	0.265425	0.066356	12.37	0.002
Residual	8	0.042913	0.005364		
Total	14	0.337793			

Appendix 5.6.42: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at physiological maturity of groundnut at Chinyudze 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	3.2592	1.6296	2.81	
BLOCK.*Units* stratum					
Cropping system	4	31.5463	7.8866	13.60	0.001
Residual	8	4.6408	0.5801		
Total	14	39.4463			

Appendix 5.6.43: ANOVA for the effects of cropping system on weed density (Square root transformed) at seven WAE of groundnut at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	17.190	8.595	1.41	
BLOCK.*Units* stratum					
Cropping system	4	183.482	45.871	7.54	0.008
Residual	8	48.678	6.085		
Total	14	249.351			

Appendix 5.6.44: ANOVA for the effects of cropping system on weed biomass (Log$_{10}$ transformed) at seven WAE of groundnut at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.29782	0.14891	5.70	
BLOCK.*Units* stratum					
Cropping system	4	0.77438	0.19359	7.41	0.008
Residual	8	0.20892	0.02612		
Total	14	1.28113			

Appendix 5.6.45: ANOVA for the effects of cropping system on weed density (Square root transformed) at 11 WAE of groundnut at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	3.161	1.580	1.31	
BLOCK.*Units* stratum					
Cropping system	4	12.675	3.169	2.62	0.114
Residual	8	9.658	1.207		
Total	14	25.494			

Appendix 5.6.46: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at 11 WAE of groundnut at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	117.683	58.841	17.42	
BLOCK.*Units* stratum					
Cropping system	4	106.382	26.595	7.87	0.007
Residual	8	27.018	3.377		
Total	14	251.083			

Appendix 5.6.47: ANOVA for the effects of cropping system on weed density (Square root transformed) at physiological maturity of groundnut at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.066	0.033	0.03	
BLOCK.*Units* stratum					
Cropping system	4	39.235	9.809	9.15	0.004
Residual	8	8.575	1.072		
Total	14	47.875			

Appendix 5.6.48: ANOVA for the effects of cropping system on weed biomass (Square root transformed) at physiological maturity of groundnut at Gowakowa 2003/4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	11.1290	5.5645	5.72	
BLOCK.*Units* stratum					
Cropping system	4	39.6041	9.9010	10.17	0.003
Residual	8	7.7855	0.9732		
Total	14	58.5186			

Appendix 6: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in pumpkin on maize and pumpkin characteristics at UZF in 2002/3 and 2003/4

Appendix 6.1: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in pumpkin on component maize characteristics

Appendix 6.1.1: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in pumpkin on component maize cob length in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	26.269	8.756	5.76	
Block.*Units* stratum					
Interval	2	2.807	1.404	0.92	0.411
Intensity	2	2.617	1.309	0.86	0.435
Interval. Intensity	4	6.681	1.670	1.10	0.380
Residual	24	36.461	1.519		
Total	35	74.836			

Appendix 6.1.2: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in pumpkin on component maize cob length in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.7055	0.2352	0.48	
BLOCK.*Units* stratum					
Interval	2	0.0190	0.0095	0.02	0.981
Intensity	2	5.7451	2.8726	5.81	0.009
Interval. Intensity	4	2.8692	0.7173	1.45	0.248
Residual	24	11.8627	0.4943		
Total	35	21.2016			

Appendix 6.1.3: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in pumpkin on component maize grain yield over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year.block stratum					
Year	1	4887096.	4887096.	0.30	0.602
Residual	6	96889740.	16148290.	10.63	
Year.block.*Units* stratum					
Interval	2	7921377.	3960689.	2.61	0.084
Intensity	2	4624525.	2312263.	1.52	0.229
Year.Interval	2	3359741.	1679871.	1.11	0.339
Year.Intensity	2	2309509.	1154755.	0.76	0.473
Interval.Intensity	4	4974613.	1243653.	0.82	0.520
Year.Interval.Intensity	4	4939279.	1234820.	0.81	0.523
Residual	48	72916227.	1519088.		
Total	71	202822108.			

Appendix 6.2: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin characteristics in the 2002/3 and 2003/4 seasons at UZF

Appendix 6.2.1: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on average harvested leaf size in pumpkin over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK.YEAR stratum					
YEAR	1	75315.	75315.	123.27	<.001
Residual	6	3666.	611.	0.60	
BLOCK.YEAR.*Units* stratum					
Cropping system (Cr Sys)	1	817058.	817058.	805.03	<.001
Interval	2	79525.	39763.	39.18	<.001
Intensity	2	22034.	11017.	10.85	<.001
YEAR.Cr Sys	1	5607.	5607.	5.52	0.021
YEAR. Interval	2	546.	273.	0.27	0.765
Cr Sys.Interval	2	723.	362.	0.36	0.701
YEAR. Intensity	2	151.	76.	0.07	0.928
Cr Sys. Intensity	2	330.	165.	0.16	0.850
Interval. Intensity	4	578.	145.	0.14	0.966
YEAR.Cr Sys.Interval	2	5.	2.	0.00	0.998
YEAR.Cr Sys. Intensity	2	2.	1.	0.00	0.999
YEAR.Interval. Intensity	4	4.	1.	0.00	1.000
Cr Sys.Interval.Intensity	4	643.	161.	0.16	0.959
YEAR.Cr Sys.Interval. Intensity	4	4.	1.	0.00	1.000
Residual	102	103524.	1015.		
Total	143	1109716.			

Appendix 6.2.2: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin vine length in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1.0145	0.3382	0.85	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	44.7931	44.7931	112.56	<.001
Interval	2	3.7940	1.8970	4.77	0.013
Intensity	2	4.7352	2.3676	5.95	0.005
Cr Sys. Interval	2	0.1729	0.0864	0.22	0.805
Cr Sys.Intensity	2	3.0161	1.5080	3.79	0.029
Interval. Intensity	4	0.4651	0.1163	0.29	0.882
Cr Sys.Interval.Intensity	4	0.6852	0.1713	0.43	0.786
Residual	51	20.2948	0.3979		
Total	71	78.9709			

Appendix 6.2.3: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin growth duration in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	644.3	214.8	2.07	
Block.*Units* stratum					
Cropping system (Cr Sys)	1	4125.3	4125.3	39.69	<.001
Interval	2	607.0	303.5	2.92	0.063
Intensity	2	1363.2	681.6	6.56	0.003
Cr sys.Interval	2	310.9	155.4	1.50	0.234
Cr sys. Intensity	2	1156.4	578.2	5.56	0.007
Interval. Intensity	4	481.4	120.3	1.16	0.340
Cr sys.Interval.Intensity	4	280.6	70.1	0.67	0.613
Residual	51	5301.0	103.9		
Total	71	14270.0			

Appendix 6.2.4: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on the number of primary branches in pumpkin in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	75.708	25.236	5.89	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	632.494	632.494	147.73	<.001
Interval	2	120.811	60.405	14.11	<.001
INTENSITY	2	7.723	3.862	0.90	0.412
CR SYS.Interval	2	106.904	53.452	12.48	<.001
CR SYS.INTENSITY	2	0.908	0.454	0.11	0.900
Interval.INTENSITY	4	12.413	3.103	0.72	0.579
CR SYS.Interval.INTENSITY	4	3.107	0.777	0.18	0.947
Residual	51	218.347	4.281		
Total	71	1178.415			

Appendix 6.2.5: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin vine length in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2.6843	0.8948	3.78	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	150.4534	150.4534	635.14	<.001
Interval	2	14.9798	7.4899	31.62	<.001
INTENSITY	2	6.7601	3.3801	14.27	<.001
CR SYS.Interval	2	7.5914	3.7957	16.02	<.001
CR SYS.INTENSITY	2	0.6531	0.3266	1.38	0.261
Interval.INTENSITY	4	0.5174	0.1294	0.55	0.703
CR SYS.Interval.INTENSITY	4	0.4603	0.1151	0.49	0.746
Residual	51	12.0811	0.2369		
Total	71	196.1810			

Appendix 6.2.6: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on the number of primary branches in pumpkin in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	135.17	45.06	4.32	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	696.89	696.89	66.77	<.001
Interval	2	9.19	4.60	0.44	0.646
Intensity	2	80.53	40.26	3.86	0.028
Cr Sys.Interval	2	23.03	11.51	1.10	0.340
Cr Sys. Intensity	2	54.53	27.26	2.61	0.083
Interval. Intensity	4	16.89	4.22	0.40	0.805
Cr Sys.Interval.Intensity	4	6.06	1.51	0.15	0.964
Residual	51	532.33	10.44		
Total	71	1554.61			

Appendix 6.2.7: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin dry leaf yield in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	10880.	3627.	2.99	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	177486.	177486.	146.14	<.001
Interval	2	4842.	2421.	1.99	0.147
Intensity	2	6452.	3226.	2.66	0.080
Cr Sys.Interval	2	4975.	2488.	2.05	0.139
Cr Sys. Intensity	2	5733.	2866.	2.36	0.105
Interval. Intensity	4	8181.	2045.	1.68	0.168
Cr Sys.Interval. Intensity	4	11891.	2973.	2.45	0.058
Residual	51	61937.	1214.		
Total	71	292377.			

Appendix 6.2.8: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin dry leaf yield in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	18080.	6027.	2.87	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	306053.	306053.	145.96	<.001
Interval	2	8540.	4270.	2.04	0.141
INTENSITY	2	11670.	5835.	2.78	0.071
CR SYS.Interval	2	8962.	4481.	2.14	0.128
CR SYS.INTENSITY	2	10216.	5108.	2.44	0.098
Interval.INTENSITY	4	13563.	3391.	1.62	0.184
CR SYS.Interval.INTENSITY	4	20574.	5144.	2.45	0.058
Residual	51	106935.	2097.		
Total	71	504593.			

Appendix 6.2.9: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on pumpkin dry leaf yield pure stands only, in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	33026.	11009.	3.24	
BLOCK.*Units* stratum					
Severity of harvest	9	81745.	9083.	2.67	0.023
Residual	27	91780.	3399.		
Total	39	206551.			

Appendix 6.2.10: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on the number of female flowers per vine in pumpkin in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	5.0624	1.6875	5.49	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	12.3273	12.3273	40.09	<.001
Interval	2	3.3849	1.6924	5.50	0.007
Intensity	2	1.8226	0.9113	2.96	0.061
Cr Sys.Interval	2	3.9483	1.9742	6.42	0.003
Cr Sys. Intensity	2	0.1579	0.0790	0.26	0.775
Interval. Intensity	4	1.1866	0.2967	0.96	0.435
Cr Sys.Interval.Intensity	4	0.4695	0.1174	0.38	0.821
Residual	51	15.6823	0.3075		
Total	71	44.0418			

Appendix 6.2.10: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on the number of female flowers per vine in pumpkin in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	5.2038	1.7346	6.54	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	30.2901	30.2901	114.19	<.001
Interval	2	4.2953	2.1476	8.10	<.001
INTENSITY	2	2.6078	1.3039	4.92	0.011
CR SYS.Interval	2	0.4086	0.2043	0.77	0.468
CR SYS.INTENSITY	2	0.2844	0.1422	0.54	0.588
Interval.INTENSITY	4	0.9322	0.2331	0.88	0.483
CR SYS.Interval.INTENSITY	4	1.1556	0.2889	1.09	0.372
Residual	51	13.5287	0.2653		
Total	71	58.7065			

Appendix 7: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on maize and mustard rape characteristics at UZF in 2002/3 and 2003/4

Appendix 7.1: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on component maize characteristics

Appendix 7.1.1: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on 1000 seed weight in component maize in Experiment 1 in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	982.2	327.4	2.13	
Block.*Units* stratum					
Interval	2	1292.7	646.3	4.20	0.027
Intensity	2	8212.4	4106.2	26.67	<.001
Interval. Intensity	4	1354.4	338.6	2.20	0.099
Residual	24	3694.7	153.9		
Total	35	15536.3			

Appendix 7.1.2: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on grain yield in component maize in Experiment 1 in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	34954801.	11651600.	29.45	
Block. *Units* stratum					
Interval	2	2237929.	1118964.	2.83	0.079
Intensity	2	1757006.	878503.	2.22	0.130
Interval.Intensity	4	737566.	184392.	0.47	0.760
Residual	24	9495060.	395627.		
Total	35	49182362.			

Appendix 7.1.3: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on 1000 seed weight in component maize in Experiment 1 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6341.	2114.	1.84	
Block.*Units* stratum					
Interval	2	3647.	1824.	1.59	0.225
Intensity	2	1734.	867.	0.76	0.480
Interval. Intensity	4	10834.	2709.	2.36	0.082
Residual	24	27522.	1147.		
Total	35	50078.			

Appendix 7.1.4: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on grain yield in component maize in Experiment 1 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	381232.	127077.	0.07	
Block.*Units* stratum					
Interval	2	2340124.	1170062.	0.68	0.518
Intensity	2	11565031.	5782516.	3.34	0.052
Interval. Intensity	4	4431188.	1107797.	0.64	0.639
Residual	24	41529987.	1730416.		
Total	35	60247561.			

Appendix 7.1.5: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on 1000 seed weight in component maize in Experiment 2 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1117.	372.	0.13	
BLOCK.*Units* stratum					
Interval	2	3963.	1982.	0.68	0.515
Intensity	2	14036.	7018.	2.42	0.110
Interval.Intensity	4	9587.	2397.	0.83	0.522
Residual	24	69632.	2901.		
Total	35	98336.			

Appendix 7.1.6: ANOVA for the effects of leaf harvest interval and leaf harvest intensity in mustard rape on grain yield in component maize in Experiment 2 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	10299587.	3433196.	2.41	
BLOCK.*Units* stratum					
Interval	2	681776.	340888.	0.24	0.789
Intensity	2	1583890.	791945.	0.56	0.581
Interval.Intensity	4	5972023.	1493006.	1.05	0.403
Residual	24	34180161.	1424173.		
Total	35	52717438.			

Appendix 7.2: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on mustard rape characteristics at UZF in the 2002/3 and 2003/4 seasons

Appendix 7.2.1: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on length of the vegetative period in the second planting of mustard rape in Experiment 1 over the 2002/3 and 2003/4 seasons at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.year stratum					
Year	1	45.623	45.623	2.77	0.147
Residual	6	98.829	16.472	5.40	
Block.year.*Units* stratum					
Cropping system (Cr Sys)	1	5933.963	5933.963	1945.25	<.001
Interval	2	560.060	280.030	91.80	<.001
Intensity	2	89.782	44.891	14.72	<.001
Year.cr sys	1	211.185	211.185	69.23	<.001
Year.Interval	2	0.316	0.158	0.05	0.950
Cr sys.Interval	2	103.011	51.506	16.88	<.001
Year.intensity	2	0.584	0.292	0.10	0.909
Cr sys.intensity	2	13.660	6.830	2.24	0.112
Interval.intensity	4	16.470	4.118	1.35	0.257
Year.cr sys.Interval	2	93.731	46.866	15.36	<.001
Year.cr sys.intensity	2	7.966	3.983	1.31	0.275
Year.Interval.intensity	4	15.815	3.954	1.30	0.277
Cr sys.Interval.intensity	4	4.757	1.189	0.39	0.815
Year.cr sys.Interval.Intensity					
	4	4.989	1.247	0.41	0.802
Residual	102	311.150	3.050		
Total	143	7511.893			

Appendix 7.2.2: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on dry leaf yield over the first and second planting of mustard rape in Experiment 2 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	155833.	51944.	3.13	
BLOCK.*Units* stratum					
Planting time (P Time)	1	3350300.	3350300.	201.57	<.001
Cropping system (Cr Sys)	1	3268542.	3268542.	196.65	<.001
Interval	2	30641.	15320.	0.92	0.401
INTENSITY	2	63019.	31510.	1.90	0.155
P Time.CR SYS	1	861767.	861767.	51.85	<.001
P Time.Interval	2	5345.	2672.	0.16	0.852
CR SYS.Interval	2	57679.	28840.	1.74	0.181
P Time.INTENSITY	2	8833.	4416.	0.27	0.767
CR SYS.INTENSITY	2	22860.	11430.	0.69	0.505
Interval.INTENSITY	4	95365.	23841.	1.43	0.228
P Time.CR SYS.Interval	2	13467.	6733.	0.41	0.668
P Time.CR SYS.INTENSITY	2	535.	267.	0.02	0.984
P Time.Interval.INTENSITY	4	117912.	29478.	1.77	0.140
CR SYS.Interval.INTENSITY	4	64878.	16220.	0.98	0.424
P Time.CR SYS.Interval.INTENSITY					
	4	80708.	20177.	1.21	0.309
Residual	105	1745224.	16621.		
Total	143	9942908.			

Appendix 7.2.3: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on dry leaf yield in the second planting of mustard rape in Experiment 1 in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	105464.	35155.	8.26	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	1974164.	1974164.	463.86	<.001
Interval	2	92374.	46187.	10.85	<.001
INTENSITY	2	18186.	9093.	2.14	0.129
CR SYS.Interval	2	128096.	64048.	15.05	<.001
CR SYS.INTENSITY	2	12367.	6183.	1.45	0.243
Interval.INTENSITY	4	9315.	2329.	0.55	0.702
CR SYS.Interval.INTENSITY	4	3963.	991.	0.23	0.919
Residual	51	217055.	4256.		
Total	71	2560984.			

Appendix 7.2.4: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on dry leaf yield in the second planting of mustard rape in Experiment 1 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	3877.6	1292.5	9.55	
BLOCK.*Units* stratum					
Cropping system (Cr Sys)	1	502023.7	502023.7	3708.48	<.001
Interval	2	12723.4	6361.7	46.99	<.001
INTENSITY	2	15675.0	7837.5	57.90	<.001
CR SYS.Interval	2	12242.2	6121.1	45.22	<.001
CR SYS.INTENSITY	2	13414.1	6707.0	49.55	<.001
Interval.INTENSITY	4	943.5	235.9	1.74	0.155
CR SYS.Interval.INTENSITY	4	913.4	228.3	1.69	0.167
Residual	51	6904.0	135.4		
Total	71	568716.9			

Appendix 7.2.5: ANOVA for the effects of leaf harvest interval and leaf harvest intensity on average harvested leaf size in the second planting of mustard rape in Experiment 1 in 2002/3 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3251.7	1083.9	2.43	
Block.*Units* stratum					
Cropping system (Cr Sys)	1	42358.1	42358.1	94.88	<.001
Interval	2	6105.6	3052.8	6.84	0.002
Intensity	2	15266.4	7633.2	17.10	<.001
Crsys.Interval	2	5440.7	2720.4	6.09	0.004
Crsys.intensity	2	14095.2	7047.6	15.79	<.001
Interval.intensity	4	388.1	97.0	0.22	0.928
Crsys.Interval.intensity	4	439.0	109.8	0.25	0.911
Residual	51	22768.7	446.4		
Total	71	110113.6			

Appendix 7.2.6: ANOVA for the effects of planting time and leaf harvest intervals and intensities on mustard rape average harvested leaf size in Experiment 1 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	11186.8	3728.9	26.57	
BLOCK.*Units* stratum					
Planting time (P Time)	1	635278.1	635278.1	4527.35	<.001
Cropping system (Cr Sys)	1	293742.3	293742.3	2093.37	<.001
Interval	2	84288.5	42144.3	300.34	<.001
INTENSITY	2	29031.9	14516.0	103.45	<.001
P Time.CR SYS	1	46.0	46.0	0.33	0.568
P Time.Interval	2	31981.8	15990.9	113.96	<.001
CR SYS.Interval	2	567.4	283.7	2.02	0.138
P Time.INTENSITY	2	3631.4	1815.7	12.94	<.001
CR SYS.INTENSITY	2	766.3	383.1	2.73	0.070
Interval.INTENSITY	4	548.7	137.2	0.98	0.423
P Time.CR SYS.Interval	2	657.2	328.6	2.34	0.101
P Time.CR SYS.INTENSITY	2	472.9	236.5	1.69	0.190
P Time.Interval.INTENSITY	4	135.2	33.8	0.24	0.915
CR SYS.Interval.INTENSITY	4	243.2	60.8	0.43	0.784
P Time.CR SYS.Interval.INTENSITY	4	716.9	179.2	1.28	0.284
Residual	105	14733.6	140.3		
Total	143	1108028.3			

Appendix 7.2.7: ANOVA for the effects of planting time and leaf harvest intervals and intensities on mustard rape average harvested leaf size in Experiment 2 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	26464.8	8821.6	71.24	
Block.*Units* stratum					
Planting time (P Time)	1	558316.6	558316.6	4508.63	<.001
Cropping system (Cr Sys)	1	339703.4	339703.4	2743.24	<.001
Interval	2	70318.1	35159.1	283.92	<.001
Intensity	2	24746.0	12373.0	99.92	<.001
PTime.crsys	1	838.2	838.2	6.77	0.011
PTime.Interval	2	28812.7	14406.3	116.34	<.001
Crsys.Interval	2	271.4	135.7	1.10	0.338
PTime.intensity	2	2178.2	1089.1	8.79	<.001
Crsys.intensity	2	406.6	203.3	1.64	0.199
Interval.intensity	4	357.6	89.4	0.72	0.579
PTime.crsys.Interval	2	750.2	375.1	3.03	0.053
PTime.crsys.intensity	2	273.5	136.7	1.10	0.335
PTime.Interval.intensity	4	157.3	39.3	0.32	0.866
Crsys.Interval.intensity	4	174.0	43.5	0.35	0.843
PTime.crsys.Interval.intensity	4	432.1	108.0	0.87	0.483
Residual	105	13002.4	123.8		
Total	143	1067202.9			

Appendix 7.2.8: ANOVA for the effects of planting time and leaf harvest intervals and intensities on length of the vegetative period in mustard rape in Experiment 2 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	109.917	36.639	14.40	
BLOCK.*Units* stratum					
Planting time (P Time)	1	658.778	658.778	258.99	<.001
Cropping system (Cr Sys)	1	2516.694	2516.694	989.40	<.001
Interval	2	492.722	246.361	96.85	<.001
INTENSITY	2	110.931	55.465	21.81	<.001
P Time.CR SYS	1	373.778	373.778	146.95	<.001
P Time.Interval	2	2.056	1.028	0.40	0.669
CR SYS.Interval	2	4.056	2.028	0.80	0.453
P Time.INTENSITY	2	0.347	0.174	0.07	0.934
CR SYS.INTENSITY	2	0.014	0.007	0.00	0.997
Interval.INTENSITY	4	90.694	22.674	8.91	<.001
P Time.CR SYS.Interval	2	29.556	14.778	5.81	0.004
P Time.CR SYS.INTENSITY	2	3.597	1.799	0.71	0.495
P Time.Interval.INTENSITY	4	5.194	1.299	0.51	0.728
CR SYS.Interval.INTENSITY	4	3.611	0.903	0.35	0.840
P Time.CR SYS.Interval.INTENSITY	4	6.944	1.736	0.68	0.606
Residual	105	267.083	2.544		
Total	143	4675.972			

Appendix 7.2.9: ANOVA for the effects of planting time and leaf harvest intervals and intensities on the total number of leaves harvested per plant in mustard rape in Experiment 2 in 2003/4 at UZF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	13.9852	4.6617	9.63	
BLOCK.*Units* stratum					
Planting time (P Time)	1	0.0779	0.0779	0.16	0.689
Cropping system (Cr Sys)	1	149.7564	149.7564	309.38	<.001
Interval	2	207.6595	103.8297	214.50	<.001
INTENSITY	2	548.7997	274.3998	566.88	<.001
P Time.CR SYS	1	0.0002	0.0002	0.00	0.986
P Time.Interval	2	12.9930	6.4965	13.42	<.001
CR SYS.Interval	2	43.8309	21.9155	45.28	<.001
P Time.INTENSITY	2	28.2819	14.1410	29.21	<.001
CR SYS.INTENSITY	2	9.5382	4.7691	9.85	<.001
Interval.INTENSITY	4	8.4477	2.1119	4.36	0.003
P Time.CR SYS.Interval	2	0.7376	0.3688	0.76	0.469
P Time.CR SYS.INTENSITY	2	1.6745	0.8372	1.73	0.182
P Time.Interval.INTENSITY	4	4.7580	1.1895	2.46	0.050
CR SYS.Interval.INTENSITY	4	1.6971	0.4243	0.88	0.481
P Time.CR SYS.Interval.INTENSITY	4	3.4292	0.8573	1.77	0.140
Residual	105	50.8254	0.4841		
Total	143	1086.4923			

Appendix 8: ANOVA for the effects of nitrogen side dress rate and time of harvesting on mustard rape characteristics at the University campus in Season 1 and Season 2 in 2004

Appendix 8.1: ANOVA for the effects of nitrogen side dress rate on average harvested leaf size in mustard rape in Season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	31942.	15971.	4.48	
Block.*Units* stratum					
Harvesting Time (HT)	1	33.	33.	0.01	0.925
Nitrogen Level (NL)	3	245347.	81782.	22.92	<.001
HT.NL	3	21789.	7263.	2.04	0.155
Residual	14	49951.	3568.		
Total	23	349061.			

Appendix 8.2: ANOVA for the effects of nitrogen side dress rate on mustard rape dry leaf yield in Season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	692943.	346471.	2.66	
Block.*Units* stratum					
Harvesting Time (HT)	1	551.	551.	0.00	0.949
Nitrogen Level (NL)	3	6107245.	2035748.	15.63	<.001
HT.NL	3	829394.	276465.	2.12	0.143
Residual	14	1823362.	130240.		
Total	23	9453494.			

Appendix 8.3: ANOVA for the effects of nitrogen side dress rate on average harvested leaf size in mustard rape in Season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	5371.5	2685.8	3.07	
Block.*Units* stratum					
Harvesting Time (HT)	1	98.1	98.1	0.11	0.743
Nitrogen Level (NL)	3	256704.3	85568.1	97.83	<.001
HT.NL	3	129.9	43.3	0.05	0.985
Residual	14	12244.7	874.6		
Total	23	274548.4			

Appendix 8.4: ANOVA for the effects of nitrogen side dress rate on mustard rape dry leaf yield in Season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	489913.	244957.	15.05	
Block.*Units* stratum					
Harvesting Time (HT)	1	3255.	3255.	0.20	0.662
Nitrogen Level (NL)	3	2009112.	669704.	41.15	<.001
HT.NL	3	10775.	3592.	0.22	0.880
Residual	14	227853.	16275.		
Total	23	2740909.			

Appendix 8.5: ANOVA for the effects of nitrogen side dress rate on percentage leaf nitrogen content at 5 WAE of mustard rape in Season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.02351	0.01175	0.21	
Block.*Units* stratum					
Harvesting Time (HT)	1	1.18370	1.18370	20.67	<.001
Nitrogen Level (NL)	3	5.99881	1.99960	34.92	<.001
HT.NL	3	0.02911	0.00970	0.17	0.915
Residual	14	0.80176	0.05727		
Total	23	8.03690			

Appendix 8.6: ANOVA for the effects of nitrogen side dress rate on percentage leaf vitamin C content (Log_{10} transformed) at seven WAE of mustard rape in Season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.12673	0.06336	4.34	
Block.*Units* stratum					
Nitrogen Level	3	0.03181	0.01060	0.73	0.572
Residual	6	0.08758	0.01460		
Total	11	0.24612			

Appendix 8.7: ANOVA for the effects of nitrogen side dress rate on percentage leaf vitamin C content at five WAE of mustard rape in Season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.6617	0.3308	3.18	
Block.*Units* stratum					
Nitrogen Level	3	0.2625	0.0875	0.84	0.520
Residual	6	0.6250	0.1042		
Total	11	1.5492			

Appendix 8.8: ANOVA for the effects of nitrogen side dress rate on percentage leaf nitrogen content at five WAE of mustard rape in Season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.3482	0.1741	1.32	
Block.*Units* stratum					
Harvesting Time (HT)	1	1.1267	1.1267	8.56	0.011
Nitrogen Level (NL)	3	1.4047	0.4682	3.56	0.042
HT.NL	3	0.3796	0.1265	0.96	0.438
Residual	14	1.8430	0.1316		
Total	23	5.1021			

Appendix 8.9: ANOVA for the effects of nitrogen side dress rate on percentage leaf nitrate content at five WAE of mustard rape in Season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.017558	0.008779	1.90	
BLOCK.*Units* stratum					
Harvesting Time (HT)	1	0.031537	0.031537	6.83	0.020
Nitrogen Level (NL)	3	0.116913	0.038971	8.44	0.002
HT.NL	3	0.028646	0.009549	2.07	0.151
Residual	14	0.064642	0.004617		
Total	23	0.259296			

Appendix 8.10: ANOVA for the effects of nitrogen side dress rate on leaf nitrogen content at 7 WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season.block stratum					
Season	1	0.20803	0.20803	3.92	0.119
Residual	4	0.21247	0.05312	0.73	
Season.block.*Units* stratum					
Harvesting Time (HT)	1	1.79413	1.79413	24.61	<.001
Nitrogen Level (NL)	3	3.09567	1.03189	14.16	<.001
Season.HT	1	0.38163	0.38163	5.24	0.030
Season.NL	3	0.28963	0.09654	1.32	0.286
HT.NL	3	0.20487	0.06829	0.94	0.436
Season.HT.NL	3	0.06870	0.02290	0.31	0.815
Residual	28	2.04087	0.07289		
Total	47	8.29600			

Appendix 8.11: Friedman test for non-parametric mustard rape vitamin C content data in Season 1 by nitrogen level blocked by block

S = 1.00 DF = 3 P = 0.801

Nitrogen level (kg ha^{-1})	**N**	**Est Median**	**Sum of Ranks**
0	3	14.443	8.0
34.5	3	16.270	9.0
69	3	11.398	7.0
103.5	3	10.310	6.0

Grand median = 13.105

Appendix 8.12: Friedman Test for non-parametric mustard rape plant height data in Season 1 by nitrogen level blocked by block

S = 20.78 DF = 7 P = 0.004

Nitrogen level (kg ha^{-1})	harvesting time	N	Est Median	Sum of Ranks
0	Morning	3	79.88	5.0
0	Sunset	3	73.12	4.0
34.5	Morning	3	115.12	12.0
34.5	Sunset	3	110.37	9.0
69	Morning	3	146.50	18.0
69	Sunset	3	143.25	15.0
103.5	Morning	3	167.62	24.0
103.5	Sunset	3	162.12	21.0

Grand median = 124.75

Appendix 8.13: Friedman Test for non-parametric mustard rape plant height data in Season 2 by nitrogen level blocked by block

S = 19.89 DF = 7 P = 0.006

Nitrogen level (kg ha^{-1})	harvesting time	N	Est Median	Sum of Ranks
0	Morning	3	73.26	3.0
0	Sunset	3	81.99	6.0
34.5	Morning	3	94.89	10.0
34.5	Sunset	3	105.81	11.0
69	Morning	3	124.67	16.0
69	Sunset	3	129.34	18.0
103.5	Morning	3	143.11	21.0
103.5	Sunset	3	148.78	23.0

Grand median = 112.73

Appendix 8.14: ANOVA for the effects of nitrogen side dress rate on SPAD values at three WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.Season stratum					
Season	1	876.042	876.042	252.11	<.001
Residual	4	13.899	3.475	1.89	
Block.Season.*Units* stratum					
Nitrogen Level (NL)	3	6.487	2.162	1.18	0.359
Season.NL	3	10.496	3.499	1.91	0.183
Residual	12	22.034	1.836		
Total	23	928.958			

Appendix 8.15: ANOVA for the effects of nitrogen side dress rate on SPAD values at four WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.Season stratum					
Season	1	278.972	278.972	144.83	<.001
Residual	4	7.705	1.926	1.02	
Block.Season.*Units* stratum					
Nitrogen Level (NL)	3	45.653	15.218	8.06	0.003
Season.NL	3	15.146	5.049	2.67	0.095
Residual	12	22.656	1.888		
Total	23	370.132			

Appendix 8.16: ANOVA for the effects of nitrogen side dress rate on SPAD values at five WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.Season stratum					
Season	1	36.902	36.902	5.81	0.074
Residual	4	25.427	6.357	3.32	
Block.Season.*Units* stratum					
Nitrogen Level (NL)	3	155.802	51.934	27.13	<.001
Season.NL	3	44.147	14.716	7.69	0.004
Residual	12	22.967	1.914		
Total	23	285.245			

Appendix 8.17: ANOVA for the effects of nitrogen side dress rate on SPAD values at six WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.Season stratum					
Season	1	42.918	42.918	69.12	0.001
Residual	4	2.484	0.621	0.37	
Block.Season.*Units* stratum					
Nitrogen Level (NL)	3	90.604	30.201	17.82	<.001
Season.NL	3	0.134	0.045	0.03	0.994
Residual	12	20.343	1.695		
Total	23	156.481			

Appendix 8.18: ANOVA for the effects of nitrogen side dress rate on SPAD values at seven WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.Season stratum					
Season	1	5.461	5.461	2.42	0.195
Residual	4	9.028	2.257	1.03	
Block.Season.*Units* stratum					
Nitrogen Level (NL)	3	337.551	112.517	51.14	<.001
Season.NL	3	0.078	0.026	0.01	0.998
Residual	12	26.404	2.200		
Total	23	378.521			

Appendix 8.19: ANOVA for the effects of nitrogen side dress rate on SPAD values at nine WAE of mustard rape over seasons 1 and 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block.Season stratum					
Season	1	33.276	33.276	14.60	0.019
Residual	4	9.119	2.280	0.64	
Block.Season.*Units* stratum					
Nitrogen Level (NL)	3	200.259	66.753	18.83	<.001
Season.NL	3	0.348	0.116	0.03	0.992
Residual	12	42.531	3.544		
Total	23	285.532			