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Abstract

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In the tropics, weeds cause more crop losses and farmers spend more of their time weeding crops than in any other part of the world. Weeds form a major factor which contributes to the miserable quality of life of smallholder farmers, especially of women and children, in rural areas of sub-Saharan Africa. The effects of maize-pumpkin and maize-bean intercropping and, narrow row planting and precise basal fertilizer placement in monocrop maize, on crop and weed radiation interception (RI), crop yields, weed emergence, growth and fecundity were investigated in this study. The effects of leaf stripping (removal of the lowest 2-6 leaves) and detasselling maize at anthesis on the radiant environment and crop yields in a maize monocrop and maize-pumpkin and maize-bean intercrops were also studied to determine the impact of these interventions on yield of component crops. The aim of the studies was to generate technologies that could be integrated into the production practices of smallholder farmers to suppress weeds and alleviate the severe weeding burden faced by these farmers while ensuring high crop productivity.

Maize-pumpkin and maize-bean intercropping reduced weed biomass by 50-66% when established at a density of 12,300 plants ha^{-1} for pumpkins equivalent to 33% of the maize density (37,000 plants ha^{-1}), and 222,000 plants ha^{-1} for beans. Lower densities of pumpkins than 33% of the maize density failed to reduce weed biomass more than that achieved by sole maize. Sole maize crops were weeded twice or thrice to achieve the same weed biomass as intercrops weeded once showed that intercropping could reduce the weeding requirements of maize by 33 to 67%. Maize grain yield was reduced by 20% in one out of four seasons in the first study on maize-pumpkin intercropping. Maize grain yield was not reduced in three seasons when the maize-pumpkin intercropping treatments were leaf stripped and/or detasselled and the trend of leaf stripping and detasselling alleviating the effects of companion crop competition on maize grain was shown in the maize-bean intercrop experiments as well. Intercrop productivity increased with leaf stripping and detasselling as a result of greater penetration of radiation to the companion crop and their effects of increasing dry matter distributed to the maize cob (indicated by 1000-grain weight, cob weight, and kernel weight cob^{-1}). Leaf stripping maize at anthesis focused on the removal of leaves that were beginning to senesce. If they would remain on the plant they would compete with the cob for assimilates as they senesce further, until necrosis. Detasselling is known to remove apical dominance and to increase radiation penetration to the middle leaves on the maize plant that produce most assimilates destined for the cob. Leaf stripping did not affect the ability of the intercrop to suppress weed growth and seed production. In maize monocrops more weed biomass and weed seeds were produced with leaf stripping and detasselling.

Maize grain yield decreased with an increase in maize density from 30,000 plants ha^{-1} to

36,000 and 42,000 plants ha^{-1} and weed growth suppression increased with an increase in maize density in a semi arid location in Zimbabwe. Planting maize using narrow row (60 cm × 45 cm) and (75 cm × 36 cm) spatial arrangements increased radiation interception by maize plants by 16 to 24% and maize grain yields by 15 to 26% compared to wide row (90 cm × 30 cm) spatial arrangement commonly used by smallholder farmers. Weed biomass was reduced by 20 to 80%, dependent on weed species, in narrow row spatial arrangements compared to normal farmer planting patterns. The duration of the weed free period required to attain maximum yield increased from 6 weeks after emergence (WAE) in the 60 cm × 45 cm spatial arrangement to 9 WAE in the wider row spatial arrangements. It is, therefore, risky for smallholder farmers to increase maize density to suppress weeds as this will lead to maize grain yield reductions. The use of narrow rows proved to be a better option.

Precise fertilizer placement (banding and spot placement) resulted in higher rates of early growth and by 4 WAE these treatments intercepted 20% more of the incoming radiation than a broadcast placement method. Weed emergence, growth and seed production was higher in the broadcast placement treatment as a result of weeds intercepting more incoming radiation and greater access to applied fertilizer nutrients. High fertilizer rates of 225 kg ha^{-1} of a compound fertilizer (8% N, 14% K_2O, 7% P_2O_5), reduced maize grain yield by 15% compared to 150 kg ha^{-1} in a season characterized by drought. It was hypothesized that high concentrations of fertilizer around the root zone predisposed the maize plants to more severe effects of drought than lower fertilizer application rates.

Reduced dosages of atrazine and nicosulfuron (25% of the Label Recommended Dosages, LRDs) protected maize from weeds as well as the full LRDs of each herbicide. The reduced dosages suppressed weed competition during the critical period for weed control in maize. However, the tolerant weed species *Eleusine indica* (L.) Gaertn., *Setaria verticillata* (L.) Beauv., *Setaria homonyma* (Stead.) Chiov. for atrazine and *E. indica*, *Galinsoga parviflora* Cav. and *Portulaca oleracea* L. for nicosulfuron, tended to escape the herbicide effects and survive as dosages were reduced. Reduced dosages of these herbicides have to be combined with hoe weeding or ox-cultivation to prevent the inadvertent selection of these species by the reduced dose strategy. Recalcitrant species recovering from tillage were shown to be more vulnerable to reduced herbicide toxicity in a greenhouse experiment.

It was concluded that cultural weed management techniques that enhance radiation capture by the crop were effective in suppressing weed growth and seed production and increasing crop yields and should be incorporated into smallholder farmer's production practices in a systematic manner as part of Integrated Weed Management and cropping system design.

Preface

I started on this project, in 1998 as someone who was fairly idealistic and set in my ways of doing things, however, interactions with a number of people who have helped to see this project to fruition, have decidedly and permanently transformed me for the better, I hope. Now I appreciate my limitations with humility and calmness and accept that when I am stuck, I need to go straight to the person that can provide the answers that I want and avoid wasting time looking for the information or trying to learn a new technique on my own.

I was spotted by Dr Joop de Kraker who had come to Zimbabwe, together with Dr Kees Eveleens, on a NECTAR-NATURA project that was developing resource materials for the MSc in Sustainable Crop Protection for the University of Zimbabwe and other Universities in the South. In the many conversations that we had with Joop as we conducted the business of the project I must have dropped a hint that I was looking for a place to register as a PhD student. He took me on my word and duly presented my credentials to Professor Martin Kropff, and I was accepted to start on a sandwich PhD programme in the then Department of Theoretical Production Ecology in January 1998. I record my appreciation of Joop, for taking me on face value, and having the conviction that I was 'real' to the extent that he did. Without that rare humanity that he showed of favourably assessing a complete stranger within a period of barely a week, I would not have embarked on this assignment. Thank you for starting me off on a roller coaster that has left me buzzing with hypotheses that arise from the work that I did during research for the thesis that I hope will further galvanize me in higher levels of scientific endeavour.

I have received all the assistance that I wished for from my promotor, Professor Dr. Martin Kropff and my co-promotors Dr Wopke van der Werf and Dr Bert Lotz. I particularly valued their resolute and insightful guidance of my work that made me feel I was in 'safe hands' and removed any doubt that I was destined to attain the target at the end of the tunnel, despite operating in a rather difficult environment of Zimbabwe. The Bert Lotz family literally adopted me and showed me all the interesting sites in the Netherlands and hosted me on countless sumptuous dinners at their home. Bert and family, thank you for the catering for the social aspects of my life and helping with all the little problems that a person in a foreign country, with zero language skills in Dutch, would inevitably encounter. For Wopke, I want to express deep respect for his attention to detail that never left me to flounder in a morass of confusion. Wopke, you simply were the best in initiating the debates that enlightened me, removing fixations of habit and character that, I see now, did not serve me to best

advantage. For what I am now and what I will be in future I owe it largely to my promotion team.

My work involved a large number of labour intensive experimentation and would not have been accomplished without the assistance of students who were carrying research projects in partial fulfilment of the requirements of either a BSc Agriculture Honours Degree or MSc in Crop Protection. These students whom I supervised in the work contributed large amounts of data required to build a picture in each research topic that was tackled. I extend my deepest appreciation of the following undergraduate students, Silent Taurayi, Benhildah Chihota, Pepukai Manjeru, Amon Mwashaireni, Ivy Mudita, M. Mandumbu and S. Mabehla who in their varied ways provided data for various chapters in my thesis. The following MSc students are deeply acknowledged for their contribution to the thesis, Patricia Tembani, Justin Chipomho and Dzingo Mafuvadze.

In the second period of the sandwich programme, from May to November 2003, I shared an office, the so called United Nations Room with Geoffrey Mkamilo, Odiaba Samaké, Peter Ebanyat and M. Ostroshy. Whenever I got stuck, these friends helped me out. In fact when one wants to write a thesis, I now believe, it is best to be surrounded by friends engaged in the same enterprise. Geoffrey Mkamilo was engaged in analysis of intercropping work as me, and my conversations with him broadened my horizons. To Venasius Lendzemo, thank you for those hectic tennis battles that broke the monotony of academic endeavour and ensured I stayed interested in what I was doing in the course of writing this thesis. Unfortunately when one writes a thesis, it becomes a single minded obsession, helped along by merciless deadlines one sets for oneself. It has the tendency to drive out the humanity in individuals such that they start responding like robots to the people and environment around them. I did not have a chance to make many friends during the period of thesis writing; I guess the robotic bug had bitten me also. I apologize unreservedly to all who might have been offended by monosyllabic responses in conversation and a general dead pan attitude during this period. I hope I have returned to be my normal convivial social animal that I normally am.

To the secretaries in the Crop Weed Ecology Group, Hilde Holleman and Leonie van Scherrenburg, I recognize your steely determination, against all odds stacked against the process to establish contact with me in Zimbabwe, to arrange travel arrangements and other administrative issues. I extend my heart-felt gratitude for all the help that you extended to me throughout my stay in the department. Your friendly, approachable and efficient demeanor is an asset to the Crop Weed Ecology Group, thank you.

Gon van Laar kindly took it upon herself to edit, typeset the thesis booklet and see

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CHAPTER 1

General introduction

GENERAL INTRODUCTION

Zimbabwe
The study, herein described, was carried out in Zimbabwe (Fig. 1). To provide a contextual background to the study, it is necessary to describe the agro-ecological and geographical features of Zimbabwe. The purpose of the introduction is to situate the reader in the contextual reality of Zimbabwe first and then provide the theoretical background and justification to each sub-problem that is tackled by the thesis.

Zimbabwe is a land locked 'tea pot shaped' country in Southern Africa with an area of 390,580 km^2, an area slightly larger than that of the state of Montana in the USA. Zimbabwe shares borders with South Africa, to the south, Zambia to the north, Mozambique to the east and Botswana to the west. Zimbabwe is separated from Zambia by the Zambezi River with its mighty Victoria Falls, and from South Africa by the Limpopo River. On the globe, Zimbabwe is situated between latitudes 15° and 22° South and longitudes 26° and 34° East (FAO sub-Regional Office for East and Southern Africa, 2000).

Climatic conditions in Zimbabwe are sub-tropical with one rainy season between November and April. Altitude ranges from 162 m above sea level at the junction of the Runde and Save rivers in the south to 2,592 m above sea level, at the top of the highest mountain, Mount Inyangani, at the eastern boundary. The sub-tropical climate is, therefore, moderated by altitude. Altitude generally increases from south to north and

Figure 1. Location of Zimbabwe in Southern Africa.

east to west, leaving a high central plateau that is predominantly situated in north central Zimbabwe. In addition, the eastern borders of the country are dominated by mountain terrain that forms the highest region of the country. Rainfall and temperature patterns largely follow changes in altitude, being wetter and cooler in the high altitude regions (highveld) and drier and hotter in the low altitude areas (lowveld). Maximum temperatures range from 25 to 30 °C in the low altitude regions and from 20 to 25 °C in the high central plateau (CIA, World Factbook, 2002).

The country is divided into five natural regions or agro-ecological regions with rainfall as the main criterion of division. Agricultural production potential of any area in Zimbabwe is dependent on its agro-ecological classification (Table 1).

Over 80% of the smallholder farmers in Zimbabwe lived and worked on the land in agro-ecological regions III, IV and IV before the changes that were ushered in by the land resettlement programme in the year 2000. All smallholder farmers produce maize, even those situated in the driest parts of the country (Mashingaidze and Mataruka, 1992).

Weed management problems in smallholder maize production in Zimbabwe

Maize (*Zea mays* L.) is the most important cereal crop grown in Zimbabwe. It is the staple cereal for 99% of Zimbabwe's 15 million inhabitants. It ranks first in terms of the number of both smallholder and large scale commercial producers, the area covered by the crop and the total production among all crops grown in Zimbabwe. Average yields in the smallholder sector are still low ranging from 1.0-1.5 t ha^{-1}, as compared to 6-12 t ha^{-1} in the large scale commercial sector (Mashingaidze and Mataruka, 1992). Maize yields are low in the smallholder sector because of poor soil fertility and the lack of resources to correct the soil nutrient deficiencies (Grant, 1981, Jonga, 1998), inadequate and untimely weed control (Chivinge, 1990; Vernon and Parker, 1983) and erratic and inadequate rainfall.

Competition from weeds early in the development of maize remains one of the most serious and widespread production problems facing smallholder maize producers in Southern Africa (Vernon and Parker, 1983; Low and Waddington, 1990; Waddington and Karigwindi, 1996). Hoe-weeding is the main weed control method used by smallholder communal area farmers. Chivinge (1990) described this method as slow, labour-intensive, cumbersome and inefficient. Most of the weed competition is a consequence of a delayed first hoe-weeding in the crop row, because of labour shortages (Waddington and Karigwindi, 1996). Shortages of labour mean that small-holder farmers invariably weed a large portion of the crop late, after the crop has already suffered significant yield damage (Chivinge, 1990). Weed competition in the initial stages of crop growth can be so severe that crops remain stunted and the final

Table 1. Rainfall characteristics of the five Agro-ecological zones of Zimbabwe and suitable agricultural activities (adapted from FAO sub-Regional Office for East and Southern Africa, 2000).

Agro-ecological region	Area (km^2)	% of total	Rainfall characteristics	Agricultural activities
I	7,000	2	More than 1050 mm per annum with some rain in all months.	Specialized and diversified farming region. Suitable for forestry, temperate fruit and intensive livestock production.
II	58,600	15	700-1050 mm confined to summer. Infrequent heavy rainfall. Subject to seasonal droughts.	Flue-cured tobacco, maize, soybean, cotton, sugar beans and coffee can be grown. Sorghum, groundnuts, seed maize, wheat and barley are also grown. Wheat and barley grown in winter under irrigation. Mixed cropping with poultry, beef and dairy production common.
III	72,900	18	500-700 mm per annum. Infrequent heavy rainfall. Subject to periodic seasonal droughts, prolonged mid season dry spells and unreliable starts of the season.	A semi intensive farming area. Smallholder farmers occupied 39% of this area and most of the land was used for extensive ranching before resettlement in 2000. Maize production dominated commercial production. Irrigation played an important role in sustaining crop production in commercial farming areas.
IV	147,800	38	450-600 mm per annum.	Suitable for extensive ranching and wildlife management. Too dry for successful crop production of most crop suitable for sorghum and millets and other drought tolerant crops. Maize is commonly grown by smallholder farmers. Sugar cane and cotton are produced under irrigation in large estates.
V	104,400	27	Normally less than 500 mm per annum.	Extensive ranching and wildlife management are the most suitable activities.
Total	390,700	100		

yields are a mere fraction of the true potential (Chivinge, 1984). In Mangwende, a communal area typical of the higher yielding sub-humid smallholder maize production zones in Zimbabwe, 42% of farmers first weeded their early maize more than 30 days after crop emergence. This was calculated to reduce grain yield by 28% from a grain yield level of about 5 t ha^{-1} (Shumba *et al.*, 1989).

Farmers invest large amounts of labour in weeding each year, approximately 35 to 70% of the total agricultural labour needed to produce a smallholder crop which sometimes exceeds all other operations combined (Chivinge, 1984; Ransom, 1990; Waddington and Karigwindi, 1996). In wet seasons, farmers may have to weed more frequently to attain high yields because of the reduced effectiveness of hoe- and mechanical-weeding under wet conditions. Most farmers abandon part of their planted crops because they would have failed to cope with heavy weed infestation brought about by delay in weed control and inefficiency of the hoe-weeding method under wet conditions. Resources and inputs previously committed to abandoned crops are invariably lost when these abandoned crops produce no or little economic yield (Mashingaidze and Chivinge, 1998). In Zambia, Vernon and Parker (1982) reported that 38% of the total labour in maize was devoted to weed control and in 1983, they concluded that in Southern Zambia the inefficiency of hoe-weeding resulted in maize yield loss of up to 30% or more. Smallholder farmers required 460 hrs to effectively hoe-weed a hectare of maize in South Africa (Auerbach, 1993).

The quality of life in the Zimbabwean rural communities in the smallholder sector lowered substantially by the burden of weeding. In Zimbabwe, Chivinge (1990) reported that smallholder farmers spend more than 75% of their time battling to control weeds in the peak weeding period of December to February. Farmers are faced with a multiplicity of tasks at peak weeding for early-planted crops such as maize and cotton, like land preparation and planting of late crops and heading of livestock. Severe labour bottlenecks are, therefore, common. Most of the burden for hoe-weeding falls on women and children because of rural urban migration and the reduction in the active work force wreaked by the HIV/AIDS pandemic (Sibuga, 1999). Labrada *et al.* (1994) report that children are sometimes denied the chance to go to school to assist in weeding during the peak weeding period, resulting in low educational performance. Weeding has, therefore, wider social effects because it may lock children from resource poor families in a vicious poverty cycle as they are hindered by weeding chores from taking advantage of schooling to escape to other more rewarding forms of employment. Despite the disproportionate effort expended in mechanical and hoe-weeding by smallholder farmers in Africa, weeds still cause considerable yield losses, possibly as much as diseases and pests combined (Labrada *et al.*, 1994). Weeds cause more crop losses in the tropics and farmers spend more of their time weeding than in

any other part of the world (Akobundu, 1991; Koch *et al.*, 1983; Parker and Fryer, 1975). Estimated yield losses caused by weeds in Africa amount to 16% compared to only 7% in Europe (Fletcher, 1983).

In Malawi, it was shown that maize needed three to four weedings in the first 10 weeks to avoid yield loss caused by weeds (Anonymous, 1973) and in Zimbabwe maize is generally weeded two times per season (Shumba, 1986). The frequency of weeding to avoid yield loss can be reduced when weeding is combined with cultural management options such as narrow row spatial arrangements, increased plant densities, mixed cropping, selecting competitive varieties and early planting which increase the competitiveness of the maize crop. Comparatively, these methods which reduce seed germination, seedling emergence, growth and competitiveness of weeds against the crop(s) are compatible with Integrated Weed Management (IWM) strategies, are environmentally friendly and are accessible to resource-poor farmers (Mashingaidze and Chivinge, 1998). These methods are based on promoting those agronomic and management practices that will give the crop a competitive advantage against weeds (Mashingaidze and Chivinge, 1998). Sibuga (1999) identified the reduction of weeding and consequently the drudgery involved, so as to release labour for other activities, as the key issue that needs to be addressed to enhance the performance of African farmers, especially women and children, in weed management. This study, therefore, focuses on cultural weed management techniques that have the potential to reduce weed pressure and the weeding burden required to control the weeds.

Rapidly changing social and political scenarios in Zimbabwe

The land reform programme

At independence in 1980, the new government inherited a highly skewed land distribution pattern, with 6,000 white-owned commercial farms and a number of large agro-industrial estates occupying more than a third of the country land area, much of it in areas of high agricultural potential (Weiner, 1988). Despite pronouncements of the government's commitment to land reform, it was highly constrained by constitutional provisions of the Lancaster House agreement that ushered in independence to Zimbabwe. The biggest constraint was the failure of the government to acquire enough land for resettlement through the 'willing seller/willing buyer' approach, with full compensation in foreign currency, which slowed down resettlement and made it expensive. Resettlement targets of 18,000, 54,000 and 1,620,000 families were set in 1980, 1982 and 1984 by the government, respectively. These targets were largely missed but the resettlement programme achieved a significant impact. By 1989, the

government had resettled some 52,000 households and had purchased 2.7 million hectares (16% of the commercial agricultural land previously held by white farmers). By 1996, a total of 71,000 families had been resettled (Palmer, 1990; Moyo, 1995, 2000).

The era of technically planned and organized land reform practically ended with the referendum on a draft constitution for Zimbabwe that absolved the government of paying compensation for land and passed on that obligation to the former colonial masters, the British, in February 2000. The current government suffered a humbling defeat on the draft constitutional referendum polls. However, there was an instantaneous reaction of massive invasions of white owned commercial farms by war veterans and landless peasants, across Zimbabwe. The invasions were overtly supported by government as political demonstrations by the land hungry at the government and donors' failure to address the highly charged 'land question' after 20 years of independence and anger at the rejection of the draft constitution. Lebert (2003) argues that it is not easy to delineate whether or not the politicization of the land issue by the ruling political party was altruistic or ideological in nature or simply an act of political self-preservation. However the prevailing view of the donor community and western governments is that the government supported the chaotic and violent model of resettlement under the guise of what became known in official documents as the 'fast track land reform programme' to thwart the rising support for the opposition Movement for Democratic Change (MDC) party. The MDC had campaigned for the rejection of the draft constitution because it was of the opinion that it would centralize power in the office of the President and reduce parliament to rubber-stamping presidential decisions. The fact that white commercial farmers openly supported the MDC whipped emotions of the current government and war veterans and unbridled violence was part and parcel of the commercial farm invasions following the referendum polls of February 2000 (Chaumba *et al.*, 2003).

The fast track land resettlement meant that there was a massive escalation of farm designation and resettlement with an officially expressed view of redistributing 9.2 million hectares of land from the commercial farming sector (approximately 80% of the land in this sector) to 160,000 poor beneficiary families and 51,000 small scale indigenous (black) commercial farmers (Zimbabwe Government, 2001). According to official records, by January 2002, 7.3 million ha on 3,074 commercial farms had been planned and pegged by the Ministry of Lands, Agriculture and Rural Resettlement and 114,830 households had already been resettled on 4.37 million ha (UNDP, 2002).

The narrative that has been given above on the land reform programme in Zimbabwe should help to situate the reader into the Zimbabwean agricultural landscape and imbue a sense appreciation at the scale of the production problems that the

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country now faces. Resettlement has practically meant that a huge expansion in the smallholder sector into previously intensively managed and heavily capitalized commercial farming sector in Zimbabwe. The resettled smallholder farmers who resettled themselves during land invasions led by war veterans, and those resettled by government officials during the fast track land resettlement programmes, have at least 5-10 hectares of arable land per household at their disposal (Mbaya, 2001). They generally lack the technical know-how, equipment and inputs such as seed and fertilizers that are required to match the intensity of production that was previously achieved by white commercial farmers. Further more, during the violent fast track programme, infrastructure such as irrigation pumps and pipes and machinery was destroyed or looted. What is particularly striking when one drives around in newly resettled areas is the apparent inability of the new farmers to manage weeds in the large pieces of land at their disposal. For some twisted logic which is not easy to fathom, farmers plant large areas but only manage to effectively weed small portions and abandoned fields previously planted to crops, are very common in the resettlement areas (personal observation). The problem of weed management in the smallholder sector has, therefore, been exacerbated by the fast track resettlement programme. Food production has plummeted to 30-40% of previous production levels, leading to widespread hunger and has created a desperate food security situation for millions of people throughout Zimbabwe (Justice for Agriculture, 2002).

Weed management in the era of 'Henry the IV'

The population in Zimbabwe is being severely debilitated and decimated by HIV/AIDS related illnesses and death. HIV has been euphemistically referred to as 'Henry the IV' (Andersson, 2002). With weed management being the most labour demanding operation on smallholder farms, the toll taken by HIV/AIDS on the ability of smallholder farmers to effectively work on the land and produce sufficient food stocks takes on a frightening dimension when its prevalence in Zimbabwe is taken into account. Zimbabwe is categorized with Botswana, Zambia, South Africa, Swaziland, Lesotho and Namibia as the high prevalence group with an average infection prevalence of 28.7%. Among this group of countries, Botswana leads in terms of prevalence with 38.8% prevalence among adults (15-49 age group) while Zimbabwe with 33.7% prevalence is a close second (UNAIDS, 2002). In all countries in Southern Africa, less than 40% of the survivors to age 15 would celebrate their 60th birthday under the current adult mortality.

The strong age-specific impact of HIV/AIDS is re-shaping the population structure of African countries, such as Zimbabwe. The depopulation of the 15-49 age group reduces the number of adults able to reproduce and productively work in industry

commerce, services and agriculture (Ngom and Clark, 2003). Besides HIV/AIDS depleting the able-bodied members of the rural society, agricultural workers with the disease easily succumb to a myriad of opportunistic infections adversely affecting their ability to productively work their fields, before developing full blown AIDS. Moreover, agricultural production working time is lost tending for the sick and dying. The rural people in Zimbabwe are also burdened with caring for 'returnees', individuals who migrated to town, find employment, who then get sick and then return to their village to die. Smallholder farmers are obliged by custom to attend the numerous HIV/AIDS funeral vigils in their villages and for relatives in other far flung areas. The vigils last at least two working days (Davies, 1998).

To mitigate the adverse effects of the HIV/AIDS pandemic on agricultural productivity, crop management techniques that reduce labour requirements for weeding while maintaining productivity were investigated in this study. In the era of 'Henry the IV', labour-saving and yield-increasing technologies are bound to have a positive impact on the ability of the smallholder farmers to cope with wide-ranging effects of the HIV/AIDS pandemic on their livelihoods and welfare in Zimbabwe.

Integrated crop and weed management techniques to increase crop productivity and reduce the impact of weeds – Rationale for the study focus
A brief background of the rationale behind the choice of crop and weed management techniques that were studied is given in this section. The aim of the studies that are described in this thesis was to evaluate the efficacy of cultural crop management techniques to increase crop productivity while at the same time suppressing weeds. Crop management techniques that enhance the interception of incoming radiation and, therefore, potentially crop growth rate and yield have the simultaneous advantage of restricting the amount of radiation incident on the weeds germinating and growing in the understorey of the crop. These techniques can potentially benefit smallholder farmers in two ways; production of high crop yields and reduction of weeding requirements, thereby addressing the two major problems that are faced by smallholder farmers in Zimbabwe, low crop yields and poor weed management.

Cultural weed management tactics
Increased radiation interception achieved by intercropping accounts for the increased productivity of intercropping systems (Liebman, 1989) and their greater ability to suppress weed competition than monocrops of either of the component crops (Mashingaidze *et al*., 2000; Akobundu, 1993). Use of high plant densities and narrow rows hastens the rapidity of canopy closure and enhances canopy radiation interception, increasing crop growth rates and yields (Andrade *et al*., 2002) and

suppressing weed growth and competitiveness (Zimdahl, 1999; Murphy *et al.*, 1996; Buchanan and Hauser, 1980; Rodgers *et al.*, 1967; Wiese *et al.*, 1964). Increased rates of crop growth as a result of adequate fertilization and precise placement of fertilizer in the vicinity of crop roots ensures that the crop has a 'starting position' advantage over weeds in the capture of resources including incoming radiation (Mahler *et al.*, 1994; Kumwenda *et al.*, 1995; Tanner, 1984). Increasing the precision of fertilizer placement in relation to plant roots, when compared with broadcast application, has been associated with reduced competitiveness of weeds (Blackshaw *et al.*, 2002; Mesbar and Miller, 1999). Cultural weed management techniques based on giving the crop a competitive advantage against weeds through capture of a larger share of the incoming radiation and concomitantly high crop growth rates and yields are the focus of this study. The aim of the studies is to put at the disposal of smallholder farmers in Zimbabwe various crop management techniques that have potential to increase pro-ductivity while at the same time reducing weeding requirements of their crops. Techniques that are relatively easy to implement for smallholder farmers include maize-bean and maize-pumpkin intercropping, use of high plant densities and narrow rows and precise placement of fertilizer. Such techniques will be studied in relation to canopy radiant energy interception, crop growth and yield, weed emergence, growth and fecundity and amount of hoe-weeding required in order to avert crop yield loss.

Leaf stripping and detasselling

Spatial arrangement and foliage architecture of component crops determine the amount of PAR intercepted by each of component crops and, therefore, their pattern of dry matter accumulation and yield (Subedi, 1996). The taller cereal shades the legume and at high densities can reduce the yield of the dominated legume in its under-growth (Ofori and Stern, 1987). Any interventions that lead to an increase in the aggregate amount of PAR reaching the crop under the cereal foliage might increase pumpkin or bean yield.

Detasselling is the removal of the male inflorescence of a maize plant. Detasselling of maize is advantageous to maize grain yield as a result of reduction in barrenness and increased grain size (Subedi, 1996). Tassel removal also increases maize yield by allowing more incoming PAR to penetrate to the cob leaves that contribute most photo-assimilates to the developing ear and by removing the apical dominance effect over the development of the ear (Hunter *et al.*, 1969).

At anthesis, leaves begin to undergo senescence and in grasses this begins at the older leaves and progresses up the plant. At this time, the leaf may fail to support its own energy requirements because of age and/or shading. Contribution from the bottom leaves to sinks declines progressively with senescence (Gardner *et al.*, 1985) and the

old leaves become net importers. It is hypothesized that removal of the bottom senescing leaves reduces competition for assimilates with the developing cob, increases maize grain yield and simultaneously allows a greater proportion of radiant energy to reach the minor crop and enhance its yield.

Another aim of this study was to determine the effect of maize leaf stripping and detasselling on the productivity of maize-pumpkin and maize-bean intercrops that are commonly used by farmers in Zimbabwe by investigating the light distribution, weed germination and growth, and component crop yields.

Reduced herbicide dosages in maize

Reduced herbicide dosages cost a fraction of the full label recommended dosage and are, therefore, more attractive to cash-strapped smallholder farmers (Mashingaidze and Chivinge, 1995). Reduction of dosages has the additional advantage of reducing the aggregate risk of herbicides contaminating the ecosystem (Price, 1990; DeFelice *et al.*, 1989). Integrating cultivation methods with reduced herbicide dosages, as planned in this study, can further reduce herbicide use (Caseley, 1994).

Field experiments in small grain cereals (Kudsk, 1989; Fisher and Davies, 1993; Wright *et al.*, 1993; Solanen, 1992), in soybeans (DeFelice *et al.*, 1989; Baldwin and Oliver, 1985), in maize (O'Sullivan and Bouw, 1993; Bicki *et al.*, 1991; Mulder and Doll, 1993) and potatoes (Wallace and Bellinder, 1990) have shown that herbicide dosages can be reduced and applied at below label recommended rates, without loss of efficacy to control weeds or loss of crop yields. The efficacy of weed control has always been assessed and modelled using percent weed kill or the reduction of weed density (Cousens, 1985; Firbank and Watkinson, 1986), yet it has been conclusively shown that the relative growth rate of weeds, leaf area development and height extension, have a robust relationship with the competitiveness of weeds and their effect on crop yield (Kropff and van Laar, 1993). A study will be designed to provide insight into the possibilities of controlling the growth and competitiveness of weeds using reduced dosages of herbicides integrated with cultivation as a way of alleviating the severe labour bottlenecks suffered by smallholder farmers at peak weeding periods.

Aims and objectives of the study

The aim of the study is to develop low input cultural weed management strategies that can increase maize grain yields while reducing the impact of weeds and can easily be integrated within the smallholder farmer's day to day crop management system in Zimbabwe. The studies are broadly based on investigating the feasibility of enhance radiation interception by the crop to increase crop growth and yield and reduce radiation interception by weeds to reduce their germination and growth. The study also

examines the possibility to enhance the productivity of maize-pumpkin and maize-bean intercropping systems by detasselling and leaf stripping and examines the effect of interventions which reduce density and fitness of weeds (reduced herbicide dosages) on the growth and competitiveness of surviving weeds and their effects on final maize grain yield. Therefore, the unifying theme among the topics that are being collectively studied in this thesis is the analysis of weed crop interactions when cultural practices which shift the competitive advantage towards the crop and away from weeds are implemented in order to increase crop yields and at the same time reduce the weeding burden of smallholder farmers. The specific objectives are therefore:

- To study the effect of maize-pumpkin mixed cropping on the emergence and growth of weeds, yield of component crops and the requirement for hoe-weeding.
- To quantify the effects of leaf stripping and detasselling on radiant environment of a maize monocrop and maize-pumpkin intercrop canopy, weed emergence and growth and the yield of component crops.
- To quantify the effects of leaf stripping and detasselling on the radiant environment and productivity of a maize-bean intercrop and on weed emergence and growth.
- To study the effect of plant density and planting pattern in maize on the crop radiant environment, maize grain yield and weed emergence and growth.
- To study the effect of fertilizer and manure placement on maize radiant environment, growth and yield; and on weed emergence and growth.
- To determine the effect of reduced herbicide dosages on the growth and competitiveness of weeds and the critical weed free period in maize.
- To optimize weed management in the smallholder sector of Zimbabwe by integrating cultural weed management techniques that have an impact on weed-crop competition dynamics into the production practices of smallholder farmers.

Thesis structure

This chapter identifies the problem of poor weed management and low yields in the smallholder agricultural sector for maize-based cropping systems. Recent developments in Zimbabwe as they relate to land reform and the HIV/AIDS pandemic and their impact on productivity levels and weed management are presented to provide justification and a template on which the research problem and research objectives are developed. Chapter 2 presents results from a series of experiments carried out on the effects of maize-pumpkin intercropping on the yield of component crops and on the emergence and growth of weeds. Chapter 3 tests the hypothesis that removing lower senescing leaves and the tassel in maize at anthesis removes a potential competitive sink and evaluates potential benefits that accrue to maize grain yield after leaf

stripping and of detasselling in monocrop maize. Since leaf stripping and detasselling increases the incident PAR on a minor crop in maize-based intercropping systems, its effects on both the maize and the understorey crop in maize-pumpkin and maize-bean intercropping systems were studied. Chapters 4 and 5, therefore, explore the potential to increase the productivity of a maize-pumpkin and maize-bean intercrop, respectively, by leaf stripping and detasselling of the maize crop at anthesis. Since an increase in incident PAR into the understorey impacts the growth rate of weeds, weed biomass and seed production, these variables were assessed in both studies. Chapter 6 describes the effects of using narrow rows and high maize densities on PAR interception by the crop and weeds, maize grain yield, weed emergence and growth. The same theme of enhancing the rapidity of canopy closure is advanced in the next study reported in Chapter 7. The effects of method of fertilizer placement and rate of application on PAR interception by the crop and weeds, maize grain yield, weed emergence and growth were studied to derive insights into whether or not the method of applying fertilizer or manure will effectively contribute to weed management. Chapter 8 reports on various experiments carried out to assess the effects of reduced dosages of atrazine and nicosulfuron on weed survival and growth and maize grain yield. This study was carried out to determine the insights into the feasibility of smallholder farmers combining hoe-weeding with application of reduced herbicide dosages. Chapter 9 is the general discussion that provides a synthesis of the results of the studies in the general context of weed suppression and economic yield enhancement by cultural practices that enhance radiation interception by the crop and radiation deprivation to weeds on the soil surface. Finally, I propose how smallholder farmers can integrate cultural practices to maximize crop growth rates and yield potential while simultaneously suppressing weeds and reducing the labour requirements for weeding.

CHAPTER 2

Crop yield and weed growth in maize-pumpkin intercropping

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Abstract

Experiments on the effect of maize-pumpkin intercropping on weed growth and crop yield were carried out at the University of Zimbabwe farm, from 1995/96-1998/99. Maize grain yield was similar in sole maize and maize-pumpkin intercrop in three seasons when pumpkins were severely damaged by powdery mildew (*Sphaerotheca fuliginea*) and failed to provide a competitive challenge to maize. In the 1996/97 season when the pumpkin crop was protected from mildew by fungicide sprays, it significantly reduced maize grain yield by 20% averaged across the weeding frequency treatments. The results indicate that maize-pumpkin intercropping may fail to guarantee maintenance of maize grain yield equal to maize monocrop yields, an important criterion used by smallholder farmers to evaluate complementarity between crops that are used in intercropping. Intercropping pumpkin into maize consistently reduced weed biomass but its efficacy in reducing weed growth depended on the pumpkin density. At a pumpkin density of less than 20% of the maize density of 37,000 plants ha^{-1}, the intercrop reduced weed biomass equally well as sole maize but more effectively than sole pumpkin. At a pumpkin density of 33% of maize density, the intercrop reduced weed biomass by between 48% and 51% compared to sole maize and between 40% and 61% compared to sole pumpkin. One early weeding, in the intercrop, was able to contain weed biomass to become equal to weeding twice or thrice in the maize monocrop, showing that maize-pumpkin intercropping can reduce smallholder farmers weeding commitments. In the 1996/97 season, late weeding at 8 weeks after emergence (WAE) caused a greater maize grain yield loss in sole maize than in a maize-pumpkin intercrop and an unweeded intercrop pumpkin produced three times the pumpkin fruit yield of the monocrop pumpkins; suggesting that the maize-pumpkin intercrop was less dependent on early and frequent weeding to avert yield loss than monocrops of either of the component crops.

Key words: Maize, pumpkin, intercropping, weeding, weed biomass, plant density.

INTRODUCTION

In Southern Africa, intercropping is mainly practised by smallholder farmers (Natarajan and Shumba, 1990). The smallholder farmers routinely intercrop cereal staple food crops (maize, sorghum and millets) with cucurbits (pumpkin, squash, gourd and cucumbers), cowpeas, beans and groundnuts (Mariga, 1990). Gwanana and Nichterlein (1995) reported that pumpkin (*Cucurbita moschata* and *C. maxima*) was the most popular crop for intercropping with staple food cereals in Zambia. Pumpkins were grown by 100%, 95%, 48%, 56% and 40% of the smallholder farmers in the Southern, Central, Western, Eastern and Luapula provinces of Zambia, respectively. Pumpkins were the most widely grown cucurbit in Malawi and are often interplanted with other crops (Chigwe and Saka, 1994).

Pumpkins are largely grown for their leaves which are used as vegetables and fruit which is boiled and eaten as a dessert (Attere, 1984). In a survey in Zambia, Breeze (1986) found that pumpkin leaves were considered as the most important vegetable in the traditional diets, both as fresh vegetables and in the dried preserved form. Male flowers, produced in large numbers by the monoecious pumpkin, are also consumed together with the leaves (Chigwe and Saka, 1994). Pumpkins play an important role in the nutrition of rural communities in Southern Africa because they supply edible organs starting in the early season when other vegetables are out of season (Gwanana and Nichterlein, 1995). The early season is sometimes called the 'hunger season' because it is the period when many farmers have depleted their food reserves (Morna *et al*., 1993). Pumpkins contain high levels of calcium, iron, and vitamin A. Chandarasekhar *et al.* (2000) reported that pumpkin leaves had the highest amount of beta-carotene in a form that promoted its absorption in adults, among selected green vegetables. Beta-carotene is a precursor of vitamin A. Conventional cooking and blanching resulted in an increase in the concentration of pro-vitamin A carotenoids in pumpkin and cowpea leaves in Tanzania (Mosha *et al*., 1997). Vitamin A deficiency is an important public health problem in developing countries, including Zimbabwe (Ncube, 2001) that increased consumption of easily available vegetables such as pumpkin leaves could alleviate (Chandarasekhar *et al*., 2000). Pumpkin seeds, contain 20-55% oil rich in unsaturated fatty oleic and linoleic acid and 23-35% protein, rich in arginine, aspartate and glutamine but are deficient in lysine and sulphur containing amino acids. Pumpkin seeds are eaten in the dry season as a snack after roasting or grinding into butter (Gwananan and Nichterlein, 1995). Pumpkins are, therefore, an important source of nutrients for the rural communities and as a bridging source of food security in times of scarcity before the next crops are harvested.

Besides their nutritional value, pumpkins may have other benefits when inter-

cropped with staple cereal crops. Being a prostrate, vining and dense crop, pumpkins have the potential to act as live mulch, suppressing weed germination and growth, and reducing loss of moisture from the soil, under the cereal canopy. Studies at the International Institute of Tropical Agriculture (IITA) demonstrated that 'Egusi melon' (*Cucumeropsis manii* (Naud), a crop with a growth habit similar to pumpkins, when interplanted with maize at 20,000 plants ha^{-1}, suppressed weeds and reduced early weeding from two-three times to once per season (Akobundu, 1993). Intra-row intercropping is commonly used by smallholder farmers because it saves time since the two crop seeds are mixed and dribbled together into the planting furrow. Nyakanda *et al*. (1995) found no yield differences in intra- and inter-row intercropped groundnuts with maize. Despite the importance of pumpkins in the smallholder sector in Southern Africa, little research has been done on this crop (Chigwe and Saka, 1994).

Three hypotheses were tested in this study (a) the ability of the maize-pumpkin intercrop to suppress weeds increases with increase in pumpkin density with little or no maize yield loss and (b) pumpkins intercropped into maize reduce the weeding requirements of the maize crop (c) overall productivity as quantified by Land Equivalent Ratio (LER) analysis (Mead and Willey, 1980) is increased in maize-pumpkin intercrops above that of the component sole crops.

MATERIALS AND METHODS

Experiments on maize-pumpkin intercropping were conducted over a four season period from the 1995/96 season to the 1998/99 season at the University of Zimbabwe farm, 14 km north-west of Harare, on red fersiallitic clay soils.

In all four seasons, maize and pumpkin were intra-row intercropped with simultaneous sowing in the month of December. The land was prepared by disc ploughing and harrowing the soil to a fine tilth. Compound D fertilizer (8% N, 14% K_2O, and 7% P_2O_5) was applied into the planting station at 300 kg ha^{-1} in all seasons. In the first experiment, ammonium nitrate (34.5% N) was side dressed on the maize at 8 weeks after planting (WAE) at 187 kg ha^{-1}. In the second and third season, ammonium nitrate was side dressed on the maize at 300 kg ha^{-1}, half of which was applied at 4 weeks after emergence (4 WAE) and the other half at 8 WAE.

Experiment 1

A drought tolerant short season maize cultivar, R201, planted at a between rows and within spacing of 90 cm and 30 cm (37,000 plants ha^{-1}), respectively, was intra-row intercropped with a local pumpkin landrace, Nzunzu, in the 1995/96 season. Pumpkin plants were established at a spacing of 90 cm × 151 cm, 90 cm × 303 cm and 90 cm ×

606 cm either as a sole crop or intra-row interplanted with the maize, to give densities of pumpkins equivalent to 20%, 10% and 5% of the maize density, respectively. Two sole maize treatments were included in the experiment, one kept weed free throughout the season and the other weeded once at 8 WAE. All other treatments were weeded once at 8 WAE. No preventative or curative measures against powdery mildew (*Sphaerotheca fuliginea*) were implemented.

The treatments were arranged in a randomized complete block design with three replications. Gross plots were 7.2 m × 7.2 m and net plots, where measurements were taken were 4.5 m × 5.2 m. Weed densities and biomass were assessed at 12 WAE. Five 30 cm × 30 cm quadrants were randomly thrown into each net plot and weeds counted by species. The weeds were cut at ground level and placed in brown paper bags, oven-dried to constant mass at 80 °C, and weighed. Maize grain yield and pumpkin fruit yields (fresh weight) were measured after maize physiological maturity, at 24 WAE.

Experiment 2

In the 1996/97 season, a 3 × 4 factorial experiment was set up in a randomized complete block design with treatments replicated three times. The two factors tested in the experiment were cropping system (C) and weeding regime (W). Cropping system had three levels designated as

- C_1 - sole maize,
- C_2 - maize-pumpkin intercrop, and
- C_3 - sole pumpkin.

The weeding regime factor had four levels designated as

- W_0 - unweeded (control),
- W_1 - weeding at 3 WAE (early weeding),
- W_2 - weeding 8 WAE (late weeding), and
- W_3 - weeding at 3, 8 and 12 WAE (frequent weeding).

Pumpkin was planted at 0.9 m × 1.5 m, in every second maize row, achieving a density of approximately 20% of the maize density. A medium-season maize cultivar SC 501 was intercropped with a commercial pumpkin cultivar, Flat White Boer. Weed density and biomass were assessed as in Experiment 1, at maize physiological maturity, 24 WAE. Preventive and curative fungicide sprays (Mancozeb, Dithane M-45) were applied to the pumpkins when required to control powdery mildew (*Sphaerotheca fuliginea*).

Experiment 3

In the 1997/98 season, a 3 × 4 factorial experiment was carried out in randomized complete block design similar to Experiment 2 in the previous season. One difference

was introduced in the weeding treatments. The late weeding treatment (W_2 - weeding at 8 WAE) was replaced with normal farmer practice of weeding at 3 and 8 WAE. Thus, in Experiment 3 there was an increasing intensity of weeding:

- W_0 - unweeded control,
- W_1 - weeding at 3 WAE (early weeding),
- W_2 - weeding at 3 and 8 WAE (farmer practice), and
- W_3 - weeding at 3, 8 and 12 WAE (frequent weeding).

In the 1997/98 season, the commercial pumpkin cultivar, Flat White Boer, was interplanted with Pan 87, a medium season maize cultivar. Pumpkin was planted at 0.9 m × 0.9 m in the maize row achieving a density of approximately 12,600 plants ha^{-1} equivalent to 33% of the maize density. Gross plots were 8.1 m × 8.4 m and net plots were 4.5 m × 4.8 m. Weed density and biomass was measured as in Experiment 2. No preventive or curative fungicidal sprays against powdery mildew were applied.

Experiment 4

Experiment 4 in the 1998/99 season was similar in all respects to Experiment 3, in the previous season, except that only two weeding regime treatments were implemented instead of four:

- W_1 - weeding 3 WAE (early weeding), and
- W_2 - weeding at 3 and 8 WAE (farmer practice).

Analysis of data

All data was subjected to analysis of variance (ANOVA) using the SAS (1999) statistical package (Release 8, Cary, NC, USA). All weed density data was expressed as number m^{-2} and square root transformed before analysis (Steel and Torrie, 1984). Maize grain yield data was standardized to 12.5% moisture content. The overall productivity of the intercropping system in comparison with monocrops of either of the two component crops was analysed using Land Equivalent Ratios (LER) as described by Mead and Willey (1980). Partial LERs (pLER) were calculated for each component crop to indicate the contribution of each component crop to the productivity of the intercropping system. The pLERs were calculated by comparing the intercrop yield of each of the component crops to the yield of the monocrop that had received an equivalent weeding treatment. The gross monetary value of crop products was calculated by multiplying the yield with the then current market price of maize (US$ 162.50 per metric tonne) and pumpkins (US$ 0.375 per kg) in June 2003. Market prices fluctuate according to when the crops are sold (Mkamilo, 2004). Standard errors of difference (Sed) are used for mean separation where treatment effects were significant at $P<0.05$. Standard errors of the difference are shown as error bars in the charts.

RESULTS

Component crop yields

Maize grain yield

Maize grain yield was not statistically (P>0.05) influenced by cropping system in three out of the four seasons (Fig. 1). The exception was in the 1996/97 season, when sole maize significantly (P<0.01) out yielded the maize-pumpkin intercrop by 20% (Fig. 1). Averaged across the cropping system treatments, the frequency of hoe weeding (weeding regime) significantly influenced (P<0.05) maize grain yield in the 1996/97 and 1997/98 seasons and had no effect (P>0.05) in the 1998/99 season (Fig. 2). In the 1997/98 season, there was no significant additional maize grain yield benefit that accrued from increasing the weeding frequency from once (at 3 WAE), to twice (at 3 and 8 WAE) or thrice (at 3, 8 and 12 WAE). The weeded treatments had significantly higher maize grain yield than the unweeded treatment in the 1997/98 season (Fig. 2). In the 1996/97 season, maize grain yield was lower in the unweeded treatment by 40%, 46% and 58% than in the late weeded (at 8 WAE), early weeded (at 3 WAE) and the frequently weeded treatment (at 3, 8 and 12 WAE) (Fig. 2). However, these effects are confounded in a significant (P<0.01) weeding regime and cropping system interaction on maize grain yield in the 1996/97 season (Fig. 3).

The effectiveness of early compared to late weeding in preventing maize grain yield loss differed between maize in monoculture and maize grown in an intercrop with pumpkin in the 1996/97 season, hence the interaction (Fig. 3). In the monocrop, early weeding raised yield to a level not significantly different from the frequently weeded plots, weeded thrice. Late weeded plots of monocropped maize had yields that were
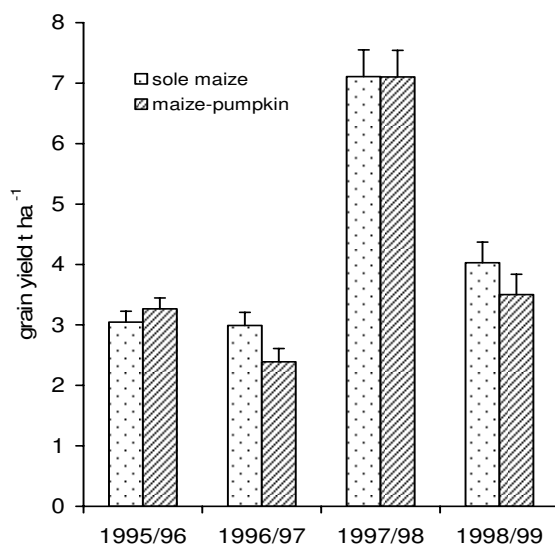
Figure 1. Effect of cropping system on maize grain yield in four seasons.
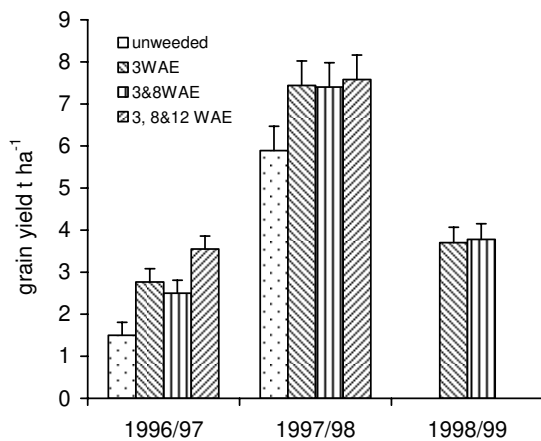
Figure 2. Effect of weeding regime on maize grain yield in three seasons. (Note: in the 1996/97 season the third column was only weeding at 8 WAE).
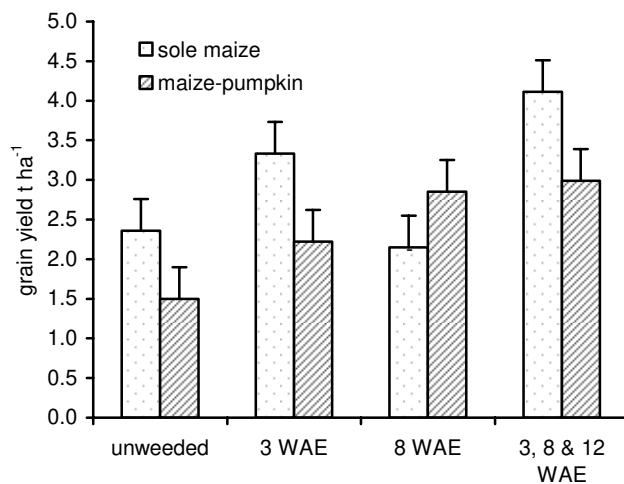
Figure 3. Interaction between cropping system and weeding regime on maize grain yield in the 1996/97 season.

similar to the unweeded plots, and significantly lower than in plots weeded early or frequently (Fig. 3). In the intercrop, the effects of weeding were smaller in the absolute sense than in maize monocrops. In the maize-pumpkin intercrop, early and late weeding had similar efficacy in maintaining yield (Fig. 3), suggesting that the pumpkin intercrop sufficiently suppressed weeds that reduced yield in late weeded sole maize.

Pumpkin fruit yield
Pumpkin fruit yields were significantly greater in the sole pumpkin crops than in the maize-pumpkin intercrops in the 1996/97 season (Fig. 4). Pumpkin yield completely failed in the 1997/98 season because of severe powdery mildew damage. In the 1995/96 season, pumpkin fruit yield was only recorded in the sole pumpkin treatments and was nil in the maize-pumpkin intercrops (Table 1) due to powdery mildew that

was more severe in the intercrop than in the pumpkin monocrops. In the 1996/97 season pumpkin fruit yield in the maize-pumpkin intercrop was less than half of that in sole pumpkin (Fig. 4). There was no difference in pumpkin fruit yield (P>0.05) between the intercrop and sole pumpkin in the 1998/99 season (Fig. 4), when yields of less than a ton ha^{-1} were achieved because of high levels of mildew.

Results in the 1996/97 season show that pumpkin fruit yield was depressed in unweeded treatments to approximately 14% of weeded treatment yields, averaged across the cropping system (Fig. 5). There was a significant (P<0.05) cropping system and weeding regime interaction on pumpkin fruit yield. The effect of not weeding was more severe in the sole pumpkin crop than in the maize-pumpkin intercrop. Pumpkin fruit yield was reduced to 0.3 and 0.9 t ha^{-1} by not weeding a sole pumpkin crop and a maize-pumpkin intercrop, respectively (Fig. 5). Weeding early in the season (at 3 WAE) produced significantly higher pumpkin fruit yields than weeding late (at 8 WAE) and weeding more frequently (at 3, 8 and 12 WAE) in 1996/97 season. Pumpkin fruit yields were similar between the two weeding regimes in the 1998/99 season (data not shown).
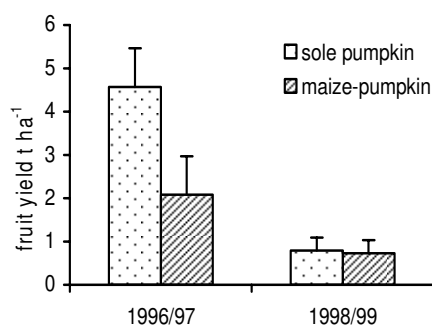
Figure 4. Effect of cropping system on pumpkin fruit yield in two seasons.

Figure 5. Interaction between cropping system and weeding regime on pumpkin fruit yield in the 1996/97 season.

Table 1. Land Equivalent Ratio (LER) and Net Monetary Return of treatments in maize-pumpkin intercropping. 2003 maize price is Z\$ 130,000 t^{-1} equivalent to US\$ 162.5 t^{-1}. June 2003 pumpkin price is Z\$ 300.00 kg^{-1} (US\$ 0.375). Official exchange rate used for customs and exercise duties in Zimbabwe is 1 US\$=Z\$ 800.00.
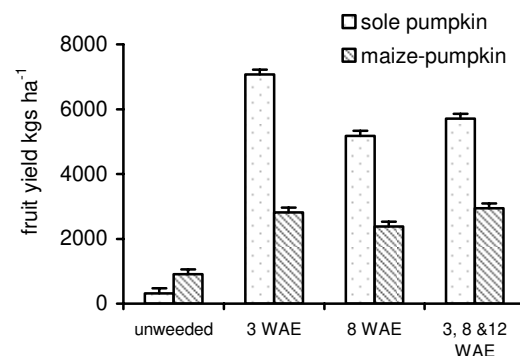
Treatment	Maize grain yield (kg ha^{-1})	Pumpkin fruit yield (kg ha^{-1})	pLER maize	pLER pumpkin	LER	Gross return (US\$ ha^{-1})
1995/96 season						
Sole maize						
Clean weeded (thrice)	3393	-	1.11[a]	-	-	551.36
Weeded at 8 WAE	3047	-	1.00	-	-	495.14
Maize-pumpkin intercrop						
Pumpkin density						
5% of maize density	3369	0	1.10	0	1.10	547.46
10% of maize density	3252	0	1.02	0	1.02	528.45
20% of maize density	3181	0	1.04	0	1.04	516.91
Sole pumpkin						
Pumpkin density						
5% of maize density		705.41	-	0.50	-	264.53
10% of maize density		1179.90	-	0.99	-	442.46
20% of maize density		1193.40	-	1.00	-	447.25
1996/97 season						
Sole maize						
Weeding treatments						
Unweeded	2360	-	1.00[b]	-	-	383.15
3 WAE	3330	-	1.00	-	-	541.13
8 WAE	2150	-	1.00	-	-	349.38
3, 8 & 12 WAE	4110	-	1.00	-	-	667.88
Maize-pumpkin intercrop						
Weeding treatments						
Unweeded	1500	910	0.63	2.88	3.48	585.00
3 WAE	2200	2810	0.66	0.40	1.06	1411.25
8 WAE	2850	2380	1.33	0.46	1.79	1193.91
3, 8 & 12 WAE	2990	2940	0.73	0.51	1.24	1561.38
Sole pumpkin						
Weeding treatments						
Unweeded	-	320	-	1.00	-	120.00
3 WAE	-	7070	-	1.00	-	2651.25
8 WAE	-	5180	-	1.00	-	1940.50
3, 8 & 12 WAE	-	5710	-	1.00	-	2141.25
1997/98 season						
Sole maize						
Weeding treatments						
Unweeded	5990	-	1.00[b]	-	-	937.88
3 WAE	7150	-	1.00	-	-	1161.88
3 & 8 WAE	7560	-	1.00	-	-	1228.50
3, 8 & 8 WAE	7720	-	1.00	-	-	1254.50
Maize-pumpkin intercrop						
Weeding treatments						
Unweeded	5980	0	0.99	0	0.99	971.75
3 WAE	7720	0	1.08	0	1.08	1254.50
3 & 8 WAE	7240	0	0.96	0	0.96	1176.50
3, 8 & 12 WAE	7430	0	0.96	0	0.96	1207.38
1998/99						
sole maize	4030		1.00	-		568.75
maize-pumpkin intercrop	3500	730	0.87	0.92	1.79	842.50
sole pumpkin	-	790	-	1.00		296.25

[a] Maize yields are compared to the maize yield when the crop was weeded once at 8 WAE to allow direct comparison with all maize-pumpkin intercrops weeded once at 8 WAE in the 1995/96 season.

[b] Maize and pumpkin yields are compared each to its equivalent weeding treatment in calculating partial LERs for the 1996/97 and 1997/98 seasons.

Intercrop productivity and value of crop products

The productivity of the maize-pumpkin intercropping system in the 1996/97 and 1998/99 seasons, when pumpkin fruit were harvested in the intercropped treatments, was greater than that of the monocrops as shown by the LER values that varied from 1.04 to 3.48, according to weeding treatment (Table 1). The maize pLER of 0.63 to 0.87 in the various weeding treatments in the 1996/97 and 1998/99 seasons showed that the maize yield was generally depressed by 13-37% in the presence of pumpkin in the two seasons. There was one exception to this trend, reflected in the interaction between cropping system and weeding regime on maize grain yield in the 1996/97 season when maize grain yield increased by 33% in the maize-pumpkin intercrop compared to the monocrop, with late weeding (at 8 WAE) (Table 1). This result suggests that pumpkin protected the maize against damage from late weeded weeds. The results also show that in seasons in which pumpkin fruit yield failed in the intercrop, pumpkins did not present any credible competitive challenge to maize as maize grain yields were not different in the maize-pumpkin intercrops and the maize monocrops. This is shown by the pLER of maize slightly greater than unity in the 1995/96 season and slightly lower than unity in the 1997/98 season (Table 1), when pumpkins were severely damaged by mildew and failed to produce fruit.

The pLER for pumpkin shows that pumpkin fruit yield was reduced by between 49 and 60% as weeding intensity was increased from once to thrice per season, by maize-pumpkin intercropping in the 1996/97 season. However, in the unweeded treatment, pumpkin fruit yield was superior by 288% in the maize-pumpkin intercrop than in the pumpkin monocrop. This accounts for the high overall LER of this treatment in the 1996/97 season (Table 1). Pumpkin fruit was marginally depressed by 8% in the maize intercrop compared to the monocrop in the 1998/99 season (Table 1).

Gross monetary return (Gmr) of the treatments followed the total yield of the two crops. In the 1995/96 season, Gmr was generally similar in the sole maize and maize-pumpkin intercrop treatments and lowest in the sole pumpkin crops (Table 1). In the 1996/97 season, Gmr was lowest in sole maize, intermediate in the maize-pumpkin intercrop and was highest in sole pumpkin, at each weeding treatment (Table 1). Gmr was similar, at each weeding regime treatment, in sole maize and maize-pumpkin intercrop in the 1997/98 season because of the failure of the pumpkin crop to produce pumpkin fruits and its non-interference with the growth of maize. Gmr was highest in the maize-pumpkin intercrop and lowest in the sole pumpkin crop in the 1998/99 season (Table 1).

Weed density and biomass

There was no effect (P>0.05) of cropping system (sole maize, maize-pumpkin

intercrop, sole pumpkin) on weed density during the four seasons (data not shown). Cropping system had a significant effect (P<0.05), however, on weed biomass consistently across the four seasons (Fig. 6). In the first two seasons when pumpkin density was below 20% of maize density, the efficacy of the pumpkins in suppressing weed growth in the pumpkin sole crops and maize-pumpkin intercrops was lower than in the last two seasons when pumpkin density had been increased to 33% of the maize density of 37,000 plants ha^{-1} (Fig. 6). Weed biomass was nearly twice as high in sole pumpkin as the maize-pumpkin intercrop or sole maize in 1995/96 and 1997/98, when pumpkin density was below 20% of maize density. There was no significant difference in weed biomass between sole maize and maize-pumpkin intercrop in 1995/96 and 1996/97 (Fig. 6). Weed biomass was reduced by 40% and 48% in the maize-pumpkin intercrop compared to sole pumpkin and sole maize, respectively in 1997/98 (Fig. 6). A similarly large effect of maize-pumpkin intercropping on weed biomass was recorded in the 1998/99 season, with the maize-pumpkin intercropping suppressing weed growth by 51% and 61% compared to sole maize and sole pumpkin, respectively (Fig. 6). When the pumpkin density is increased to 33% of the maize density of 37,000 plants ha^{-1} in the 1997/98 and 1998/99 seasons, the ability of the sole pumpkin to suppress weed growth approached that of the sole maize (Fig. 6). By comparison, sole pumpkin distinctly stood out as the least able crop to suppress weed growth in the two previous seasons when pumpkin density was lower than 20% of the maize density (Fig. 6).

There was a significant cropping system × weeding regime interaction on weed biomass in the 1997/98 and 1998/99 seasons. In the 1997/98 season, the significant interaction (P<0.05) between weeding regime and cropping system is illustrated by differences in the effectiveness of weeding in reducing weed biomass in sole maize
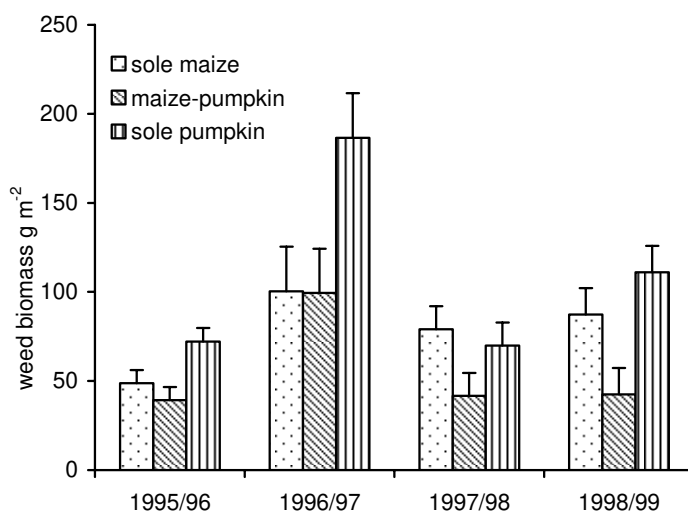
Figure 6. Effect of cropping system on weed biomass in four seasons.
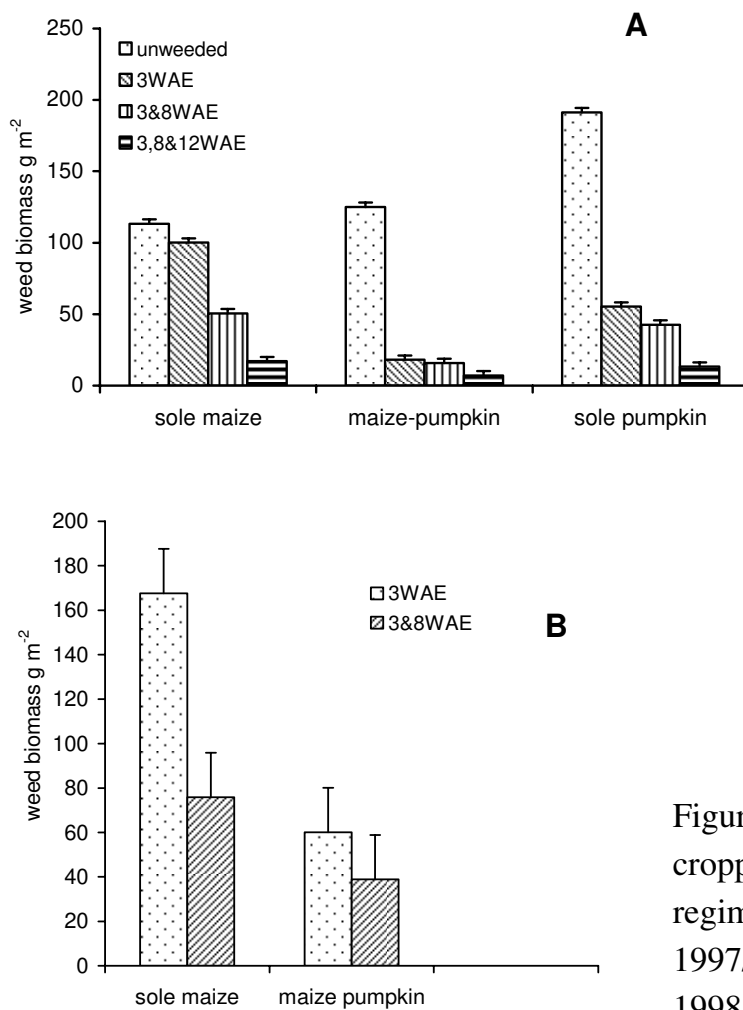
Figure 7. Interaction between cropping system and weeding regime on weed biomass in (A) the 1997/98 season and in (B) the 1998/99 season.

and sole pumpkin in comparison to the maize-pumpkin intercrop. It required the sole maize and the sole pumpkin crop to be weeded thrice (at 3, 8 and 12 WAE) to attain the same weed biomass as a maize-pumpkin intercrop weeded once (at 3 WAE) (Fig. 7a). Similarly, in the 1998/99 season, weeding twice, at 3 and 8 WAE, was required in sole maize to bring weed biomass to the same level as in a maize-pumpkin intercrop weeded once at 3 WAE (Fig. 7b).

DISCUSSION

Yield of component crops and intercrop productivity

A major priority of smallholder farmers in maize-legume or maize-cucurbit intercropping is the maintenance of maize grain yields similar to maize monocrop yields and to reap additional benefits in the form of consumable products (leaves, pods, small fruits) during the season and the economic yield from the minor crop at the

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end of the season (Mariga, 1990; Mutangamiri *et al*., 2001). Maize is prioritized by the smallholder farmers to secure the basic food requirements of the household (Mkamilo *et al*., 2004).

The results of this study showed that maize grain yield was not significantly reduced by maize-pumpkin intercropping in three out of four seasons. However, these three seasons were characterized by either zero or low pumpkin fruit yields as a result of the high levels of infection of the pumpkins by powdery mildew (*Sphaerotheca fuliginea*). In the 1996/97 season, when credible pumpkin fruit yields were produced, pumpkins showed their potential to compete for resources with maize by decreasing maize grain yield by 27-37% according to weeding regime (Table 1). These results suggest powdery mildew played a significant role in the competitive relationships between pumpkin and maize in this study. Powdery mildew caused premature necrosis of the pumpkin foliage before pumpkin plants could produce fruit. Pumpkins were, therefore, unable to compete with the maize for available resources because of the damage caused by powdery mildew infection in these three seasons. The results in the 1996/97 season when powdery mildew was controlled by fungicide show that pumpkins when interplanted with maize, unaffected by powdery mildew, are able to cause a significant grain yield depression in maize. Our results suggest that complementarity of the two crops according to the criterion of prioritizing cereal food security, as specified by smallholder farmers, is not guaranteed in a maize-pumpkin intercropping system. However, the LERs of 1.06 to 3.48 obtained in the 1996/97 and 1998/99 seasons, when pumpkin fruits were harvested, show a higher efficiency of utilization of available resources in the environment in the maize-pumpkin intercrops than monocrops of either of the component crops. Similar results have been reported by Benedict (1983), Silwani and Lucas (2002), Chaves (1988), and Hernandez and de Los (1997) in maize-pumpkin intercropping systems. Despite the potential for a significant decrease in maize grain yield, smallholder farmers can still benefit from the increased productivity and monetary returns when they intercrop maize and pumpkin (Table 1).

The maize-pumpkin intercrop reduces weed biomass

The lack of effect of cropping system on weed density in four seasons is largely similar to what other workers working with live mulch crops have observed. Live mulch crops may not affect weed density because they take time to attain full ground cover but instead affect weed biomass (Nyakanda *et al*., 1995; Mugabe *et al*., 1989), similar to what was observed in this study.

Weed biomass was significantly reduced by maize-pumpkin intercrops throughout the four seasons but the extent of suppression of weed growth depended on pumpkin

density. Results in the first two seasons, when pumpkin density was less than 20% of the maize density, lend themselves to the interpretation that maize was the dominant crop in suppressing weed growth. This is because it apparently did not matter whether pumpkin was present or not, the same weed weights were obtained in the sole maize and the maize-pumpkin treatments. The increase in pumpkin density to 33% of maize density in 1997/98 and 1998/99 seasons increased the density of the combined foliage of the maize and pumpkin and allowed attainment of ground cover earlier than the sole maize crop. This explains the observed increased capacity of the intercrop to suppress weed growth that was 50% more than that exhibited by either of the monocrops. Smallholder farmers should, therefore, plant pumpkins at or above 33% of the maize density to take advantage of the pumpkin suppressive effects on weed growth.

The interaction between weeding regime and cropping system on weed biomass observed in the 1997/98 and 1998/99 seasons clearly shows that there is potential to reduce weeding frequency by two-thirds in the intercrop compared to the sole crop of either of the companion crops but still attain a similar weed biomass. Smallholder farmers who routinely intercrop maize and pumpkin could, therefore, save on weeding by one- to two-thirds provided they achieved a minimum pumpkin density of 12,600 plants ha^{-1} in a maize stand of 37,000 plants ha^{-1}. Studies at the International Institute of Tropical Agriculture (IITA) have demonstrated that 'Egusi melon' (*Cucumeropsis manii*, Naud) interplanted with maize at 20,000 plants ha^{-1}, suppressed weeds, and reduced early weeding to once instead of 2-3 times (Akobundu, 1993). Obiefuna (1989) reported on an increase in the capacity of melons to suppress weed growth in plantains with increased melon density. Melons (*Colocynthis citrullus*) planted at the highest density (10,000 melons ha^{-1}) rapidly covered the ground in 20 days and effectively suppressed weed competition for seven months after planting in plantains in Nigeria. The density-dependent effects on weed biomass reported by Akobundu (1993) and Obiefuna (1989), on melons, a crop with a prostrate and vining growth and canopy architecture similar to that of pumpkins, concurs with the findings of this study.

Weeds cause less damage to yield of component crops in the intercrop

There was an interaction between cropping system and weeding regime on maize grain yield in the 1996/97 season. The results can be interpreted as follows: pumpkin suppressed weed competition in the maize-pumpkin intercrops without forming a strong competitive threat to maize grain yield formation when the crop was weeded late, at 8 WAE. This resulted in late weeded maize having similar yield to early weeded (at 3 WAE) and frequently weeded maize (at 3, 8 and 12 WAE) in the maize-pumpkin intercrop. In contrast, in the maize monocrop, late weeding was associated

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with a 35% and 48% maize grain yield reduction compared to the early and frequently weeded treatment, respectively (Fig. 3). The weed biomass in the maize-pumpkin intercrop (20.3 g m^{-2}) was less than half of the amount measured in the sole maize (52.3 g m^{-2}) in 1996/97. The weed biomass in the unweeded pumpkin was 44% greater in the sole pumpkin crop (399.7 g m^{-2}) than the maize-pumpkin intercrop (222.8 g m^{-2}) in the 1996/97 season. It appears, therefore, that the considerable suppression of weed growth in the intercrops in treatments where weed management tactics were applied late (maize weeded at 8 WAE) or not at all (unweeded pumpkin), protected the maize and the pumpkin, respectively, from the yield-reducing effects of weeds. This result was obtained in one season only and additional experiments are required to verify its generality. If proven to be common and consistent occurrence in intercrops, this property of intercrops could be exploited by smallholder farmers to spread their weeding efforts over a longer period of time, allowing them to manage well a larger acreage of their maize crop than would be possible when they grow maize in monoculture (requiring early weeding).

Leaf stripping and detasselling increase maize grain yield

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Abstract

Experiments were conducted in the 1998/99 and 1999/00 seasons at the University of Zimbabwe farm to determine the effects of detasselling and leaf stripping on maize grain yield. Detasselling increased maize grain yield by 11.2-12.2% while the effect of leaf stripping on grain yield depended on timing. Leaf stripping at anthesis (50% silking), at 12 WAE (weeks after emergence), increased maize grain yield by 16.6% and 28% compared to the unstripped control in the 1989/99 and 1999/00 seasons, respectively. Leaf stripping three or four weeks before or after anthesis had no significant effect on maize grain yield. There was a significant interaction between detasselling and leaf stripping on maize grain yield in the 1999/00 season. Detasselling only increased maize yield when leaf-stripping effects were absent. These results suggest that detasselling and leaf stripping affect the same processes of embryo formation and grain filling in maize grain yield formation. Maximum photosynthesis, nitrogen content and dry weight of stripped leaves suggested that leaf stripping at anthesis increased maize grain yield by removing leaves that were beginning to senesce competing for resources with the embryo formation and grain filling process if they remained on the plant. Detasselling increased radiation interception (RI) by sub-tassel leaves and by the cob leaf by 10-28% and 5-27%, respectively. A reduction in apical dominance by the tassel and the increased RI at the critical three-week period bracketing anthesis most probably accounted for the observed maize grain yield increases caused by detasselling in this study.

Key words: Leaf stripping, detasselling, radiation interception, grain yield.

INTRODUCTION

The domestication of the maize plant (*Zea mays* ssp. *mays*) from its wild ancestor *teosinte (Zea mays* ssp. *parviglumis*) was accompanied by an increase in apical dominance which concentrates resources in the main stem and apex of the plant with a corresponding suppression of axillary branches (Iltis, 1983; Doebley *et al.*, 1997). In maize one or more of the topmost axillary branches develops into the female part of the plant (Lejeune and Bernier, 1996), which on pollination produces the economic yield of maize, the maize grain. Apical dominance in maize during the reproductive stages is expressed through the tassel. The tassel is the centre for the production of indole-acetic acid (IAA), which mediates the partitioning of photo-assimilates in favour of the main stem and apex at the expense of the developing axillary buds (ears) (Medford and Klee, 1989; Damptey, 1982). Selection for small tassels that impose little apical dominance on the developing ear has been proposed to increase maize grain yield (Paterniani, 1981). Garnier *et al.* (1993) demonstrated a strong negative (−0.88) correlation between tassel weight and maize grain yield. Detasselling, the removal of the tassel after its emergence, is an option available to smallholder farmers, to improve maize yield by reducing the apical dominance effect and by increasing the penetration of radiant energy into the canopy (Subedi, 1996; Mostert and Marais, 1982).

Leaf stripping, i.e., the removal of lower leaves from the maize plant at anthesis or post-anthesis, increases radiant energy penetration to the understorey crop in intercropping (Subedi, 1996) and can provide fodder to feed animals (Dzowela, 1985). Photosynthesis occurs in the leaf and the leaf is the source of photo-assimilates from which partitioning occurs to the sinks that are proximal to this source and which show the highest sink demand. In maize, upper leaves export principally to the shoot apex, middle leaves to both the shoot apex and the roots and lower leaves to the roots. A fully expanded leaf under conducive environmental conditions for photosynthesis may export 60-80% of the total assimilates it produces to other parts of the plant (Gardner *et al.*, 1985). With time, the leaves undergo senescence, and in grasses this begins at the lower older leaves and progresses up the plant. At some time during this process, the leaf may fail to support its own energy requirements because of a reduction in net photosynthesis due to senescence and/or shading. Contribution of assimilates from bottom leaves declines progressively with senescence (Gardner *et al.*, 1985) and possibly the senescing leaves become net importers of assimilates from other parts of the plant, in competition with the developing maize embryos and grain filling. We, therefore, hypothesize that removing senescing leaves (leaf stripping) during the reproductive stages in maize has potential to increase yield.

Detasselling and leaf stripping have potential to increase the yield of a minor crop, intercropped with a tall cereal crop, by increasing photosynthetically active radiation (PAR) intercepted by the minor crop (Subedi, 1996). The two experiments reported on in this chapter were part of a wider study to determine the effect of detasselling and leaf stripping on the radiant environment and yield of component crops in maize-pumpkin and maize-bean intercropping systems. If leaf stripping and detasselling increased yield in maize, then it would be an added benefit that would accrue to smallholder farmers that leaf-strip and detassel to increase the yield of the minor crop. Only one previous study (Subedi, 1996) has attempted to quantify the effects of detasselling and leaf stripping simultaneously on maize yield and demonstrated benefits to maize grain yield with detasselling but not with leaf stripping, in a maize-finger millet (*Eleusine coracana* (L.) Gaertn.) intercropping system. There was no testing of the effect of timing and intensity (number of leaves stripped) of leaf stripping in the study by Subedi (1996). We hypothesize that timing and intensity of leaf stripping are important factors in determining the effects of leaf stripping on maize grain yield in view of the anticipated competition for assimilates that will occur when lower leaves in the canopy senesce and are shaded by the upper leaves after anthesis.

The aim of this study was to determine the effect of detasselling and timing and intensity of leaf stripping on the radiant environment and yield of monocrop maize. The results would provide insight into the effects of leaf stripping and detasselling on tropical maize varieties used by smallholder farmers in Zimbabwe and allow optimization of these processes for application in mixed cropping systems. Hypotheses tested during the study were (a) leaf stripping and detasselling will increase maize grain yield and (b) timing of leaf stripping is important in determining the effect of leaf stripping on maize grain yield.

MATERIALS AND METHODS

Experiments on the effect of detasselling and leaf stripping were conducted at the University of Zimbabwe farm in 1998/99 and 1999/00. The University of Zimbabwe farm is 14 km to the north-west of Harare, at an altitude of 1500 m above sea level, on fersiallitic red clay soils with more than 40% clay and an annual rainfall average of 800-1000 mm. In both seasons, the land was disc-ploughed and disc-harrowed to a fine tilth and planting furrows were opened at 90 cm spacing in November, unless stated otherwise. Two maize seeds were dropped into the planting furrows at 30 cm spacing to achieve a maize density of 37,000 plants ha^{-1} after thinning. Basal fertilizer (compound D, 8% N, 14% K_2O, 7% P_2O_5) was banded into the open planting furrows at 300 kg ha^{-1}, before seeding in all seasons. Ammonium nitrate (34.5% N) was side-

dressed on the maize plants at 300 kg ha^{-1}, half of which was applied at 4 WAE (weeks after emergence) and the other half at 8 WAE.

Experiment 1 (1998/99 season)

A 3 × 3 factorial experiment with three replications was set up in a randomized complete block design. The first factor was the intensity of leaf stripping with three levels viz. stripping four bottom leaves, stripping four alternate bottom leaves and stripping six bottom leaves. The second factor, timing of leaf stripping had three levels viz. stripping at 9 WAE, 12 WAE and at 15 WAE. Superimposed on this factorial design was detasselling treatment achieved by detasselling half of each plot. A short season three-way maize hybrid, Pan 67 obtained from Pannar Seeds® and recommended for the smallholder sector in Zimbabwe, was planted. The crop was hoe-weeded twice, at 4 and 8 WAE.

Leaf stripping was accomplished by cutting the required leaves at 9, 12 and 15 WAE. The leaves were cut at the junction between the leaf sheath and the stem, oven-dried to a constant weight at 80 °C, and weighed. A representative sample of ground leaves from each treatment was analysed for nitrogen content using the Kjeldahl method.

PAR penetration into the canopy was determined by placing Li-Cor 191-SA line quantum sensors (Li-Cor, Lincoln, Nebraska, USA) at four levels in the canopy: ground level, cob level, just below the tassel and above the tassel. The PAR measurements were taken, next to the maize stems, at 15 WAE. Measurements were made at three positions at 2, 4 and 6 m along the middle row of each treatment plot. The average PAR reading from the three positions was analysed.

Detasselling of half of all plots was done when 50% of all plants had produced silks (50% silking), at 12 WAE. Tassels were grabbed and pulled upwards leaving all the upper maize leaves intact.

The gross plot was 4.5 m wide and 7.5 m long having five rows of maize at 90 cm spacing. The net plot was 2.7 m wide and 6.0 m long consisting of three rows. Maize cobs from the net plot were hand-harvested and shelled and moisture content of the grain was measured using a moisture meter. Maize grain yield was standardized to 12.5% moisture before analysis.

Experiment 2 (1999/00 season)

The second experiment in the 1999/00 growing season was set up as a 3 × 2 factorial in a randomized complete block design at the University of Zimbabwe farm and measured the effects of leaf stripping and detasselling on the productivity of maize. The first factor was timing of leaf stripping of four bottom leaves from the plant with

three levels viz. no leaf stripping, stripping at 8 and 12 WAE. The second factor was the detasselling treatment with two levels viz. removing the tassel as soon as it emerged (detasselled) and leaving the tassel on the plant (tasselled). The treatments were replicated three times. A short season maize three-way hybrid, SC 513, from Seed-Co® (Zimbabwe), was planted at an inter-row spacing of 0.8 m and a within-row spacing of 0.3 m to establish a final density of 41,600 plants ha^{-1}.

Photosynthesis measurements

To determine the photosynthetic performance of leaves that would be stripped, photosynthesis was measured on isolated fully lit maize plants at 50% silking (anthesis) in March 2003. A portable photosynthesis system (Model LI-6200, Li-Cor, Lincoln, Nebraska, USA) was used to measure photosynthesis starting from the lowest leaf that was still alive at anthesis and moving up the plant to the highest leaf just below the tassel. Photosynthesis was measured on a sample of seven plants of cultivar SC 701, a single cross hybrid from Seed-Co® (Zimbabwe). The pooled measurements of PAR and CO_2 exchange rate from each leaf position from the seven plants were fitted with the negative exponential equation ($P_n = P_{n,max} (1-e^{-\varepsilon H/P_{n,max}})$) using the SAS NLIN procedure (SAS 1999, Raleigh NC, USA). P_n is the net photosynthesis of the leaf in micromoles of CO_2 m^{-2} s^{-1}, H is the radiation incident on the leaf in Joules (J) m^{-2} s^{-1}, ε is the light use efficiency of the leaf (the initial slope of the P_n curve as H approaches zero) in micromoles of CO_2 J^{-1} of incident H, and $P_{n,max}$ is the maximum P_n at PAR saturation. The estimated values of $P_{n,max}$ for the leaf positions up the plant were compared using the generated standard errors. Dark respiration is ignored. It remains to be seen in the results whether this is justified.

Analysis of data

All maize yield data were standardized to 12.5% moisture content before analysis. All data were subjected to analysis of variance using a SAS (1999) statistical programme. The standard error of the difference was calculated and used for mean separation when treatment effects were significant at P<0.05. Standard errors of the difference are shown as error bars in the charts, unless otherwise stated.

RESULTS

Maize grain yield

Detasselling significantly (P<0.05) increased maize grain yield by 11.2% and 12.2% in the 1998/99 and 1999/00 seasons, respectively (Fig. 1). There was no interaction (P>0.05) between the timing of leaf stripping with detasselling in Experiment 1 (Fig.

2a). Averaged across the detasselling treatments, leaf stripping at 12 WAE (anthesis) produced significantly (P=0.002) higher grain yield than leaf stripping three weeks earlier, at 9 WAE or later at 15 WAE (Fig. 2a). Averaged across the detasselling treatments, leaf stripping at 12 WAE produced a 16.6% increase in maize grain yield compared to the unstripped and tasselled control (Fig. 2a). There was no difference in maize grain yield between the maize that was leaf stripped at 9 and 15 WAE and the control (Fig. 2a).

In Experiment 2, there was a significant interaction (P=0.009) between detasselling and timing of leaf stripping on maize grain yield (Fig. 2b). Maize grain yield was similar in the detasselled and tasselled treatments when leaf stripping was done at 12 WAE and was lower in the tasselled than in the detasselled treatment when leaf was stripped at 8 WAE and in the unstripped treatment (Fig. 2b). Averaged across the detasselling treatments, grain yield was 28% higher when maize was leaf stripped at 12 WAE than in the unstripped control (Fig. 2b).

Grain yield was significantly higher when 4 and 6 bottom leaves were stripped than
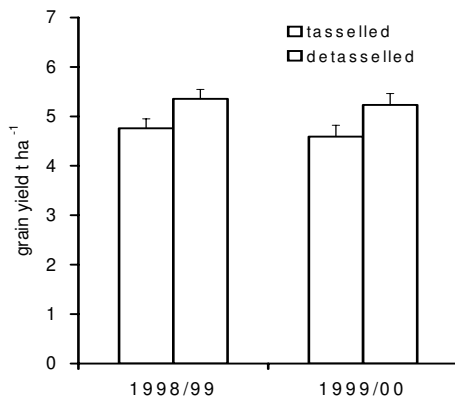
Figure 1. Effect of detasselling on maize grain yield in Experiment 1 (1998/99 season) and Experiment 2 (1999/00 season).
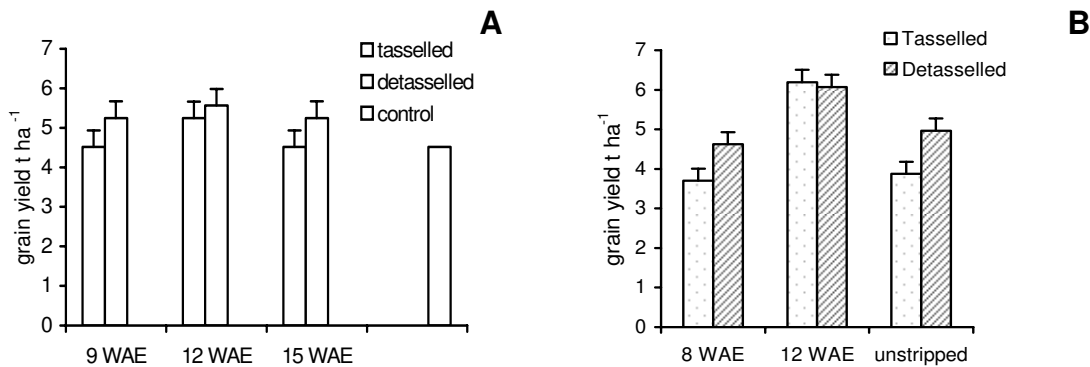
Figure 2. Effect of timing (weeks after emergence) of leaf stripping on maize grain yield in tasselled and detasselled maize in (A) Experiment 1 and (B) Experiment 2.
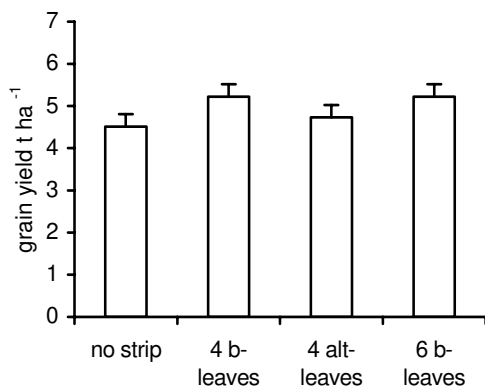
Figure. 3. Effect of intensity of leaf stripping on maize grain yield in Experiment 1.

in the unstripped control in Experiment 1. The stripping of 4 alternate leaves resulted in an intermediate maize grain yield, not significantly different from other stripping treatments (Fig. 3).

Leaf nitrogen content and dry mass of stripped leaves

The nitrogen content of stripped leaves measured in Experiment 1, significantly ($P<0.001$) decreased when they were removed from the plant at a later stage (Fig. 4a). Leaf dry mass was significantly ($P<0.001$) higher when the leaves were stripped at 12 than at 9 and at 15 WAE in Experiment 1 (Fig. 4b). In Experiment 2, dry mass of stripped leaves significantly ($P=0.001$) increased from 355 to 591 kg ha^{-1} between 8 and 12 WAE. The dry mass of stripped leaves significantly ($P<0.001$) increased from 499, 643 to 756 kg ha^{-1}, with increased intensity of leaf stripping, from 4 bottom, 4 alternate to 6 bottom leaves stripped, respectively, in Experiment 1.
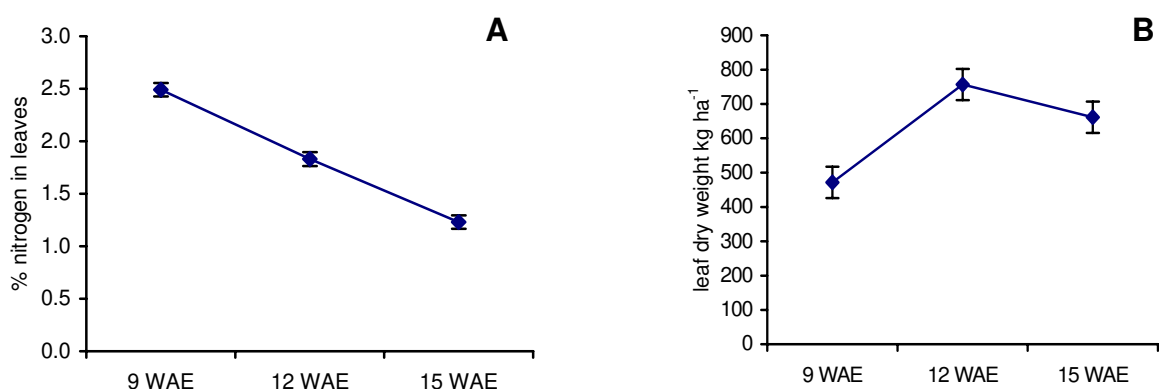
Figure 4. (A) Effect of timing (weeks after emergence) on percent nitrogen (dry weight basis) in stripped leaves in Experiment 1. (B) Effect of timing of leaf stripping on the dry weight of stripped leaves in Experiment 1.
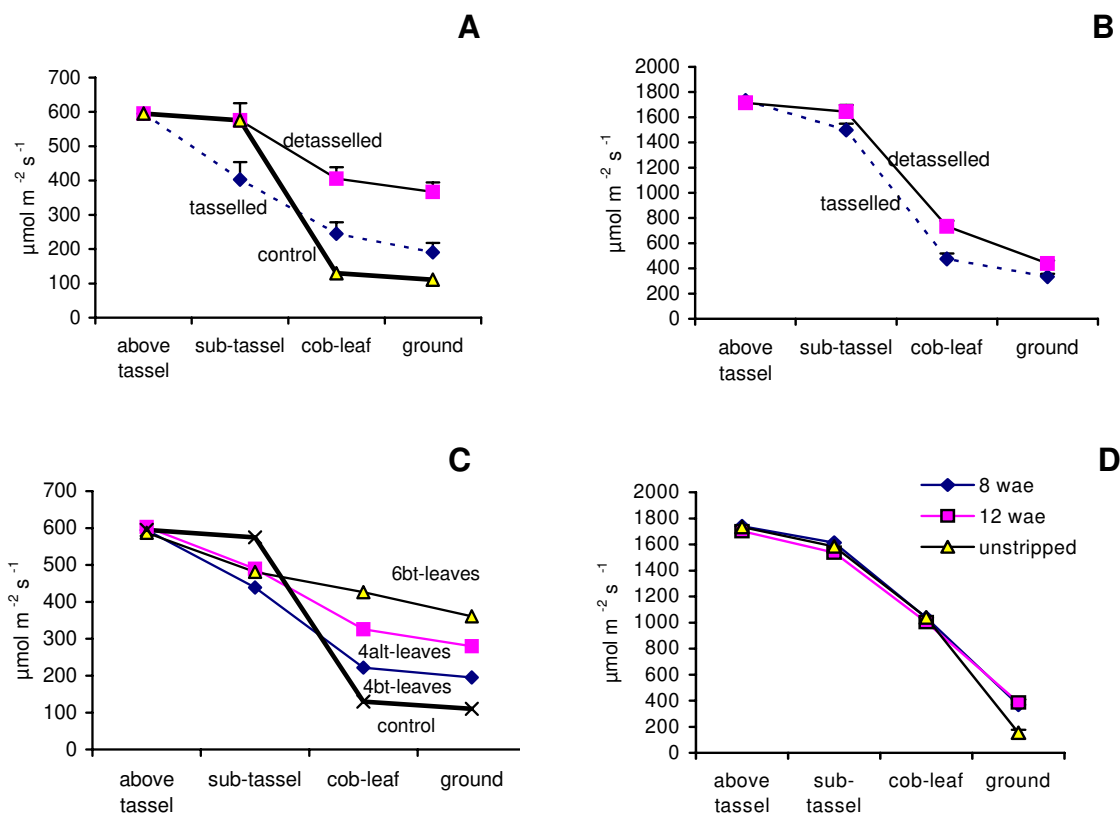
Figure 5. Effect of detasselling on PAR extinction within the maize canopy at anthesis in (A) Experiment 1 and (B) Experiment 2. (C) Effect of leaf stripping intensity averaged across detasselling treatments on PAR extinction within maize canopy at anthesis in Experiment 1. (D) Effect of timing of leaf stripping on PAR extinction within maize canopy at anthesis in Experiment 2.

Canopy radiant environment

Incident PAR (IPAR) on the leaves immediately below the tassel was significantly ($P<0.05$) increased by detasselling, from 68% to 97% of total incoming PAR and from 86% to 96%, in Experiment 1 (Fig. 5a) and in Experiment 2 (Fig. 5b), respectively. Averaged across the leaf stripping treatments, detasselling significantly ($P<0.05$) improved IPAR on cob leaves by 15% and 27% of total incoming PAR in Experiment 2 and Experiment 1, respectively. In comparison to the unstripped and tasselled control, detasselling increased the proportion IPAR reaching the cob leaves by 46% in Experiment 1 (Fig. 5a). The proportion of total IPAR reaching the ground was 61%, 32% and 10% in the detasselled, tasselled and control treatment, respectively, in Experiment 1 (Fig. 5a). In Experiment 2, 25% and 19% of the total IPAR reached the ground in the detasselled and tasselled treatments, respectively (Fig. 5b).

The IPAR reaching the cob-leaves increased (P=0.049) with increased intensity of leaf stripping from 0 (control), 4 bottom, 4 alternate to 6 bottom leaves stripped in Experiment 1 (Fig. 5c). This represented an increase in the proportion of incoming total PAR from 22%, 37%, 54% and 72% when 0, 4 bottom, 4 alternate and 6 bottom leaves were stripped, respectively. There was a significant increase (P=0.047) in the amount of IPAR reaching the ground with increased intensity of leaf stripping from 110, 195, 277, to 361 µmol m^{-2} s^{-1} when 0, 4 bottom, 4 alternate or 6 bottom leaves were stripped in Experiment 1 (Fig. 5c). Timing of leaf stripping had no (P>0.05) effect on PAR extinction within the maize canopy in Experiment 1 and 2. Averaged across the detasselling treatments, leaf stripping at 8 and 12 WAE resulted in 13% more total incoming PAR reaching the ground, than in the unstripped treatment (Fig. 5d). Leaf stripping did not affect IPAR on cob leaves in Experiment 2 (Fig. 5d).
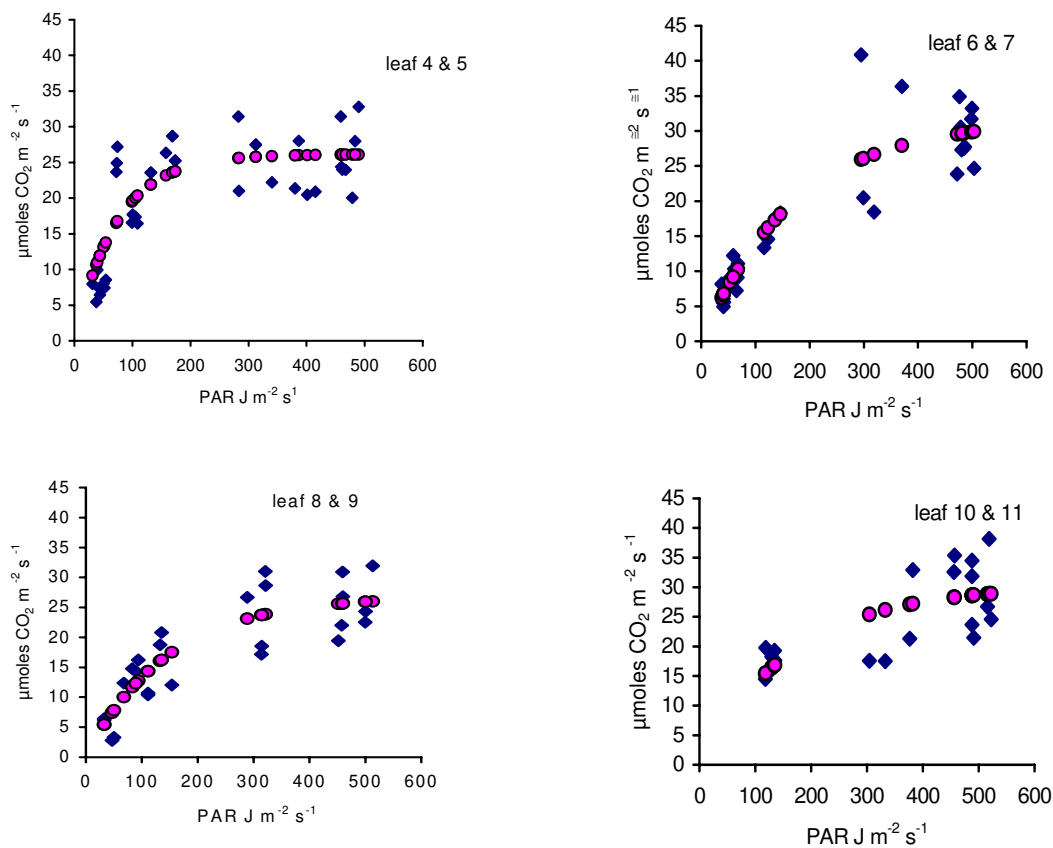
Figure 6. Fitted (circles) and actual (diamonds) net carbon dioxide exchange rate (CER) of maize leaves grouped according to position from the bottom at anthesis. The data was fitted to the equation $P_n = P_{n,max}(1-e^{-\varepsilon H/P_{n,max}})$, where P_n is the CER, H is the PAR incident on the leaf. $P_{n,max}$ is the maximum photosynthesis at PAR saturation and ε is the light use efficiency of the leaf.
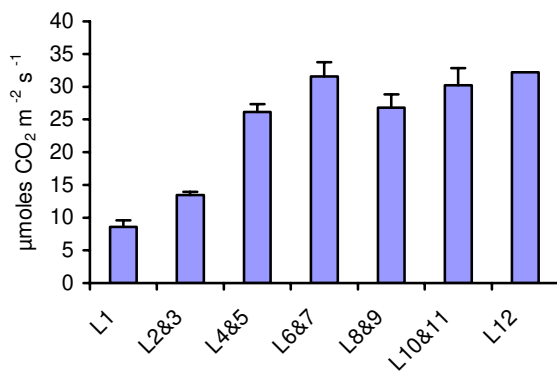
Figure 7. Estimated maximum rate of photosynthesis at PAR saturation in maize leaves from the lowest leaf alive (L1) to the top leaf just below the tassel (L12) at anthesis in cultivar SC 701, a single cross hybrid from Seed-Co® (Zimbabwe). Error bars represent the standard error of the mean.

Photosynthesis in maize leaves at anthesis

The relationship between photosynthesis and incident PAR in maize leaves from the fourth lowest leaf alive at anthesis and up the plant are shown in Fig. 6. It is apparent that, at this phenological growth stage of the maize, the lowest three leaves have lower $P_{n,max}$ than the upper leaves (Fig. 7). $P_{n,max}$ was similar from the 4th lowest leaf to the 12th leaf just below the tassel (Fig. 7).

DISCUSSION

Detasselling and maize grain yield

The significant increase in maize grain yield in responses to detasselling at tassel emergence observed consistently over the two experiments in this study are similar to what has been observed by Hunter *et al.* (1969), Mostert and Marais (1982), Subedi (1996), Edje (1983) and Amitai (1982). It is widely acknowledged that detasselling at tassel emergence, removes apical dominance, which is mediated by the production and consequent high concentrations of auxins in the tassel, and suppresses the growth of the ear (Hunter *et al.*, 1969; Doebley *et al.*, 1997; Iltis, 1983; Paterniani, 1981). In addition, detasselling removes the shading effect by the tassel, thereby increasing the amount of incoming PAR reaching the leaves in the maize canopy and, therefore, increasing canopy photosynthesis and reducing the rate of leaf senescence (Mostert and Marais, 1982; Hunter *et al.*, 1969). Tassels obstructed an average of 21% of incoming

PAR at a maize density of 100,000 plants ha^{-1} and this contributed to observed maize grain yield differences between tasselled and detasselled treatments (Duncan and Caldwell, 1967). In this study, detasselling increased the incident PAR on the sub-tassel leaves by 10-29% and on the cob leaves by 15 and 27% compared to the tasselled treatments. Gardner *et al.* (1985) established that although all maize leaves contributed to grain yield, the actual contribution of each leaf was far much less than potential due to mutual shading. Therefore, the increased amounts of incoming PAR that reached the upper and middle levels of the leaves in this study partly explain the observed increases in maize yield in the detasselled treatments.

Andrade *et al.* (2002) and Barbieri *et al.* (2000) demonstrated that maize grain yield was positively correlated to the amount of radiation intercepted by the maize canopy during critical period bracketing flowering in maize. In this study, detasselling increased the proportion of total incoming PAR that penetrated into the canopy from anthesis onwards, well within the same critical period identified by Andrade *et al.*, 2002 and Barbieri *et al.*, 2000 for the grain yield response to increased radiation interception in maize. Barbieri *et al.* (2000) noted that the increases in maize grain yield that occurred as a result of increased radiation interception during the reproductive stages in maize occurred through increased kernel number and kernel weight per unit land area. It is well established that the number of grains that develop on a maize plant is determined by the amount of PAR intercepted per plant during a two- to three-week period around silking. The IPAR plant^{-1} determines potential plant growth rate, which is a critical factor for determining the number of maize female pollinated flowers that continue to develop into grains (Andrade *et al.*, 1999). Subsequent studies (Mashingaidze *et al.*, Chapter 4) on leaf stripping and detasselling showed that grain numbers and test weight were positively affected by leaf stripping and detasselling. Interactions between leaf stripping and detasselling on kernel test weight and kernel number were similar to interactions of the same two factors on maize grain yield (Mashingaidze *et al.*, Chapter 4).

The interaction between timing of leaf stripping and detasselling observed in Experiment 2 of this study indicates that these two interventions may act on the same processes during the grain development and grain filling stages. Evidence of this phenomenon was provided by measurements on the yield components of maize that responded with mutual exclusivity to detasselling and leaf stripping and whose interactions were mirrored in the grain yield (Mashingaidze *et al.*, Chapter 4).

Leaf stripping and maize yield
Removal of leaves (leaf stripping) below the ear, before silking and 30 days after, resulted in no significant effect on maize grain yield (Subedi, 1996). In contrast to

these results, this study showed that the removal of the lowest four to six leaves at 50% silking significantly increased maize grain yield by 16-28%. The timing of leaf stripping was established to be the crucial factor determining the grain yield response to stripping of the lower leaves in this study. Leaf stripping three or four weeks before and three weeks after 50% silking had no significant effect on maize grain yield, in part confirming the results obtained by Subedi (1996). The results on the effect of timing of leaf stripping on maize grain yield and photosynthesis measurements support the hypothesis that leaf stripping increased maize grain yield when the removed leaves were becoming senescent and consequently had low photosynthetic capacity. These leaves, when they remained on the plant under low IPAR, would conceivably become net importers of assimilates in competition with the developing cob. This assertion is supported by the results on leaf nitrogen measured in Experiment 1 and leaf dry weights measured in Experiments 1 and 2 of this study. A strong positive correlation has been demonstrated between net photosynthetic rate and leaf nitrogen content (Dwyer *et al.*, 1985; Sinclair and Horie, 1989; Edwards, 1986; Wong *et al.*, 1985). The strong assimilate demand imposed by the developing ear on the rest of the plant appears to be part of the triggering mechanism for senescence of lower leaves in maize (Thomas and Smart, 1993) and leaf N loss from the maize leaves and roots has been shown to begin at anthesis (Weiland and Ta, 1992; Ta and Weiland, 1992).

The snapshot of maize leaf photosynthesis that we took at anthesis on isolated maize plants that were acclimatized to fully lit conditions shows that the photosynthetic capacity of the lowest three leaves was lower than that of the rest of the upper leaves because of senescence. In a maize canopy it would be expected that the stages of senescence of the lower leaves at anthesis would be more advanced because of higher levels of shading in the lower part of the canopy and greater interplant competition for water and nitrogen within the maize stand (Rousseaux *et al.*, 1993; Sadras *et al.*, 2000). In the maize canopy, N translocation from the older lowest leaves actually starts earlier than the anthesis stage (Sinclair and de Wit, 1975). It is conceivable that within the maize canopy, the advanced state of senescence of the lower leaves and lower PAR conditions in the lower parts of the canopy made lower leaves a competitive sink for assimilates in competition with the grain formation and grain filling stage. The increase in maize grain yield that was recorded after leaf stripping at anthesis recorded in this study seems to be explainable based on the above scenario.

The effect of leaf stripping intensity on maize grain yield in Experiment 1 of this study suggests that the benefits of leaf stripping at anthesis are only realized when the lowest leaves are removed. When one upper leaf above the cob was stripped together with the lower leaves in the treatment in which four alternate leaves were stripped, maize grain yield became similar to that of the unstripped control. Removing leaves

above the cob leaf that remain green and photosynthesizing throughout the grain development and grain filling stages in maize apparently cancelled out the benefits that accrued from removing the lower senescing leaves. It is foreseeable from these results that if more of the upper leaves had been removed, grain yield was likely to be reduced through a reduction of active photosynthetic area during the critical post-anthesis period for embryo formation and grain filling.

It was shown in this study that leaf stripping resulted in an increase in IPAR on cob leaves in Experiment 1. Maize leaves arc upwards before drooping and hanging down in the middle of the maize row and it was observed that removing lower leaves opened up the density of leaf area around the cob leaf position, admitting more PAR. Increased IPAR onto cob leaves may have contributed to the observed yield effects. However, with a denser maize stand and leafier SC 513 with broad drooping leaves (Seed-Co, 2000) used in Experiment 2, leaf stripping of four bottom leaves failed to have an impact on IPAR on the cob leaves but still increased maize grain yield as in Experiment 1. On this evidence, it would seem that the effect of leaf stripping on removing assimilate competition between the senescing leaves and developing cob would be a more plausible explanation for the observed effects of leaf stripping on maize grain yield.

In the context of mixed cropping systems, the demonstration that detasselling and leaf stripping can increase maize grain yield opens up the possibilities of fruitfully integrating these interventions to increase the productivity of these systems. As hypothesized by Subedi (1996), an increase in IPAR onto the minor crop under the dominant cereal crop brought about by leaf stripping and detasselling is expected to increase the growth and yield of the minor crop. The scenario of increased maize grain yields and increased minor crop yields with leaf stripping and detasselling is expected to result in substantial benefits in smallholder farming systems where maize-pumpkin and maize-bean intercropping system are widely practised.

The effect of maize leaf stripping and detasselling on component crop productivity and weeds in maize-pumpkin intercropping systems

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Abstract

Experiments were conducted at the University of Zimbabwe and Chibero Agricultural College to determine the effect of leaf stripping and detasselling on the radiant environment, yield of component crops and weed biomass in a maize-pumpkin intercropping system in the 1999/00 and 2001/02 seasons. Detasselling at tassel emergence increased maize grain yield by 12-40% and leaf stripping at anthesis increased maize grain yield by 12-45% depending on season and variety of maize. The increase in maize grain yield caused by detasselling was greater in maize-pumpkin intercrops than in the maize monocrop, similar to detasselling responses that have been reported to be greater at high than at low maize densities. The effects of detasselling and leaf stripping were expressed through increases in cob mass, 1000-grain weight and number of kernels per cob showing that they increased maize grain yield by inducing greater assimilate allocation to the developing grain, post-anthesis. Leaf stripping increased the percentage of incident photosynthetically active radiation (IPAR) reaching pumpkin leaves from 10% to 20% and increased pumpkin fruit yield by 40-64%, depending on number of leaves stripped and maize cultivar. Maize-pumpkin intercropping reduced the percentage of IPAR reaching weeds from 22% in the maize monocrop to 8% in the intercrop and reduced weed biomass and seed production in the intercrop. Late weed biomass and fecundity were increased with leaf stripping, and more so in the maize monocrop than in the maize-pumpkin intercrop. The study showed that leaf stripping and detasselling have potential to strongly improve the productivity of the maize-pumpkin intercropping system by increasing maize grain yield and pumpkin fruit yield.

Key words: Maize, pumpkin, intercropping, leaf stripping, detasselling, weed biomass, weed seed production.

INTRODUCTION

Intercropping has remained popular in smallholder agriculture in Africa despite the emphasis on monocropping, mechanization and use of pesticides by local research and extension that was inspired by the modern 'green revolution' methodologies for maximization of productivity of uniform crop stands (Richards, 1983). Various socio-economic and environmental reasons have been advanced to explain the widespread cereal-legume and cereal-cucurbit practices in semi-arid areas of Africa. These include minimization of risk (Ruthenberg, 1980; Richards, 1983; Tafera and Tana, 2002), higher net economic returns (Norman *et al.*, 1982), diversification of food supply (Francis, 1985) and more efficient use of environmental resources such as light, nutrients and water (Richards, 1983; Natarajan and Willey, 1986; Ofori and Stern, 1987; Rao *et al.*, 1987; Willey, 1990).

Pumpkin is a popular crop for intercropping with staple food cereal crops in Zambia (Gwanana and Nichterlein, 1995), Malawi (Chigwe and Saka, 1994) and Zimbabwe (Mariga, 1990). Pumpkin fruits and other edible products (leaves, flowers and seeds) provide a food security bridge in the 'hunger season' before the new crops are harvested and food stores from the previous season depleted (Gwanana and Nichterlein, 1995; Morna *et al.*, 1993). Being a prostrate crop with large leaves, pumpkins reduce the germination and growth of weeds in the maize understorey and can reduce the number of times the maize crop needs to be weeded to achieve maximum yields (Akobundu, 1993; Mashingaidze *et al.*, 2000).

Although intercropping has largely been shown to be advantageous in terms of greater efficiency of land utilization, yield of the dominated minor crop, grown under the canopy of the dominant cereal crop, has always been low. Ofori and Stern (1987) reviewed 40 papers on cereal legume intercropping and found that the legume component crop yield declined by an average of 52% and that of the cereal crop by an average of 11% of their respective monocrop yields. Pumpkin fruit yield from maize-pumpkin intercrops was 46% lower than from pumpkin monocrops (Mashingaidze *et al.*, 2000). The greater yield loss of the minor crop when intercropped with a dominant cereal is mainly because of reduced photosynthetically active radiation (PAR) reaching the lower parts of the intercrop canopy, occupied by the minor legume/cucurbit crop. This is particularly so during the anthesis and post-anthesis stages crucial to yield formation in either crop. Any interventions that lead to an increase in the amount of PAR incident on the minor crop under the dominant cereal canopy has potential to increase the minor crop yield and increase the productivity of the intercropping system.

Detasselling and leaf stripping have the potential of improving the penetration of

incoming PAR into the canopy to the benefit of the dominated minor crop and the dominant cereal crop (Subedi, 1996). Maize grain yield increases have been recorded when maize was detasselled in a number of studies. These increases have been attributed to increased PAR penetration into the maize canopy (Hunter *et al.*, 1969; Duncan *et al.*, 1967) and removal of the apical dominance imposed by the tassel over the growth and development of the ear (Mostert and Marais, 1982; Subedi, 1996). The greater grain yield responses to detasselling that were displayed when the maize was under population stress (Hunter *et al.*, 1969; Grogan, 1956; Mostert and Marais, 1982) suggest that the same type of response might be realized when maize is subjected to interplant competition stress imposed by an intercrop. Muleba *et al.* (1983) found that temperate maize hybrids had weak apical dominance that enabled early and rapid growth of the ear and produced high grain yields while tropical open pollinated varieties had strong apical dominance that led to a small sink and lower grain yields. Detasselling tropical open pollinated maize varieties that are widely intercropped with beans and cucurbits in smallholder agriculture (Mariga, 1990) may, therefore, reap the added benefits of an anticipated greater maize yield response. However, the growth and fecundity of late weeds might also benefit from the increased penetration of PAR into the canopy brought on by leaf stripping and detasselling. The effects of leaf stripping and detasselling on weeds needs to be ascertained to assure farmers that this practice will not cancel out the weed control advantages associated with intercropping.

Nepal hill farmers remove senescing leaves below the ear in maize, late in the season (when the silks are drying), to allow more PAR to reach relay-intercropped finger millet (*Eleusine coracana* Gaertn.). Subedi (1996), however, could not detect any yield benefits accruing to the dominant maize crop or the relay-intercropped finger millet from this intervention. Mashingaidze *et al.* (Chapter 3), however, found that removal of four to six lower leaves in maize at anthesis increased maize grain yield and attributed the grain yield increase to reduced competition between the lower aging leaves and the developing cob for assimilates. Timing of leaf stripping was crucial for it to increase maize yield: leaf stripping three weeks before or after anthesis did not affect maize yield whereas leaf stripping at anthesis significantly increased maize grain yield (Mashingaidze *et al.*, Chapter 3).

The aim of this study was to investigate the effects of leaf stripping and detasselling on the radiant environment and yield of component crops of a maize-pumpkin intercropping system. Hypotheses tested during the study were (a) leaf stripping and detasselling will increase maize grain yield in a maize-pumpkin intercrop (b) leaf stripping and detasselling will increase pumpkin fruit yield in a maize-pumpkin intercrop (c) leaf stripping and detasselling will increase weed biomass and seed production of late emerging weeds.

MATERIALS AND METHODS

Experiments to study the effect of detasselling and leaf stripping of maize in a maize-pumpkin intercrop were conducted at the University of Zimbabwe farm in 1999/00 and Chibero Agricultural College in 2001/02. The University of Zimbabwe farm site is 14 km to the north-west of Harare, at an altitude of 1500 m above sea level, on fersiallitic red clay soils with more than 40% clay and an average annual rainfall of 800 to 1000 mm. The Chibero Agricultural College site has sandy soils (less than 20% clay) derived from granite parent material and an annual rainfall between 600 and 800 mm. It is located 60 km south-west of Harare at 1325 m above sea level. In all seasons, the land was disc-ploughed and disc-harrowed to a fine tilth and planting furrows were opened in November. Two maize seeds were dropped into the planting furrows at the required spacing to achieve the proper maize density of 37,000 plants ha^{-1} after thinning. Basal fertilizer (compound D, 8% N, 14% K_2O, 7% P_2O_5) was banded into the open planting furrows at 300 kg ha^{-1}, before seeding at both sites. Ammonium nitrate (34.5% N) was side-dressed on the maize plants at 300 kg ha^{-1}, half of which was applied at 4 weeks after emergence (WAE) and the other half at 8 WAE.

Experiment 1 (1999/00 season)

The first experiment was set up as a $3 \times 3 \times 2$ factorial in a randomized complete block design at the University of Zimbabwe farm and measured the effects of leaf stripping and detasselling of maize on the productivity of maize-pumpkin mono and intercropping systems and on weed emergence and growth in these systems. The first factor was the cropping system with three levels viz. sole maize, maize-pumpkin intercrop and sole pumpkin. The second factor was timing of leaf stripping of four bottom leaves from the plant with three levels viz. no leaf stripping, stripping at 8 and 12 WAE. The third factor was the detasselling treatment with two levels viz. removing the tassel at 50% silking (detasselled) and leaving the tassel on the plant (tasselled). The treatments were replicated three times. A short-season maize three-way hybrid, SC 513, obtained from Seed-Co$^®$ (Zimbabwe) was intercropped with Flat White Boer, a commercial pumpkin variety from National Tested Seeds$^®$ (Zimbabwe). The maize was planted at an inter-row spacing of 0.8 m and a within row spacing of 0.3 m to establish a final density of 41,600 plants ha^{-1}. The pumpkin was planted in the maize row at 1.5 m apart to establish a final density of 8,300 plants ha^{-1}, which is equivalent to 20% of the maize density.

Leaf stripping was accomplished by cutting the required leaves at the junction between the leaf sheath and the stem. The cut leaves were oven-dried to constant weight at 80 °C, and weighed.

PAR penetration into the canopy was determined by placing a Li-Cor 191-SA line quantum sensor at four levels in the canopy viz. the ground, level with the cob, just below the tassel immediately above the sub-tassel leaves and above the tassel. PAR measurements were taken in sunny weather, adjacent to the crop row and in the middle of the inter-row, at 6, 8 and 12 WAE. The measurements were made at three positions in the middle row of each treatment plot. The average PAR reading from the three positions was used in the analysis of variance.

Detasselling of half of all plots was done when 50% of all plants had produced silks (50% silking). Tassels were grabbed and pulled upwards leaving all the upper maize leaves intact. Weeds were counted by species at 11 and 15 WAE in three randomly placed 1 m × 1 m quadrants in each plot, cut at ground level and oven dried to a constant mass and weighed.

The gross plot was 4.0 m wide and 7.5 m long, thus, including five rows of maize at 80 cm spacing. The net plot was 2.4 m wide and 6.0 m long consisting of three rows. Maize cobs from the net plot were hand harvested and shelled. Maize grain yield was standardized to 12.5% moisture before analysis.

Experiment 2 (2001/02 season)

The second experiment in the 2001/02 season was set up as a 3 × 2 × 2 factorial in a randomized complete block design at Chibero Agricultural College and determined the effect of leaf stripping and detasselling on the productivity of a maize-pumpkin intercropping system. The treatments were replicated four times. The first factor was the cropping system as in Experiment 1. The second factor was the intensity of leaf stripping with three levels: stripping 0, 2, or 4 leaves at maize anthesis (50% silking). The third factor was the detasselling treatment as in Experiment 2. An open-pollinated maize variety obtained from National Tested Seeds[®] (Zimbabwe), ZM 621, was planted. A local pumpkin landrace, Nzunzu was planted in the maize row at 33% of the maize density of 37,000 plants ha^{-1}. In addition to grain yield, other components of yield viz. cob length, cob weight, number of kernels per row, number of rows per cob and 1000-grain weight were determined from five randomly selected cobs from each replicate. No weed data was collected.

Experiment 3 (2001/02 season)

The third experiment, in the 2001/02 season, was designed to determine the effects of cropping system, leaf stripping and detasselling on the productivity of the maize-pumpkin intercropping system and weeding requirements. The experiment was located at Chibero Agricultural College and was set up as a 2 × 2 × 2 × 3 factorial in a randomized complete block design replicated four times. The first factor was the

cropping system with two levels viz. sole maize and maize-pumpkin intercrop. The second factor was leaf stripping with two levels viz. no leaf stripping and removal of four leaves at 50% silking. Detasselling was the third factor as in Experiments 1 and 2. The fourth factor was weeding regime with three levels viz. hoe weeding once at 3 WAE, hoe weeding twice at 3 and 6 WAE and hoe weeding three times at 3, 6 and 9 WAE. Plant spacing and varieties were as in Experiment 2. Similar measurements on maize grain yield components were made as in Experiment 2. Weed density and biomass were determined at 3, 6 and 15 WAE. A 30 cm × 30 cm quadrant was randomly thrown in each plot five times and weed density and biomass determined as in Experiment 1. Seed heads were counted on specimens of two major weeds, *Richardia scabra* and *Acanthospermum hispidum*, randomly selected from each plot at 20 WAE. Weed seeds were oven-dried to a constant mass and weighed.

Analysis of data

All weed density data was square-root transformed (Steel and Torrie, 1984) and maize grain yield was standardized to 12.5% moisture content before analysis.

Data from the experiments was subjected to analysis of variance (ANOVA) using the SAS statistical package (SAS Institute, Release 8, Cary NC, USA). Standard errors of the difference were calculated and used for mean separation where the analysis of variance indicated a significant treatment effect at $P<0.05$. Standard errors of the difference are shown as error bars in the charts.

RESULTS

Maize grain yield

Detasselling significantly ($P<0.05$) increased maize grain yield in the three experiments (Fig. 1). Maize grain yield increased by 12.2%, 27.4% and 39.5% in Experiments 1, 2 and 3, respectively, on detasselling. Greater responses of grain yield to detasselling were recorded in Experiments 2 and 3 when an open pollinated maize variety was used than in Experiment 1 when a hybrid maize variety was used (Fig. 1). The timing of leaf stripping and cropping system ($P<0.05$) significantly interacted with respect to their effect on maize grain yield in Experiment 1 (Fig. 2). Grain yield significantly decreased when leaf stripping was done at 8 WAE, compared to the unstripped control, in the maize monocrop but was not significantly affected in the maize-pumpkin intercrop. Leaf stripping at 12 WAE, however, significantly increased maize grain yield above that of the unstripped control in both the intercrop and the monocrop (Fig. 2). Significant cropping system and detasselling interactions on maize grain yield were recorded in Experiments 2 and 3 (Figs 3a and b). In Experiments 2

and 3, maize grain yield was similar in the tasselled and detasselled treatments of the maize monocrop. In contrast, in the maize-pumpkin intercrop, maize grain yield in the tasselled treatment was approximately 50% of that in the detasselled treatment (Figs 3a and 3b). Detasselling appeared to nullify the competition effects of the pumpkin on maize as detasselled maize grain yield was similar to the tasselled and detasselled monocrop maize grain yield (Figs 3a and 3b).
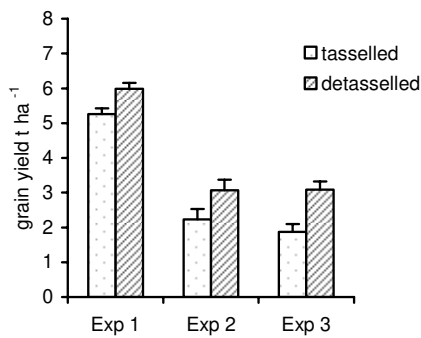
Figure 1. Effect of detasselling on maize grain yield (t ha^{-1}).
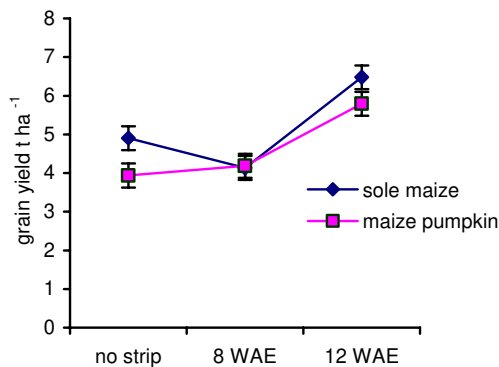
Figure 2. Interaction between cropping system and timing of leaf stripping on maize grain yield (t ha^{-1}) in Experiment 1.
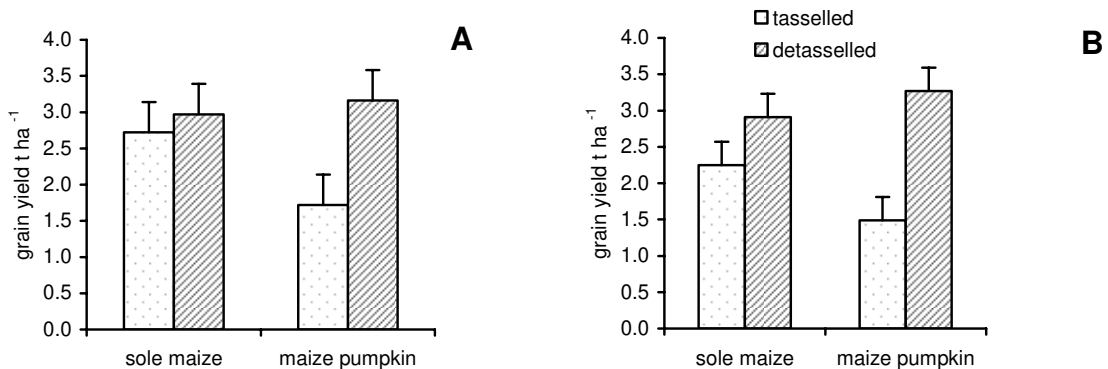
Figure 3. Interaction between cropping system and detasselling on maize grain yield in (A) Experiment 2 and (B) Experiment 3.

There was a significant (P<0.01) increase in maize grain yield with increased intensity of leaf stripping at anthesis. A significant interaction (P=0.02) between leaf stripping and detasselling on maize grain yield was recorded in Experiment 3 (Fig. 4a). Detasselling was only effective in increasing maize grain yield when the maize was not leaf stripped and had no effect when four leaves were stripped (Fig. 4a). In Experiment 2, the effect of the intensity of leaf stripping on maize yield was confounded in a significant leaf stripping and cropping system interaction (Fig. 6a). Maize yield significantly increased with increase in intensity of leaf stripping from two to four leaves in the maize-pumpkin intercrop but was not significantly affected (P>0.05) in the maize monocrop (Fig. 6a). Cropping system did not significantly affect maize grain yield in Experiments 1, 2 and 3.

Maize yield components

The 1000-grain weight, similar to maize grain yield, significantly increased (P<0.001) by 20% and 21% in Experiments 2 and 3, respectively, on detasselling (Fig. 5). Cob weight followed suit, significantly (P<0.001) increasing by 14.6% and 22.6% in
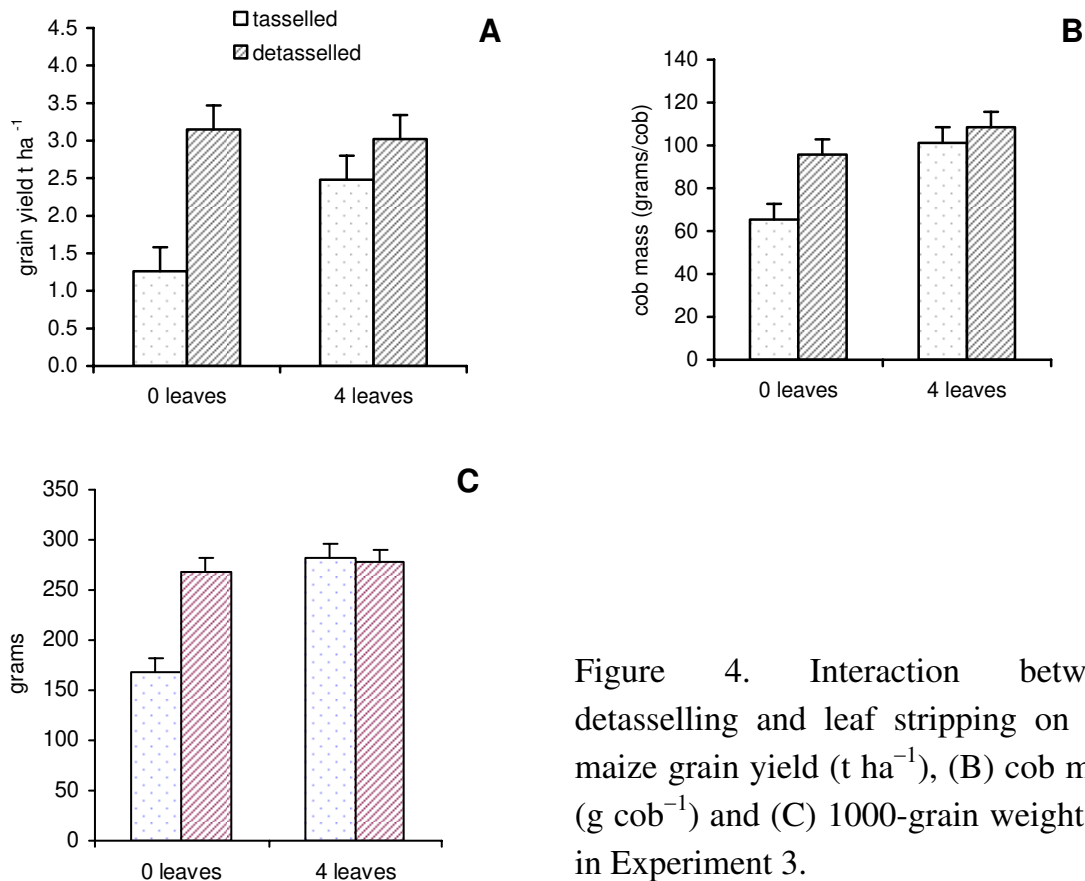
Figure 4. Interaction between detasselling and leaf stripping on (A) maize grain yield (t ha^{-1}), (B) cob mass (g cob^{-1}) and (C) 1000-grain weight (g) in Experiment 3.
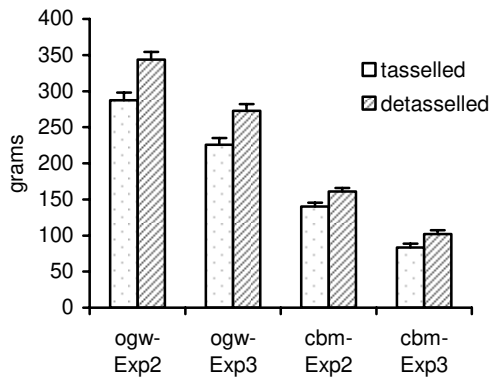
Figure 5. Effect of detasselling on 1000-grain weight (ogw) and cob mass (cbm) in Experiments 2 and 3.
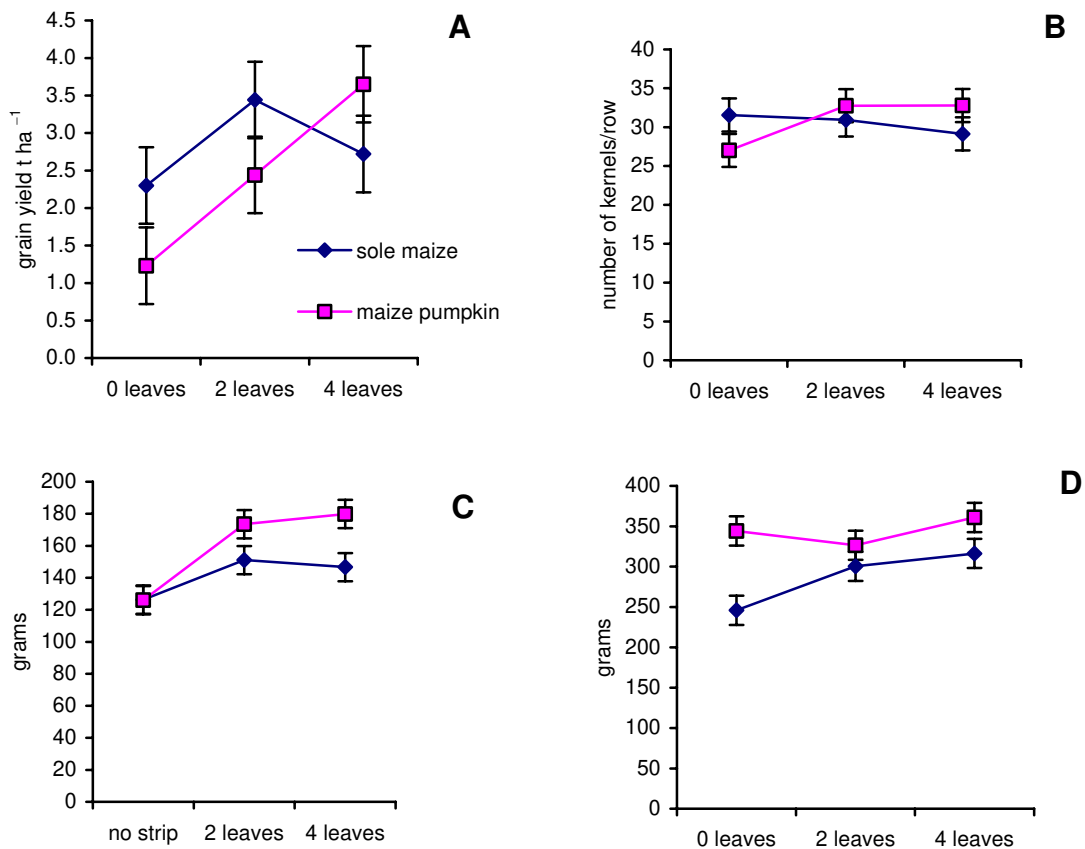
Figure 6. Interaction between cropping system and intensity of leaf stripping on maize (A) grain yield (t ha^{-1}) (B) number of kernels per row (number row^{-1}) (C) 1000-grain weight and (D)interaction between intensity of leaf stripping and detasselling on 1000-grain weight in Experiment 2.

Experiments 2 and 3, respectively, on detasselling (Fig. 5). In Experiment 2, number of kernels per row and cob weight significantly increased with increased intensity of leaf stripping in the maize-pumpkin intercrop but these traits were not significantly affected by leaf stripping intensity in the maize monocrop (Figs 6b and c, respectively). The differential effect of leaf stripping in the two cropping systems on the maize yield components, explain the significant interaction of these two factors on maize grain yield (Fig. 6a) in Experiment 2. There was a wide difference in 1000-grain weight between tasselled and detasselled maize, which narrowed when maize was leaf stripped in Experiment 2 (Fig. 6d). There was a significant (P=0.03) leaf stripping and detasselling interaction with respect to maize cob mass in Experiment 3. In the unstripped treatment, there was a significant 32% difference in cob mass between the detasselled and tasselled treatment while in the stripped treatment, cob mass was not affected by detasselling (Fig. 4b). This interaction closely resembled the one observed between the same two factors with respect to maize grain yield in Experiment 3 (Fig. 4a). There was a highly significant (P<0.001) interaction of leaf stripping and detasselling on 1000-grain weight of the maize in Experiment 3 (Fig. 4c). In the tasselled treatment, 1000-grain weight was increased by 40% in the stripped compared to the unstripped treatment. In contrast, test weight was similar between the stripped and unstripped treatments in the detasselled treatment (Fig. 4c).

Pumpkin fruit yield

Detasselling had no significant (P>0.05) effect on pumpkin fruit yield in Experiments 1, 2 and 3. However, a consistent trend of higher pumpkin yields was recorded in the detasselled treatments compared to the tasselled treatments. Pumpkin fruit yield was 0.95, 0.90 and 1.61 t ha^{-1} higher in the detasselled treatments than in the tasselled treatments in Experiments 1, 2 and 3, respectively (data not shown). In Experiment 1, pumpkin fruit yield was significantly affected (P<0.05) by the timing of leaf stripping while intensity of leaf stripping had no effect (P>0.05). Pumpkin fruit yield increased by 59% and 40% above that of the unstripped control when the maize was leaf stripped at 8 and 12 WAE, respectively (Fig. 7). In Experiment 2, there was a highly significant effect (P<0.001) of leaf stripping intensity on pumpkin fruit yield. Stripping two and four leaves at anthesis increased pumpkin fruit yield by 55% and 64%, respectively, above that of the unstripped control (Fig. 8). In Experiment 3, stripping of four leaves at maize anthesis significantly increased pumpkin fruit yield by 40% compared to the unstripped control (Fig. 8). The highest pumpkin yield was obtained in the leaf stripped/detasselled treatment and the pumpkin yield response to a combination of leaf and detasselling treatments is suggestive of additive effects of leaf stripping and detasselling in increasing pumpkin fruit yields (Fig. 9).
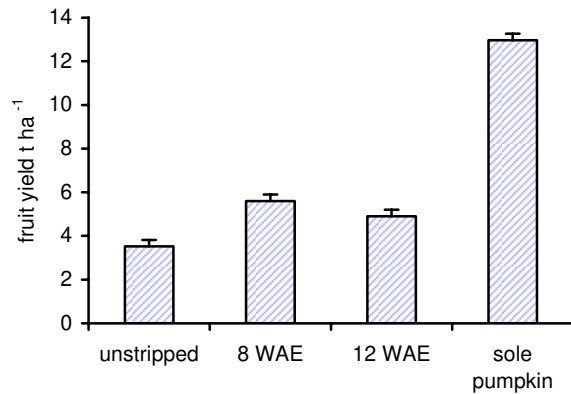
Figure 7. Effect of timing of stripping of maize leaves on pumpkin fruit yield (t ha^{-1}) in Experiment 1.
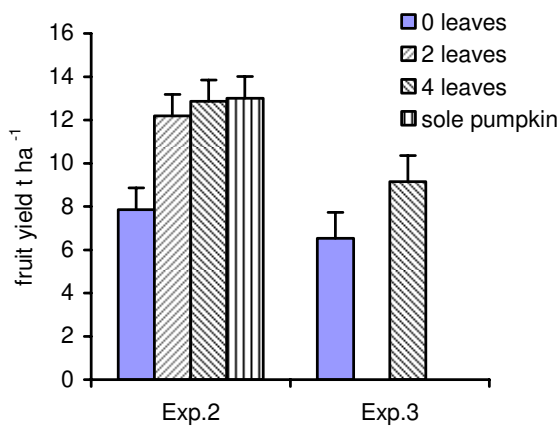
Figure 8. Effect of intensity of stripping of maize leaves on pumpkin fruit yield (t ha^{-1}) in Experiments 2 and 3.
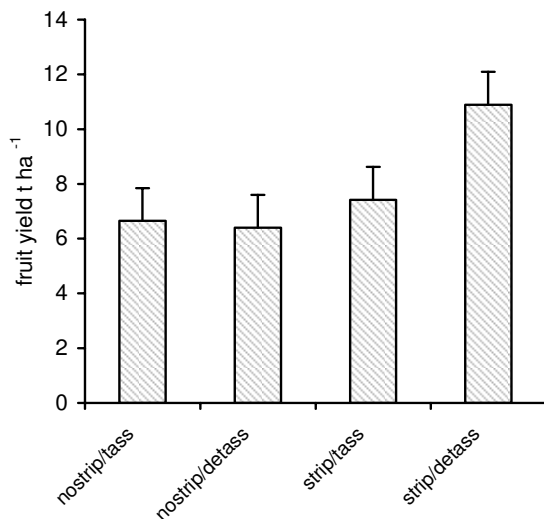
Figure 9. Combined effects of leaf stripping and detasselling on pumpkin fruit yield (t ha^{-1}) in Experiment 3.

Weed density, biomass and seed production

Weed density was not (P>0.05) significantly influenced by cropping system, detasselling or leaf stripping in Experiment 1. In Experiment 3, the total density of weeds was not significantly influenced by cropping system. However, there was a

significantly (P<0.05) higher *Richardia scabra* density in the maize monocrop (56 plants m^{-2}) compared to the maize-pumpkin intercrop (42 plants m^{-2}) at 6 WAE in Experiment 2. Total weed density was significantly (P=0.007) higher in the monocrop maize (32 plants m^{-2}) than in the maize-pumpkin intercrop (22 plants m^{-2}) at 9 WAE in Experiment 3.

Averaged across the timing of leaf stripping treatments, weed biomass was 64.5 and 25.4 g m^{-2}, in the maize monocrop and maize-pumpkin intercrop, respectively, in Experiment 1. There was a significant interaction (P<0.001) between cropping system and timing of leaf stripping with respect to weed biomass. Weed biomass was 8% and 11% lower in the unstripped control (60.5 g m^{-2}) than when leaf stripping was carried out at 12 (65.2 g m^{-2}) and 8 WAE (67.8 g m^{-2}), respectively, in monocrop maize. In the maize-pumpkin intercrop weed biomass was similar in the unstripped control (26.1 g m^{-2}) and when stripping was carried out at 8 (26.6 g m^{-2}) or 12 WAE (23.4 g m^{-2}). There was a significant timing of leaf stripping and detasselling interaction (P<0.001) with respect to weed biomass in Experiment 1. Detasselling increased weed biomass by 17% above that of the tasselled treatment in the unstripped control but there was no difference in weed biomass between the tasselled and detasselled treatments when the maize crop was leaf stripped at 8 and 12 WAE (data not shown).

Cropping system significantly (P=0.002) influenced *R. scabra* biomass but its effect was confounded in a significant (P<0.001) cropping system and leaf stripping interaction in Experiment 3 (Fig. 10). Significantly (39%) more *R. scabra* biomass was recorded in the leaf stripped than in the unstripped treatment in the monocrop maize. In contrast, in the maize-pumpkin intercrop, leaf stripping did not affect the *R. scabra* biomass (Fig. 10).

There were 23% and 55% more (P<0.01) seed capsules counted on *R. scabra* and *A. hispidum* plants, respectively, in the monocrop maize compared to the maize-pumpkin intercrop (Fig. 11). Seed dry weight per plant in *A. hispidum* was significantly

Figure 10. Effect of cropping system and leaf stripping on *R. scabra* biomass (g m^{-2}) in Experiment 3.

(P<0.001) higher in the maize monocrop (0.20 g plant^{-1}) than in the maize-pumpkin intercrop (0.16 g plant^{-1}). There was a significant (P<0.001) leaf stripping and detasselling interaction with respect to number of *R. scabra* seed capsule per plant (Fig. 12). There were significantly more (40%) *R. scabra* capsules in the leaf stripped treatment than in the unstripped treatment in tasselled maize. In the detasselled maize, leaf stripping had no effect on seed capsule production by *R. scabra* (Fig. 12).

Canopy radiant environment

Incident PAR on the leaves immediately below the tassel was significantly (P<0.05) increased by an average of 10% in the detasselled treatment compared to the tasselled treatment adjacent to the row and in the middle of the inter-row in Experiment 1 (Fig. 13a) and 2 (data not shown). Detasselling significantly (P<0.05) increased the amount of incident PAR on cob leaves by an average of 4% when compared to the tasselled treatment in Experiment 2. On average, 15% and 20% of the incident PAR reached the pumpkin crop under the maize canopy in the tasselled and detasselled treatments, respectively, in Experiment 1 (Fig. 13a).
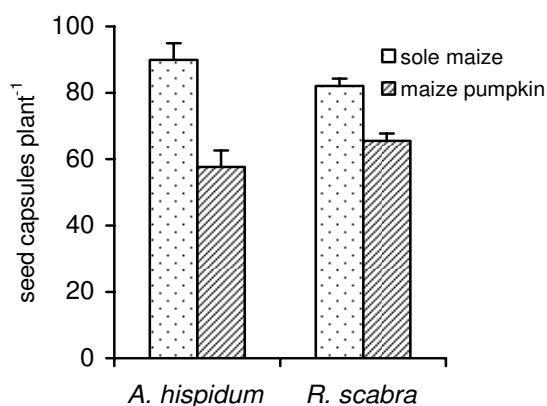
Figure 11. Effect of cropping system on number of seed capsules (number plant^{-1}) produced by *R. scabra* and *A. hispidum* in Experiment 3.
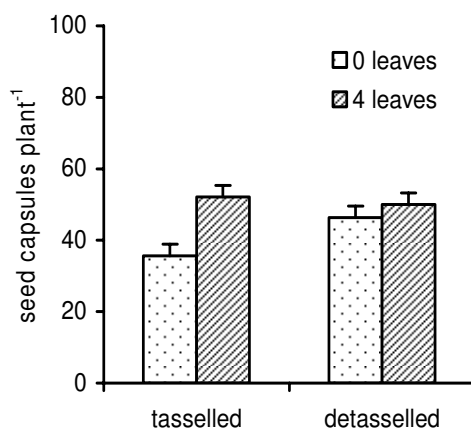
Figure 12. Effect of leaf stripping and detasselling maize on number of seed capsules (number plant^{-1}) produced by *R. scabra* in Experiment 3.

Incident PAR onto the pumpkin leaves below the maize canopy, significantly ($P<0.001$) increased from 10% to 22% of the total incoming PAR, regardless the timing of leaf stripping, in Experiment 1 (Fig. 13b). PAR incident on the ground was significantly ($P<0.001$) reduced from 23% in the maize monocrop to 13% of total incoming PAR in the maize-pumpkin intercrop in Experiment 1 (Fig. 13c). Similar results were obtained in Experiment 2 with 44% of the total incident radiation reaching the ground in the maize monocrop, while only 17% did so in the maize-pumpkin intercrop (Fig. 13c).

Productivity of the maize-pumpkin intercropping system

Table 1 shows the effect of leaf stripping and detasselling treatments on the land equivalent ratio. Only main factor effects are shown for the sake of brevity. Leaf
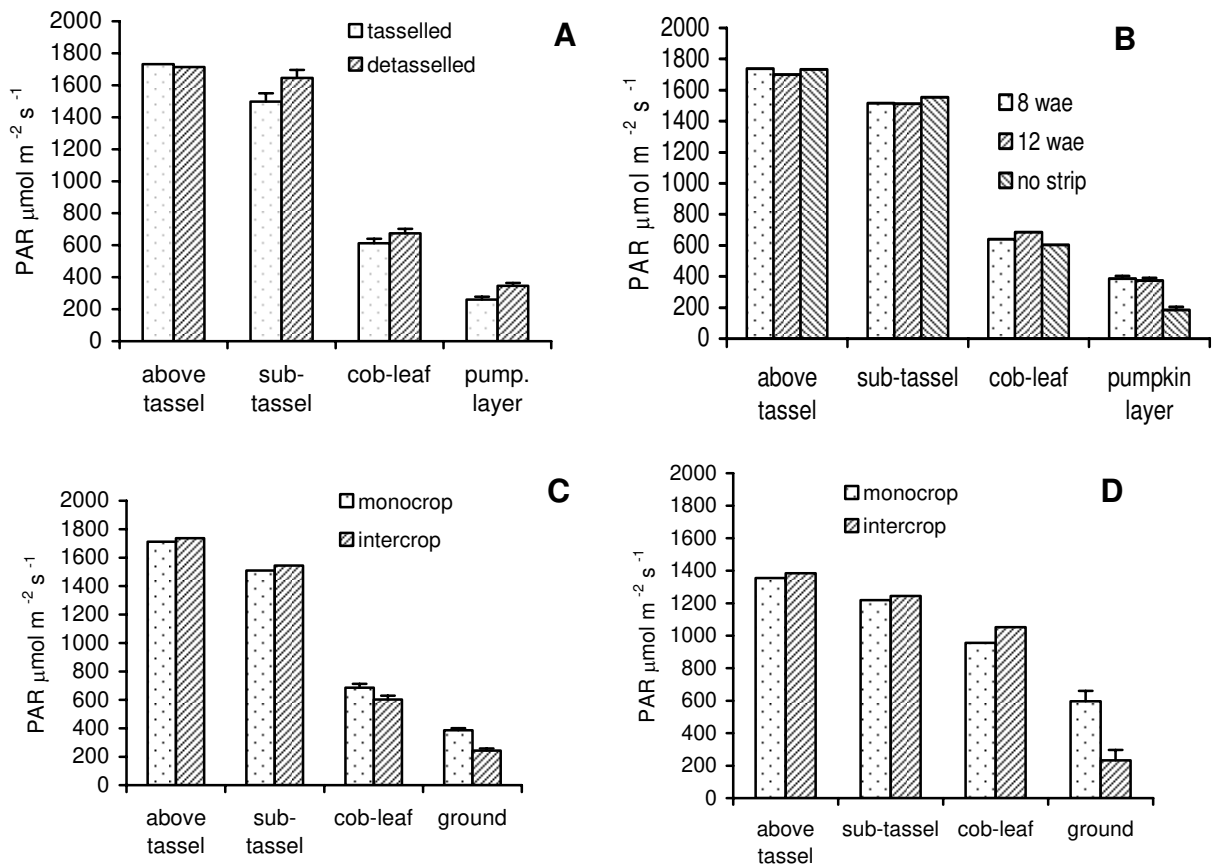
Figure 13. (A) PAR extinction in tasselled and detasselled maize in the middle of the inter-row in Experiment 1 at four heights in the canopy. (B) PAR extinction in the middle of the inter-row in maize in three leaf stripping treatments in Experiment 1. PAR extinction in a maize monocrop and a maize-pumpkin intercrop in the middle of the inter-row in (C) Experiment 1 and (D) Experiment 2.

stripping at 12 WAE, at 50% silking (anthesis) and detasselling at the same time conferred a 50% and 19% grain yield advantage, respectively, over the unstripped and tasselled control in the monocrop, in Experiment 1 (Table 1). An extra 0.39, 0.56 and 0.56 ha of land would be required to produce the equivalent maize-pumpkin intercrop yield of maize grain and pumpkin fruit if the crops were monocropped, compared to a maize-pumpkin intercrop leaf stripped at 8 and 12 WAE and detasselled, respectively, in Experiment 1 (Table 1). The efficiency of land use in the maize-pumpkin intercrop compared to sole unstripped and tasselled maize increased with intensity of leaf stripping from two to four leaves (Table 1). An additional commitment of 0.91 and 1.44 ha of land would be required to produce the equivalent maize and pumpkin yields, if the two crops were monocropped, compared to the intercrops with two and four leaves stripped, respectively. Detasselling in the maize-pumpkin intercrop conferred a 114% increase in efficiency of land use over the monocropped maize and pumpkin in Experiment 2. An additional commitment of one 1.0 and 1.29 ha would be required to produce equivalent maize and pumpkin fruit yields in monocropped maize and pumpkin compared to stripping of four leaves and detasselling in the maize-pumpkin intercrop, respectively, in Experiment 3 (Table 1).

DISCUSSION

Detasselling and maize grain yield

Increases in maize grain yield due to detasselling have been attributed to increased radiation interception by maize leaves as a result of the removal of the 'tassel shading effect' (Chinwuba *et al.*, 1961; Duncan *et al.*, 1967; Hunter *et al.*, 1969; Lambert and Johnson, 1978; Mostert and Marais, 1982) and/or the removal of the 'apical dominance effect' (Mostert and Marais, 1982; Subedi, 1996). However, Muleba *et al.* (1983) observed that when tassels were removed from the plant it became impossible to separate the tassel shading effect and the apical dominance effect on maize grain yield as the two effects are confounded. The increased penetration of PAR into the maize canopy observed on detasselling in this study occurs during the critical three week period bracketing anthesis when Andrade *et al.* (2002) and Barbieri *et al.* (2000) recorded a strong positive correlation between radiation interception and maize grain yield. The increase in maize grain yield was, therefore, partly from the aggregate increases in radiation interception by the maize canopy on detasselling. The grain yield increases were observed to occur through increases in kernel number per unit area and increased kernel weight by Andrade *et al.* (2002) and Barbieri *et al.* (2000), similar to observations made in this study. However, removal of apical dominance that occurs on detasselling, by changing assimilate allocation in favour of the ear (Mostert and

Table 1. Land Equivalent Ratios (LER) for maize-pumpkin intercrops with detasselling and leaf stripping main factor treatments.

Treatments	Maize grain yield (t ha^{-1})	Pumpkin fruit yield (t ha^{-1})	Maize partial LER	Pumpkin partial LER	LER
Experiment 1					
Sole maize (no stripping/tasselled)	4.38	-	1.00	-	1.00
Sole maize					
Leaf stripping					
No leaf stripping	4.90	-	1.12	-	1.12
Leaf stripping at 8 WAE	4.13	-	0.94	-	0.94
Leaf stripping at 12 WAE	6.48	-	1.50	-	1.50
Detasselling					
Tasselled	4.70	-	1.07	-	1.07
Detasselled	5.23	-	1.19	-	1.19
Maize-pumpkin intercrop					
Leaf stripping					
No leaf stripping	3.94	3.52	0.90	0.27	1.17
Leaf stripping at 8 WAE	4.19	5.62	0.96	0.43	1.39
Leaf stripping at 12 WAE	5.17	4.97	1.18	0.38	1.56
Detasselling					
Tasselled	4.45	4.56	1.02	0.35	1.37
Detasselled	5.21	4.48	1.19	0.37	1.56
Sole pumpkin	-	12.97	-	1.00	1.00
Experiment 2					
Sole maize (no stripping/tasselled)	2.51	-	1.00	-	1.00
Sole maize					
Leaf stripping					
No leaf stripping	2.30	-	0.92	-	0.92
Leaf stripping 2 leaves	3.44	-	1.37	-	1.37
Leaf stripping 4 leaves	2.72	-	1.08	-	1.08
Detasselling					
Tasselled	2.72	-	1.08	-	1.08
Detasselled	2.97	-	1.18	-	1.18
Maize-pumpkin intercrop					
Leaf stripping					
No leaf stripping	1.23	7.86	0.49	0.60	1.09
Leaf stripping 2 leaves	2.44	12.19	0.97	0.94	1.91
Leaf stripping 4 leaves	3.65	12.86	1.45	0.99	2.44
Detasselling					
Tasselled	1.72	10.51	0.69	0.81	1.50
Detasselled	3.16	11.41	1.26	0.88	2.14
Sole pumpkin	-	13.01	-	1.00	1.00
Experiment 3					
Sole maize (no stripping/tasselled)	2.18	-	1.00	-	1.00
Sole maize					
Leaf stripping					
No leaf stripping	2.10	-	0.96	-	0.96
Leaf stripping 4 leaves	2.93	-	1.34	-	1.34
Detasselling					
Tasselled	2.25	-	1.03	-	1.03
Detasselled	2.91	-	1.33	-	1.33
Maize-pumpkin intercrop					
Leaf stripping					
No leaf stripping	1.64	6.52	0.75	0.60	1.35
Leaf stripping 4 leaves	2.52	9.16	1.16	0.84	2.00
Detasselling					
Tasselled	1.49	7.04	0.68	0.64	1.32
Detasselled	3.27	8.65	1.50	0.79	2.29
Highest pumpkin yield	-	10.89	-	1.00	1.00

Marais 1982; Subedi, 1996) would cause the same effects on kernel number and test weight as increased radiation interception.

The effects of detasselling on maize grain yield are more strongly expressed when the maize is under water, nutrient or population (high density) stress (Mostert and Marais, 1982; Hunter *et al.*, 1969; Grogan, 1956). In this study, it was observed that detasselling significantly increased maize yield in the maize-pumpkin intercrop but had no effect in the monocrop in Experiments 2 and 3. The greater levels of competitive stress that the maize plants were subjected to in the maize-pumpkin intercrop compared to the monocrop explains the contrasting effects of detasselling on maize grain yield observed in the intercrop and monocrop. Increased apical dominance is manifested by individual plants with increase in plant density (McIntyre, 1964; Phillips, 1975) and increased numbers of barren plants at high maize densities have been attributed partly to this phenomenon (Grogan, 1956; Chinwuba *et al.*, 1961). Subedi (1996) attributed the maize yield increases that he obtained on detasselling to reduced barrenness and higher maize grain test-weight as a result of detasselling eliminating the apical dominance effect. An increase in the apical dominance effect in the maize-pumpkin intercrop as a result of the increased competitive stress and its alleviation by detasselling should partly explain the cropping system × detasselling interaction observed on maize grain yield in this study.

The cropping system and detasselling interaction was only observed when the open pollinated variety was used in Experiments 2 and 3, and not in Experiment 1, when the three-way hybrid SC513 was used; suggesting a variety specific response. Muleba *et al.* (1983) reported that tropical open pollinated maize varieties such as ZM 621 had stronger apical dominance than temperate hybrids. This observation may partly explain the differing magnitudes by which maize grain yield increased on detasselling in the hybrid in Experiment 1 and the open pollinated maize variety in Experiments 2 and 3.

The significant interaction between the effects of leaf stripping and detasselling on maize grain yield in Experiment 3, indicated that there was no additional maize grain yield benefit that accrued on leaf stripping maize that was detasselled. The benefits of leaf stripping in redistributing assimilates more towards the ear are superseded by the detasselling effects which achieve the same end, presumably earlier than the leaf stripping effects. The significant interaction between leaf stripping and detasselling on maize grain yield in Experiment 3 was a replica of the one on cob mass, suggesting that the effects of detasselling and leaf stripping on grain yield occurred through their effects on cob mass. The tallying of the cob mass and 1000 grain-weight and the maize grain yield response to detasselling in Experiments 2 and 3, provides additional evidence that the extent of grain filling and finally cob weight were the processes

affected by detasselling. These observations are consistent with the hypothesis that detasselling changes the dry matter distribution in the plant in favour of the developing cob once apical dominance and competition for assimilates from the pollen production process are removed, by detasselling. Thom and Bryant (1978) reported that detasselling increased the dry matter yield and mineral content of the cob. Sheikh and Mall (1977) recorded a significantly greater 100-grain weight and higher yield in detasselled than tasselled maize. Subedi (1996) attributed the higher yields in the detasselled compared to tasselled maize to reduced number of barren plants and increased test (100-grain) weight. These studies lend themselves to similar interpretation to our results of the effect of detasselling being expressed in increased rates of grain filling and the consequent attainment of higher grain test weight, cob mass and grain yields than the tasselled treatments.

Leaf stripping and maize yield

Leaf stripping at anthesis increased maize grain yield in the three experiments of this study contrary to findings by Subedi (1996). In a previous study (Mashingaidze *et al*., Chapter 3) in a maize monocrop, it was shown that maize grain yield was only increased by stripping bottom leaves at anthesis. Leaf stripping earlier or later than anthesis did not significantly affect maize grain yield. This led to the hypothesis that leaf stripping at anthesis removed leaves that were becoming senescent and if they remained on the plant, under low PAR conditions in the canopy, competed with the developing cob for assimilates. Their removal by leaf stripping would increase assimilate supply to the developing cob for the kernel setting and grain filling processes, increasing maize grain yield. The cropping system × timing of leaf stripping interaction observed in Experiment 1 of this study confirms the effect of timing of leaf stripping observed in the maize monocrop studies (Mashingaidze *et al*., Chapter 3). The detasselling × leaf stripping interactions and the nature of the interactions on 1000-grain weight recorded in Experiments 2 and 3, showed that leaf stripping and detasselling affected the process of grain filling post-anthesis. The effects of detasselling on 1000-grain weight were only expressed when the maize was not leaf stripped and vice-versa, indicating that leaf stripping could not further influence assimilate allocation to the developing cob once maize was detasselled. The interaction between leaf stripping and detasselling on maize grain yield in Experiment 3 suggested that when detasselling had been carried out, there would be no additional yield gain accrued by leaf stripping. If the two processes, detasselling and leaf stripping were expressed on grain yield through the same process of increased partitioning of assimilates to the cob and grain, as hypothesized in this study, then the observed interaction would be expected.

The cropping system × leaf stripping interaction on number of kernels per row on the cob and 1000-grain weight recorded in Experiment 2 reinforces the assertion that leaf stripping at anthesis increases the amount of assimilates available for the kernel formation and grain filling process. There was less PAR reaching the lower leaves in the maize-pumpkin intercrop than in the maize monocrop and it is conceivable that the competition for assimilates between the senescing leaves and the ear would be more intense in the intercrop compared to the monocrop. Such a scenario would explain why leaf stripping increased number of kernels per row and the 1000-grain weight much more in the maize-pumpkin intercrop than in the maize monocrop. Leaf stripping at anthesis also nullified the reduction in maize grain yield that was observed in the maize-pumpkin intercrop compared to the monocrop in unstripped maize in Experiment 1. This result suggests that leaf stripping maybe alleviating the effect of increased shading of lower leaves in the intercrop on assimilate supply to the ear and thereby nullifying the effect of competition for PAR between the maize and the pumpkin, in the lower part of the canopy, on maize yield. When maize was not leaf stripped, there was more competition for assimilates between senescing leaves and the developing ear in the intercrop than in the monocrop, accounting for the yield differences. The senescence of maize leaves in the intercrop is expected to be faster because of higher levels of competition for water and nutrients and greater levels of shading (Sadras *et al.*, 2000) than in the maize monocrop. These results, in which the leaf stripping effects on increased allocation of assimilates to the ear (kernels number per row, 1000-grain weight and cob mass) and maize grain yield seem to be more strongly expressed under intercropping competitive stress are similar to those observed with detasselling in this study.

Pumpkin fruit yield in leaf stripped and detasselled maize
The subdued impact of detasselling on pumpkin fruit yield in this study is reflective of its low impact on the amount of PAR reaching the pumpkins below the maize canopy. Detasselling only caused a 5% increase in the amount of PAR that reached the pumpkin foliage in Experiment 2 and caused the modest pumpkin yield increases that were observed, which did not significantly differ from the tasselled treatments. Leaf stripping had the largest influence on pumpkin fruit yield because it doubled the percentage of incoming PAR that reached the pumpkin foliage from 10% to 20% in Experiment 2 at a row spacing of 0.8 m. Smaller maize plants of the open pollinated variety and wider row spacing (0.9 m) in Experiments 2 and 3, allowed more PAR to reach the pumpkin leaves and hence the far greater responses of pumpkin yield, to leaf stripping, that were registered compared to Experiment 1. PAR measurements could not be continued in Experiments 2 and 3 because of equipment failure. The effect of

timing of leaf stripping in Experiment 2 shows the increased beneficial effect of increasing the duration of exposure to increased amounts of PAR, with early leaf stripping (8 WAE) compared to later leaf stripping (12 WAE) on pumpkin fruit yield.

Subedi (1996) could not find a significant effect of maize leaf stripping and detasselling on the yield of relay intercropped finger millet. The results of this study contradict those of Subedi (1996) and suggest that the effects depend on the growth habit and phenological growth parameters of the minor crop *vis à vis* the timing of leaf stripping and detasselling of the cereal dominant crop. In our study, pumpkins were observed to begin flowering and fruit production at the time of leaf stripping and detasselling, at 12 WAE and being indeterminate in growth habit, continued to do so until maize and pumpkins were harvested at 20 WAE. This means that the pumpkins were exposed to increased radiation levels for a period of 8 weeks during the crucial flowering and fruit development stages, leading to the increases in fruit yield that were observed.

Weed density and biomass

The effects of intercropping on weed density rarely come through because the intercrops take time to reach full ground cover and miss affecting the major flushes of weeds at the beginning of the season, soon after planting (Nyakanda *et al*., 1995; Mashingaidze *et al*., 2000). The effects of maize-pumpkin intercropping were only apparent on the density of *R. scabra* and total weed density in Experiment 3 because *R. scabra* emerged late into the season in response to soil disturbance caused by hoe weeding (personal observation). Its emergence and those of other annual weeds were reduced, in the maize-pumpkin intercrop, by the higher levels of shading and the attenuation of the spectral composition of incoming radiation into far-red rich light that is inhibitory to weed germination as proposed by Radosevich *et al*. (1997).

The maize-pumpkin intercrops consistently reduced weed biomass in Experiments 1 and 3 of this study when compared to the maize sole crops, similar to what was observed by Mashingaidze *et al*. (2000); Akobundu (1993) and Obiefuna (1989) with minor crops of similar architecture and growth habit as pumpkins. The 14%-21% reduction in total incoming PAR reaching the ground caused by maize-pumpkin intercropping when compared to monocropped maize, recorded in this study, accounts for the greater weed growth suppression effects exhibited by the intercrop over that of the maize monocrop. For *R. scabra* and *A. hispidum*, weed seed capsule and seed weight production, followed the trend set by weed biomass and were significantly lower in the maize-pumpkin intercrop than in the sole maize crop. This conforms to observations made by Baumann *et al*. (2001), Wilson *et al*. (1988) and Thompson *et al*. (1991) that there is a linear relationship between vegetative plant size and seed

production in annual weed species. The effects of the maize-pumpkin intercrop on weed biomass and seed production were modified by the leaf stripping and detasselling treatments as shown by the significant cropping system and leaf stripping or detasselling interactions on these factors that were recorded in this study.

In Experiment 1, the longer duration of exposure of the weeds to elevated levels of PAR when leaf stripping was done at 8 WAE than at 12 WAE is reflected in the higher weed biomass. This effect was more evident in the sole maize crop than in the maize-pumpkin intercrop, because the single crop allowed more PAR into the canopy on leaf stripping than in the intercrop, hence the significant cropping system and leaf stripping interaction in Experiment 1. The same explanation applies for the interaction between cropping system and leaf stripping on *R. scabra* biomass in Experiment 3. Leaf stripping only affected weed biomass and *R. scabra* seed capsule production in the tasselled treatment but not in the detasselled treatment (Experiments 1 and 3, respectively), implying that leaf stripping did not add on to the effects of detasselling, on weed biomass and seed production. These leaf stripping and or detasselling interactions with maize-pumpkin intercropping on weed biomass and seed production, point to a possibility of these two interventions increasing the biomass and seed production of late weeds because of the increase in the proportion of incoming PAR that reaches the weeds, on detasselling and leaf stripping. These effects are, however, more likely to be apparent in the maize monocrop, where the foliage density allows more PAR to pass through to weeds, on leaf stripping and or detasselling, than in the maize-pumpkin intercrop.

Productivity and implications for smallholder farmers

This study has shown that the productivity of the maize-pumpkin intercropping system can be increased by 50% to 100% by leaf stripping and detasselling the maize. The study has also shown that the increases in productivity occur as a result of the positive impact of both these interventions on the yield of the dominant crop, maize, and on the yield of the minor crop, pumpkin. Maize-pumpkin intercropping is part of the indigenous knowledge system of traditional cropping systems in Zimbabwe (Mashingaidze *et al*., 2000), Malawi (Chigwe and Saka, 1994) and Zambia (Gwanana and Nichterlein, 1995). Maize-pumpkin intercropping is, therefore, not an alien technology for smallholder farmers in Southern Africa, and leaf stripping and detasselling represent an option to improve the productivity of this widely practised technology and positively contribute to food security in Southern and East Africa. The observation that the effects of leaf stripping and detasselling on maize grain yield maybe more strongly expressed when the maize is subjected to competitive stress will be an added advantage to smallholder farmers who routinely intercrop maize with pumpkin or legumes.

In the tropics, 40-80% of the livestock is associated with mixed crop-livestock farming systems (Brumby, 1987). Leaf stripping and detasselling can potentially enhance the productivity of the crop livestock farming systems by providing high quality forage. The tassels and stripped leaves can be fed to livestock when fresh or can be dried together and used as livestock fodder in the dry season. Defoliated maize leaves used as fodder have been integrated into crop livestock production trials in Kenya with satisfactory results (Abate and Abate, 1994). Simenye *et al.* (1994) reported that defoliating one leaf per week beginning at the tasselling stage produced 1.4 t ha^{-1} dry matter of forage but did not affect grain yield of maize. The defoliated maize leaves had 12% crude protein and *in vivo* dry matter digestibility of 60%. Abate and Abate (1994) showed that defoliated maize leaves were more acceptable to weaner lambs and were of a higher nutritional value than Napier grass. As a result, the animals fed maize leaves gained more weight than those fed Napier grass. The extent to which leaf stripping and detasselling can be integrated to benefit livestock production systems in smallholder farming systems requires further investigation.

CHAPTER 5

The effect of leaf stripping and detasselling on the productivity of a maize-bean intercrop

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Abstract

Three experiments were carried out in Zimbabwe in the 2001/02 and 2002/03 season to assess the feasibility of increasing the productivity of a maize-bean intercropping system by leaf stripping and/or detasselling of the maize plants at anthesis. The three factors in the experiments were cropping system (sole maize, maize-bean intercrop or sole beans), leaf stripping (stripping of 0, 4 or 6 lowest green leaves at anthesis from the maize crop) and detasselling (maize detasselled at anthesis or tasselled). Leaf stripping and detasselling did not significantly increase bean yield in the maize-bean intercrops. The increase in radiant energy penetration in the canopy caused by detasselling and leaf stripping was too late for the bean crop and modestly increased bean yield by 5-10% compared to the tasselled unstripped control. However, maize grain yield in the detasselling and leaf stripped maize-bean intercrop was equal to monocrop maize grain yield and added to the modest increases of 5-10% in bean yield, resulting in LERs of 1.46-2.16 in Experiment 1. Delaying leaf stripping and detasselling by one week reduced their effect on maize grain yield such that LER for the maize-bean intercrop varied between 1.13-1.30 in Experiment 2. Results from Experiments 2 and 3 of this study indicated that leaf stripping of six leaves may be too severe and potentially detrimental to maize grain yield especially in crops with reduced number of leaves due to drought or mineral nutrient deficiency. Maize-bean intercropping reduced weed biomass by 44-72%. A cropping system × weeding regime interaction on weed biomass showed that the maize-bean intercrop required one hoe-weeding at 3 WAE (weeks after emergence) to attain a similar weed biomass as sole maize weeded twice at 3 and 6 WAE.

Key words: Maize, bean, intercropping, leaf stripping, detasselling, weed biomass.

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is an important source of protein and a valuable cash crop for smallholder farmers in Southern Africa. The protein content of common bean varieties ranges from 17% to 22% (Singh *et al.*, 2002; Ochetim *et al.*, 1980). Beans, therefore, play an important nutritional role as a meat substitute and are frequently the only source of protein for the poor in smallholder farming communities of Africa and Central America. Beans are not only valued as a food but traditionally fetch 10 to 20 times higher prices, on weight basis, than cereal crops such as maize and are, therefore, viewed as an important cash crop (Mutungamiri *et al.*, 2001).

Maize-bean intercropping is a common cropping system in most parts of southern Africa where rainfall ranges from 700-1500 mm spread over five months. Ngwira *et al.* (1990) reported that 94% of the total land area in Malawi was under intercropping, with 94% of the maize and 99% of the pulses grown in association. Maize-bean intercropping is an integral part of the cropping system in the smallholder sector (Mariga, 1990). Munguri (1996) found that a high proportion (92%) of the farmers who practiced intercropping used the maize-bean intercropping system in the Chinyika Resettlement Area in Zimbabwe.

Leaf stripping and detasselling have been shown to increase the yield of pumpkins in the under story of the maize crop by increasing the amount of photosynthetically active radiation (PAR) reaching the pumpkins in the crucial reproductive stages of flowering and fruit production (Mashingaidze *et al.*, Chapter 4). Chipomho (1997) showed that increased radiation penetration to the beans under an erectophile maize cultivar PHB3442 resulted in 12% higher bean yield when compared to beans intercropped with a planophile maize cultivar SC501. Mutungamiri *et al.* (2001) reported an increase in bean yield of 37% in maize-bean intercropping with a lower maize density (90 cm × 45 cm) than the conventionally used 90 cm × 30 cm spatial arrangement. The aggregate increase in the radiation intercepted by the beans under the maize canopy was cited as being responsible for the observed increase in bean yield in the 90 cm × 45 cm maize spatial arrangement (Mutungamiri *et al.*, 2001).

Detasselling and leaf stripping were shown to increase the amount of assimilates available to the ear during the grain formation and grain filling stages, as evidenced by their positive effect on cob weight, number of grains per ear and grain test weight, leading to increases in maize grain yield (Mashingaidze *et al.*, Chapter 4). Leaf stripping and detasselling were, therefore, able to substantially increase the productivity of a maize pumpkin intercropping system by both increasing the maize grain yield and pumpkin fruit yield (Mashingaidze *et al.*, Chapter 4). It was, therefore, decided to study the effects of leaf stripping and detasselling on the productivity of a

maize-bean intercropping system as well. It was hypothesized that, by increasing the aggregate amount of PAR intercepted by the bean crop during the reproductive stages, leaf stripping and detasselling would increase bean yield. With the anticipated increases in bean yield added to the earlier noted benefits of increased maize yield as a result of leaf stripping and detasselling, it was hypothesized that leaf stripping and detasselling will increase the productivity of the maize-bean intercropping system.

The hypothesis tested in this study were (a) leaf stripping and detasselling at anthesis increase maize yield in maize bean intercrops; (b) leaf stripping and detasselling increase the amount of PAR reaching the beans and result in increases in bean yields; and (c) maize-bean intercropping will reduce weed germination and growth more than the sole crops of either component crop.

MATERIALS AND METHODS

The experiments to investigate the effect of leaf stripping and detasselling on the productivity of a maize-bean intercrop were conducted at the University of Zimbabwe (UZ) farm in the 2001/2002 and 2002/2003 seasons. A third experiment was conducted on a smallholder farm at Village 40, in the Chinyika Resettlement Area (CRA) in 2003. The UZ farm site lies 31°10′ East and 18°25′ South and is 14 km north-west of Harare, on red fersiallitic clay soils with more than 40% clay, and an average annual rainfall of 800 mm. Village 40, CRA, lies between 32°05′ and 32°44′ East and between 18°00′ and 18°20′ South, 140 km south-east of Harare, on granitic sandy soils with 20% clay.

The land was ploughed and harrowed to a fine tilth and planting furrows were opened using hoes. Maize was planted at 90 cm × 30 cm spacing to establish a plant density of 37,000 plants ha^{-1}. Two maize seeds were dropped per planting station and the maize was thinned to one plant per planting station at 2 weeks after crop emergence (WAE). Beans were planted at 45 cm × 10 cm spacing to establish a density of 222,000 plants ha^{-1} in the bean monocrop treatments. In the intercrop, two rows of beans, 30 cm apart, were planted between the maize rows. The distance between bean rows located on adjacent maize inter-row area was 60 cm. A basal dressing of 150 kg ha^{-1} of compound D fertilizer (8% N, 14% K_2O, 7% P_2O_5) was applied to the maize and bean planting furrows. The maize crop was top-dressed with 150 kg ha^{-1} ammonium nitrate (34.5% N) at 5 WAE.

Experiment 1 (UZ farm 2001/02 season)
The experiment was laid out as a 3 × 2 × 2 factorial in a randomized complete block design replicated three times. The first factor was cropping system with three levels

viz. sole maize, maize-bean intercrop and sole beans. The second factor was the detasselling treatment with two levels viz. detasselling at tassel emergence (detasselled) and leaving the tassel on the plant (tasselled). The third factor was leaf stripping with two levels viz. stripping of four leaves at 50% silking (stripped) and leaving the leaves on the plant (unstripped). The treatments were replicated three times. A long season single-cross maize cultivar, SC 701, from Seed-Co[®] (Zimbabwe) was intercropped with a common bean cultivar, Natal Sugar, obtained from National Tested Seeds[®] (Zimbabwe). The crop was hoe-weeded twice, at 3 and 8 WAE.

Detasselling and leaf stripping were conducted at 50% silking (anthesis), at 94 days after emergence. The four lowest leaves that were alive at anthesis were cut at the junction between the leaf sheath and the stem. Tassels were grabbed and pulled from the leaf sheath without damaging the sub-tassel leaves on the maize plant on detasselling. PAR penetration into the crop canopy was measured by placing Li-Cor 191-SA line quantum sensors (Li-Cor, Lincoln, Nebraska, USA) at three levels in the canopy: ground level, cob level and above the tassel at 15 WAE, after detasselling and leaf stripping. Measurements were made in the middle of the row and adjacent to the maize row, at three positions in a plot. The average from the three readings was analysed. Weeds were counted by species at 8 and 15 WAE, in five randomly thrown 30 cm × 30 cm quadrants in each plot, cut at ground level and dried at 80 °C to a constant weight and weighed.

The gross plots were 4.5 m wide and 7.5 m long and the net plots were 2.7 m wide and 6 m long. Maize cobs were hand harvested at 26 WAE and shelled and the grain yield was adjusted to 12.5% moisture content and expressed on a hectare basis. Beans were harvested by pulling the plants from the ground after the pods began to dry out and turn brown, at 19 WAE. The number of pods per plant was counted and bean yield was adjusted to 14% moisture content before analysis.

Experiment 2 (UZ farm 2002/03 season)

The experiment was laid out as a 3 × 3 × 2 factorial in a randomized complete block design with three replications. The experimental factors and their levels were the same as in Experiment 1, except that an additional leaf stripping level, leaf stripping of 6 lowest leaves at anthesis, was added.

A short season three-way hybrid, SC 513, from Seed-Co[®] (Zimbabwe) was intercropped with the bean cultivar Natal Sugar obtained from National Tested Seeds[®] (Zimbabwe). Leaf stripping and detasselling was scheduled to be done at 12 WAE at 50% silking, however, because of logistical problems due to industrial action by UZ workers it was delayed by one week. Measurements of yield components of maize (cob mass, grain mass per cob and cob length) and of beans (number of pods per plant,

mass of pods per plant and mass of beans per plant) were made after harvesting in Experiment 2.

Experiment 3 (Village 40, Chinyika Resettlement Area 2002/03)

The experiment was laid out as a $3 \times 2 \times 2 \times 2$ factorial in a randomized complete block design with three replications. The first, second and third factors were cropping system, leaf stripping and detasselling as in Experiment 1. The only difference with Experiment 1 was in the leaf stripping treatments. There were two leaf stripping levels, leaf stripping of 4 lowest leaves and 6 lowest leaves in Experiment 3. The fourth factor was weeding regime with two levels, weeding once at 3 WAE and weeding twice at 3 and 6 WAE. Additional measurements as described for Experiment 2 made for Experiment 3. SC 513 and Natal Sugar were intercropped as in Experiment 2. Experiment 3 was located in a farmer's field. Detasselling and leaf stripping was conducted at 12 WAE.

Analysis of data

All weed density data were square root ($x + 0.5$) transformed (Steel and Torrie, 1984) before analysis. Analysis of variance was carried out on the data using the SAS statistical package (SAS Institute 1999, Release 8, Cary, NC, USA). The standard error of the difference (Sed) was calculated used for mean separation when $P<0.05$. Error bars on figures represent +1 Sed unless otherwise stated. Intercrop productivity was assessed by calculating Land Equivalent Ratios from component crop yields (Mead and Willey, 1980).

RESULTS

Maize grain yield

Maize grain yield was significantly reduced, by 12.0%, 11.6% and 22.0% in Experiments 1, 2 and 3, respectively, by maize-bean intercropping (Fig. 1a). The main effects of leaf stripping and detasselling were not consistent across the Experiments 1, 2 and 3 (Figs 1a, b and c). There were significant cropping system × leaf stripping × detasselling ($P<0.01$), cropping system × leaf stripping ($P<0.05$) and cropping system × detasselling × weeding regime ($P<0.05$) interactions in Experiments 1, 2 and 3, respectively.

The three-way cropping system × leaf stripping × detasselling interaction in Experiment 1 means that the effect of cropping system depended on the treatment combinations of detasselling and leaf stripping (Fig. 2a). It is apparent that maize-bean intercropping only significantly reduced maize grain yield when 4 leaves were stripped

and the crop detasselled. When the crop was either detasselled or leaf stripped only, maize grain yield in the maize-bean intercrop was similar to that of sole maize (Fig. 2a).

In general, maize grain yield was higher in the detasselled and leaf stripped treatments than in the unstripped tasselled treatments, when averaged across cropping system treatments (Fig 2a).

The interaction between cropping system and leaf stripping in Experiment 2 is shown in Fig. 2b. Sole maize produced higher maize grain yield than the maize-bean intercrop at all leaf-stripping levels. However, the grain yield was only significantly higher in sole maize than in the maize-bean intercrop when 6 leaves were stripped, but not when no leaves or 4 leaves were stripped (Fig. 2b).

The three-way cropping system × detasselling × weeding regime interaction with respect to maize grain yield in Experiment 3 is shown in Fig 2c. In general, sole maize produced higher maize grain yield than the maize in the maize-bean intercrop.
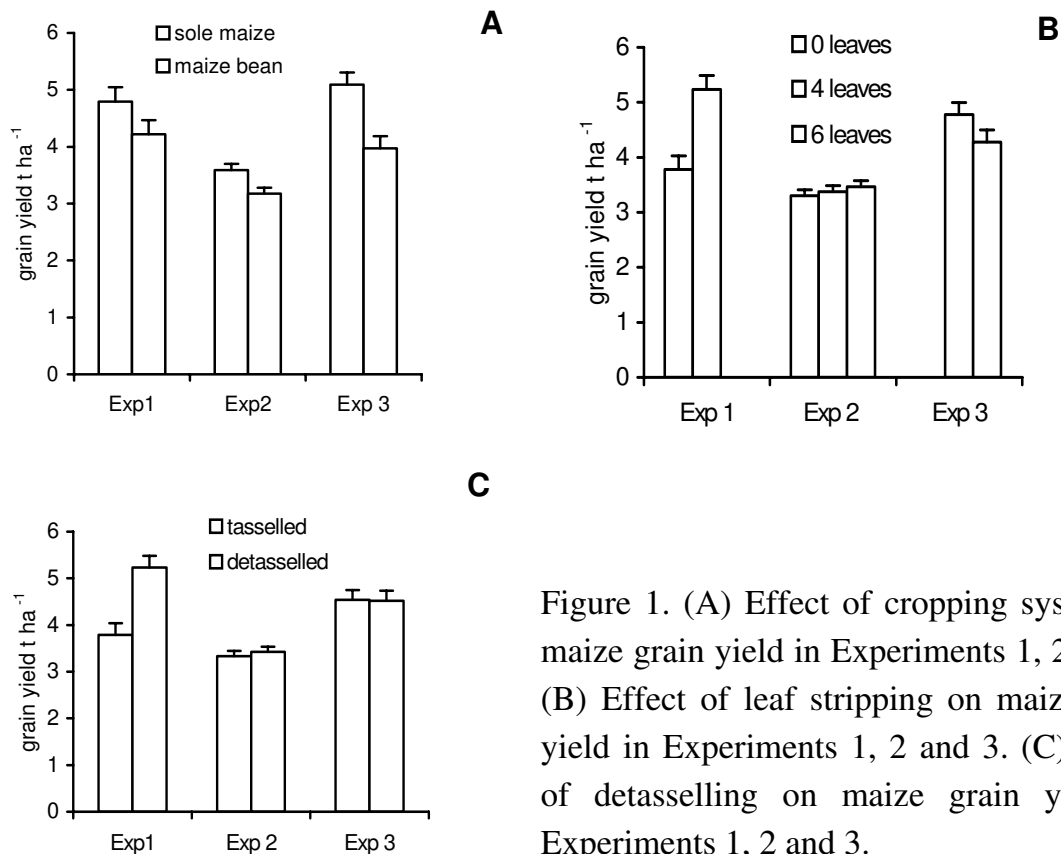
Figure 1. (A) Effect of cropping system on maize grain yield in Experiments 1, 2 and 3. (B) Effect of leaf stripping on maize grain yield in Experiments 1, 2 and 3. (C) Effect of detasselling on maize grain yield in Experiments 1, 2 and 3.
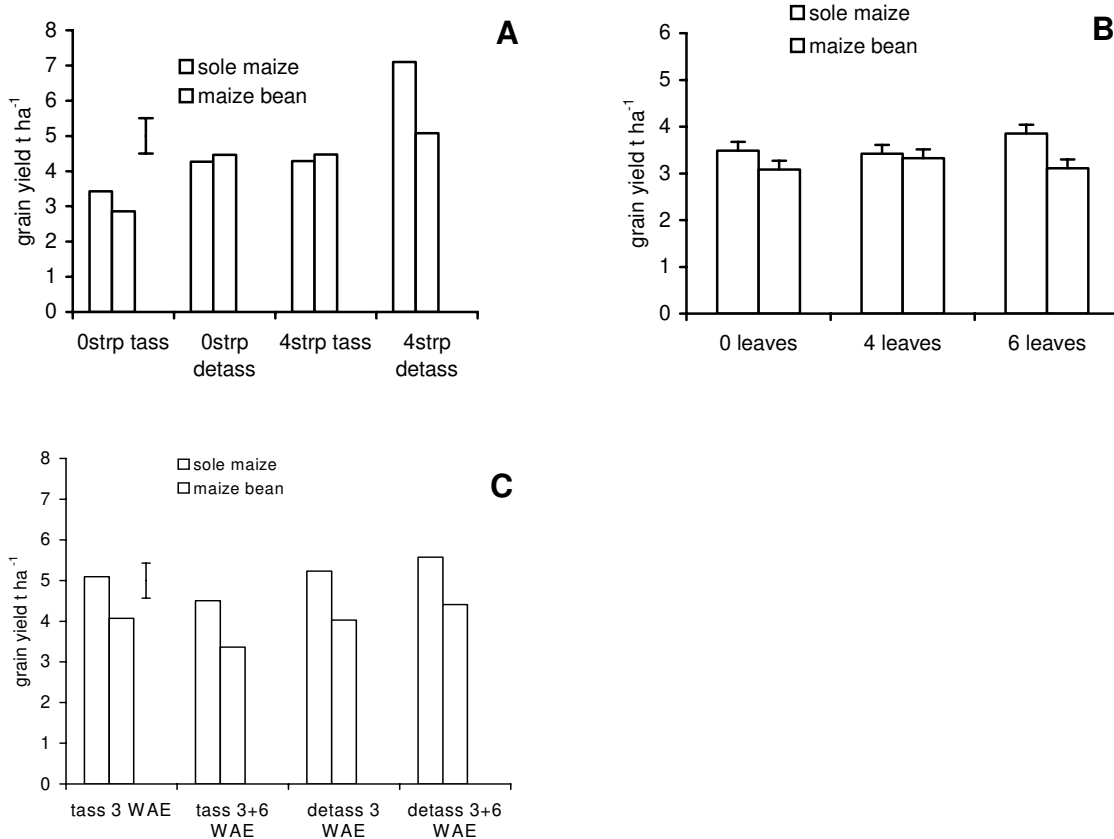
Figure 2. (A) Effect of detasselling and leaf stripping in sole and intercropped maize on maize grain yield in Experiment 1. (B) Effect of leaf stripping on maize grain yield in sole and intercropped maize in Experiment 2. (C) Effect of detasselling and weeding regime on maize grain yield in sole and intercropped maize in Experiment 3.

Maize grain yield components

Sole maize produced significantly heavier cobs in Experiment 3 and heavier grain mass cob^{-1} in Experiment 2 than the maize-bean intercrop (Table 1). It is also apparent, from Table 1, that sole maize produced heavier cobs and more grain mass per cob than in the maize-bean intercrop in Experiments 2 and 3, respectively.

The effects of leaf stripping on maize grain yield components are shown in Table 2. There was a consistent trend of increase in cob mass, grain mass cob^{-1}, cob length and kernel rows cob^{-1} with increase in intensity of leaf stripping in Experiment 2. This effect of leaf stripping on grain yield components was only significant on grain mass cob^{-1} (Table 2). In Experiment 3, stripping of 6 leaves significantly reduced cob mass when compared to stripping 4 leaves (Table 2). This difference was maintained for grain mass cob^{-1} but was not statistically significant (Table 2).

Table 1. Effect of cropping system on maize grain yield components in Experiments 2 and 3.

Cropping system	Cob mass g cob^{-1}		Grain mass cob^{-1}		Cob length cm	
	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3
Sole maize	218a	259b	193b	207a	19a	21a
Maize-bean	208a	209a	182a	183a	18a	20a
P-value	P>0.05	P<0.001	P<0.05	P>0.05	P>0.05	P>0.05
Sed	8.2	12.3	4.5	24.7	0.2	0.5
$Lsd_{0.05}$	NS	25.1	9.3	NS	NS	NS

Table 2. Effect of intensity of leaf stripping on maize grain yield components in Experiments 2 and 3.

Intensity of leaf stripping	Cob mass g cob^{-1}		Grain mass cob^{-1}		Cob length cm cob^{-1}		Kernel rows cob^{-1}	Grain nr cob^{-1}
	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3
Unstripped	209a		182a		19a		15a	
4 leaves stripped	212a	252b	187ab	211a	19a	20a	15a	428
6 leaves stripped	217a	218a	194b	180a	19a	19a	15a	407
P-value	P>0.05	P<0.05	P<0.05	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Sed	10.0	12.3	5.5	24.8	0.3	0.5	0.3	23.5
$Lsd_{0.05}$	NS	25.1	11.5	NS	NS	NS	NS	NS

The effects of detasselling on maize yield components are shown in Table 3. Detasselling increased yield components when compared to the tasselled treatment in Experiments 2 and 3; however, the effect was not statistically significant (Table 3).

There was a significant interaction (P<0.05) between cropping system and detasselling on cob mass in Experiment 3. Cob mass was higher in sole maize than in the maize-bean intercrop but it was statistically significant in the detasselled treatment and not in the tasselled treatment (Fig. 3a). There was a significant (P<0.01) cropping system × leaf stripping interaction with respect to grain number cob^{-1} (Fig. 3b). Grain number cob^{-1} was lower in the maize-bean intercrop compared to sole maize when 4 leaves were stripped but was not significantly different when 6 leaves were stripped.

Table 3. Effect of detasselling on maize grain yield components in Experiment 2.

Treatment	Cob mass g cob^{-1}		Grain mass cob^{-1}		Cob length cm cob^{-1}		Kernel rows cob^{-1}	Grain number cob^{-1}
	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3
Tasselled	212a	229a	186a	180a	19a	19a	15a	409a
Detasselled	215a	241a	190a	216a	19a	20a	15a	426a
P-value	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Sed	8.2	12.3	4.5	24.8	0.2	0.5	0.3	23.5
Lsd$_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS

Bean yields

Bean yields were reduced by 31.8, 71.6 and 11.0% in the maize-bean intercrop compared to the sole beans averaged across the leaf stripping and detasselling treatments in Experiments 1, 2 and 3, respectively (Fig. 4a). Leaf stripping (Fig. 4b) and detasselling (Fig. 4c) did not significantly affect bean yields in any of the experiments. There is, however, a noticeable trend of an increase in bean yield with leaf stripping and detasselling in Experiment 2 (Figs 4b and 4c).
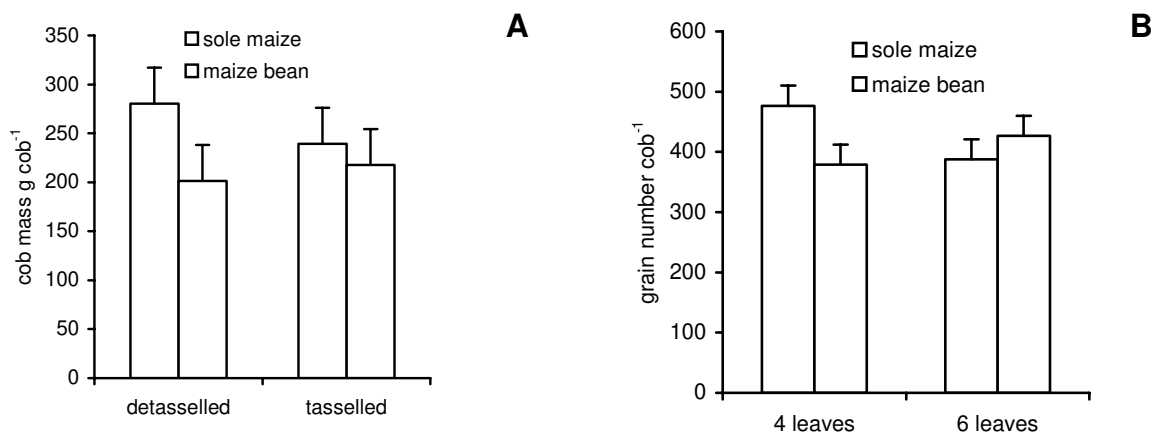
Figure 3. (A) Interaction between effects of detasselling and cropping system on maize cob mass in Experiment 3. (B) Interaction between effects of cropping system and leaf stripping intensity on number of grains per cob in Experiment 3.
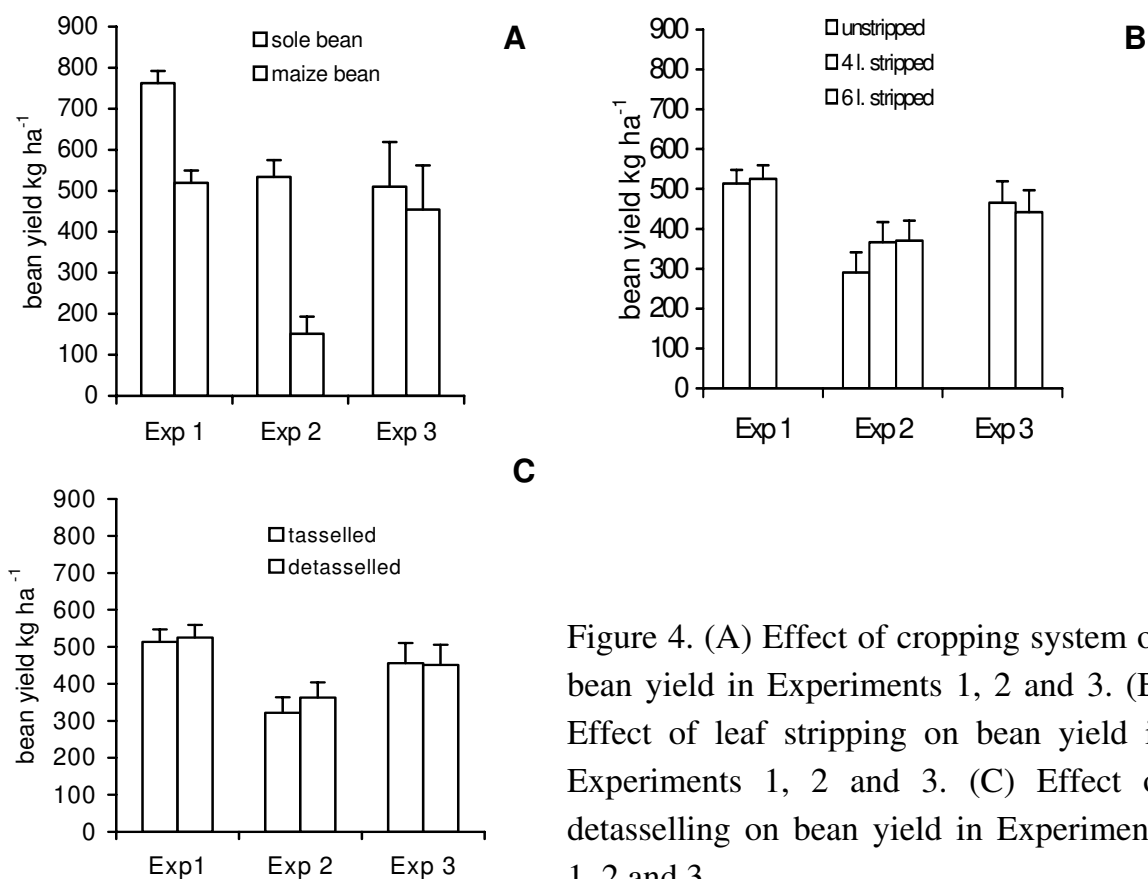
Figure 4. (A) Effect of cropping system on bean yield in Experiments 1, 2 and 3. (B) Effect of leaf stripping on bean yield in Experiments 1, 2 and 3. (C) Effect of detasselling on bean yield in Experiments 1, 2 and 3.

Bean yield components

All bean yield components were reduced by approximately 50% in the intercrop when compared to sole beans in Experiment 2 (Table 4). Bean yield components showed a consistent trend of increasing with the number of leaves stripped in Experiment 2 but treatment differences were not statistically significant (Table 5).

Table 4. Effect of cropping system on bean yield components in Experiments 1 and 2.

Cropping system	Pods plant^{-1}		Pod mass plant^{-1}	Mass of beans plant^{-1}
	Exp 1	Exp 2	Exp 2	Exp 2
Sole bean	17a	16b	25b	23b
Maize bean	14a	8a	14a	11a
P-value	P>0.05	P<0.001	P<0.001	P<0.001
Sed	0.8	0.8	1.6	1.5
Lsd$_{0.05}$	NS	1.8	3.6	3.2

Table 5. Effect of leaf stripping intensity on bean yield components in Experiment 2.

Intensity of leaf stripping	Pods plant^{-1}	Pod mass g plant^{-1}	Mass of beans plant^{-1}
Unstripped	11a	21a	15a
4 leaves stripped	11a	21a	16a
6 leaves stripped	12a	22a	17a
P-value	P>0.05	P>0.05	P>0.05
Sed	1.1	2.1	1.9
Lsd$_{0.05}$	NS	NS	NS

Table 6. Effect of cropping system on weed density {sqrt(x+0.5) transformed} and weed biomass at 15 WAE in Experiments 1 and 3.

	Weed density (number m^{-2})		Weed biomass g m^{-2}	
	Experiment 1			
Cropping system	*L. martinicensis*	Total density	Experiment 1	Experiment 3
Sole maize	3.4b	4.6b	21.6b	6.3b
Maize-bean intercrop	2.2a	3.6a	6.0a	3.6a
P-value	P<0.05	P<0.05	P<0.01	P<0.05
Sed	0.51	0.4	5.06	1.32
Lsd$_{0.05}$	1.11	0.87	10.86	2.70

Weed density and biomass

Weed density was lower in the intercrop compared to the sole crop in Experiment 1 (Table 6). Weed biomass behaved similar to weed density in the intercrop and the monocrop in Experiments 1 and 3 (Table 6). There was a significant (P<0.01) cropping system × weeding regime interaction on weed biomass in Experiment 3. The maize-bean intercrop that was weeded once at 3 WAE suppressed weed growth as effectively as sole maize and the maize-bean intercrop that was weeded twice at 3 and 6 WAE (Fig. 5). Weed biomass in sole maize was more than three times that in the maize-bean intercrop when the crops were weeded once at 3 WAE (Fig. 5).
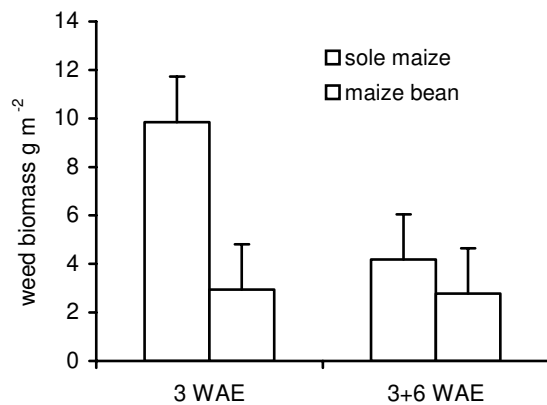
Figure 5. Interaction between cropping system and weeding regime on weed biomass in Experiment 3.

The radiant environment of the crop

PAR penetration into the canopy was measured in Experiment 1. More PAR penetrated to the cob leaf level in the maize-bean intercrop because of smaller plants with a reduced leaf area that were observed in the maize-bean intercrop compared to the sole maize stands (Fig. 6a). There was 5.1% more PAR penetrating to the ground in the sole maize than in the maize-bean intercrop (Fig. 6a). Stripping of four leaves increased PAR reaching the ground by 6% (Fig. 6b). Detasselling increased the proportion of incoming PAR reaching the cob leaf level and the ground by 6% and 2%, respectively (Fig. 6c).

Productivity

The productivity of the maize-bean intercropping system with leaf stripping and detasselling was assessed through comparison of the Land Equivalent Ratios (LER) (Mead and Willey, 1980) of the treatment combinations (Table 7). Leaf stripping and/or detasselling in the sole or intercropped maize in Experiment 1 conferred a yield advantage over the unstripped tasselled maize, which is the normal farmer practice, The calculated LER values reflect this and show that a farmer would need an extra 0.21, 0.22 and 1.01 ha of land planted to sole unstripped tasselled maize to produce the same yield as detasselled, leaf stripped and detasselled and leaf stripped sole maize crop (Table 7). The partial LERs for maize in the maize-bean intercrop was calculated based on the unstripped and tasselled sole maize yield. The partial LER for the unstripped and tasselled, detasselled, leaf stripped and, leaf stripped and detasselled maize was 0.88, 1.27, 1.27 and 1.44, respectively. Addition of the bean partial LERs to the maize partial LERs resulted in the higher LERs reflected in Table 7 for the intercrop than the monocrop. Yield of maize did not decrease in the intercrop compared to the sole crop when leaf stripped, detasselled and detasselled and leaf stripped in Experiment 1 (Table 7).
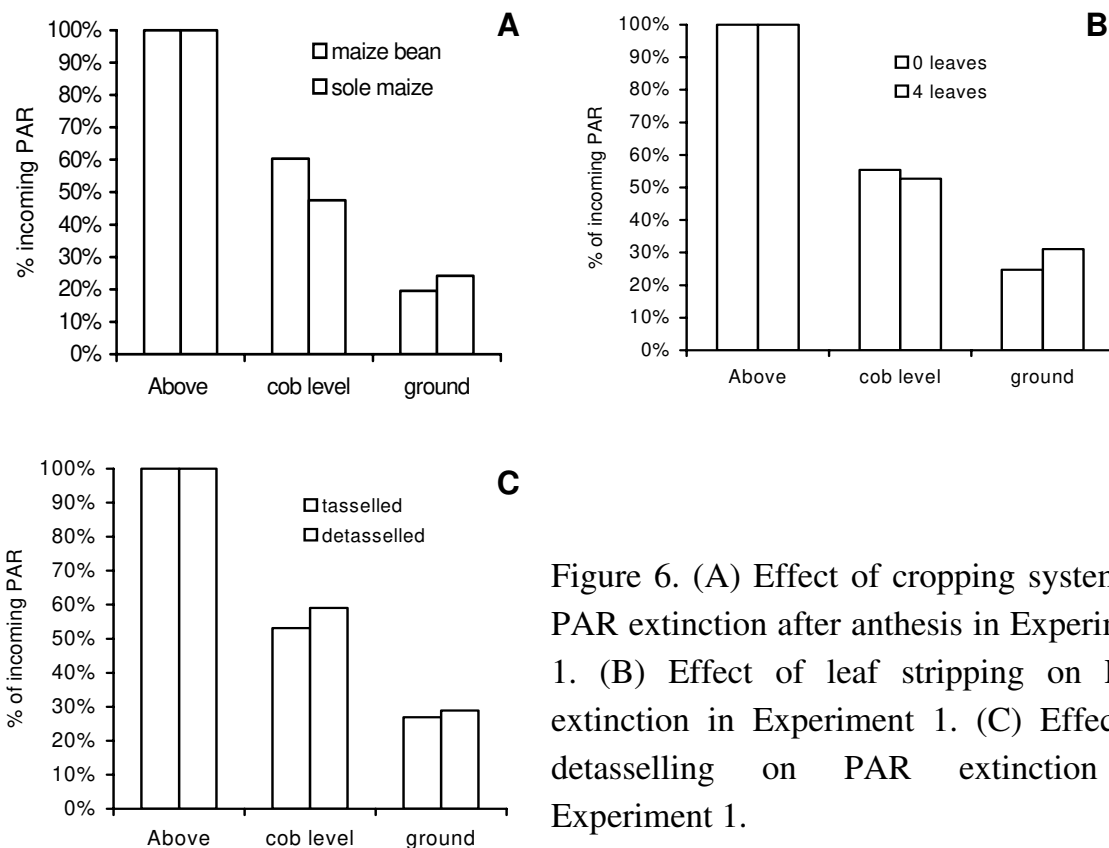
Figure 6. (A) Effect of cropping system on PAR extinction after anthesis in Experiment 1. (B) Effect of leaf stripping on PAR extinction in Experiment 1. (C) Effect of detasselling on PAR extinction in Experiment 1.

The LERs for detasselled, leaf stripped and, detasselled and leaf stripped maize in the monocrop and in the intercrop reflects the modest maize yield responses caused by these interventions in Experiment 2. This in turn is reflected in the modest gains in LER in the maize-bean intercrop that is detasselled, leaf stripped, and detasselled and leaf stripped in Experiment 2 (Table 7). Stripping of six leaves from the maize plant negatively affected maize yield and the sole maize LERs show this effect in Experiment 3 (Table 7).

DISCUSSION

Maize grain yield

Maize yields were depressed by 12-22% when intercropped with beans because of competition for water and nutrients. The crop architecture of the common bean is such that it offers little competition for light except in the early stages of growth. In this study, it was noticeable that during dry spells, the maize in the maize-bean intercrop wilted earlier and generally exhibited more severe symptoms of water stress than the sole maize. The maize plants in the maize-bean intercrop were generally smaller with a smaller leaf area as shown by the greater proportion of incoming radiation that

Table 7. Land Equivalent Ratio (LER) analysis of treatment combinations in maize-bean intercropping experiments. Maize yield was measured in t ha^{-1} and bean yield in kg ha^{-1}.

	Experiment 1			Experiment 2			Experiment 3		
	Maize yield	Bean yield	LER[1]	Maize yield	Bean yield	LER[1]	Maize Yield	Bean yield	LER[2]
Sole maize									
Unstripped tasselled	3.52	-	1.00	3.43	-	1.00			
Unstripped detasselled	4.27	-	1.21	3.60	-	1.04			
4 l. stripped tasselled	4.29	-	1.22	3.47	-	1.01	5.13	-	0.88
4 l. stripped detasselled	7.10	-	2.01	3.38	-	0.98	5.81	-	1.00
6 l. stripped tasselled				3.69	-	1.08	4.47	-	0.77
6 l. stripped detasselled				4.02	-	1.17	4.96	-	0.85
Maize-bean									
Unstripped tasselled	2.86	498	1.46	2.94	145	1.13			
Unstripped detasselled	4.46	501	1.92	3.29	155	1.25			
4 l. stripped tasselled	4.48	528	1.96	3.46	156	1.30	4.41	461	1.61
4 l. stripped detasselled	5.08	549	2.16	3.18	164	1.24	4.04	487	1.61
6 l. stripped tasselled				3.03	149	1.16	4.35	441	1.61
6 l. stripped detasselled				3.14	141	1.17	3.36	443	1.45
Sole bean		761	1.00		534	1.00		510	1.00

[1] Maize yields are compared to the normal farmer practice of monocropping unstripped tasselled maize, and bean yield to the sole bean yield in calculating LER for Experiments 1 and 2.

[2] Maize yields are compared to the highest maize monocrop yield, and bean yield to the sole bean yield in calculating LER for Experiment 3.

penetrated into the maize-bean intercrop to the cob leaf level than in sole maize in Experiment 1 of this study. The effects of bean competition for water and nutrients are reflected in the degree of the maize yield depression that was recorded. In this study, the crop that suffered the most severe drought stress also exhibited the largest maize yield depression. This crop was in Experiment 3, located in a farmer's field, in a drier part of Zimbabwe, without any irrigation facilities. Experiments 1 and 2, located at the UZ farm were occasionally rescued from severe drought stress by supplementary irrigation. Under semi-arid conditions in Ethiopia, maize yields were reduced by an average of 24% under maize-bean intercropping (Fininsa, 1997), similar to the 22% yield depression recorded in semi-arid Chinyika Resettlement Area in this study.

The interaction of cropping system and treatment combinations of detasselling and leaf stripping on maize grain yield in Experiment 1 bears some resemblance to what was observed with leaf stripping and detasselling experiments in maize pumpkin-intercropping (Mashingaidze *et al.*, Chapter 4). Leaf stripping or detasselling nullified the yield reduction caused by the presence of bean in the maize-bean intercrop and grain yield is similar in intercrop maize and in sole maize in Experiment 1 (Fig. 2a). The increased expression of the positive effects of detasselling (Mostert and Marais, 1982; Grogan 1956; Mashingaidze *et al.*, Chapter 4) or leaf stripping on maize grain yield when the plant is subjected to competitive stress (Mashingaidze *et al.*, Chapter 4) are confirmed by results of this study. Analysis of the LERs for maize that was leaf stripped or detasselled in Experiments 2 and 3 (Table 7) suggests that leaf stripping and detasselling ameliorate the competitive effects of the companion bean crop on maize yield. There is increased apical dominance with increased plant density (McIntyre, 1964; Phillips, 1975) leading to increased percentages of barren plants and lowering grain yields in maize (Chinwuba *et al.*, 1961). Detasselling increases maize grain yield by removing apical dominance (Mostert and Marais, 1982; Subedi, 1996) and by increasing radiation penetration into the maize canopy (Lambert and Johnson, 1978; Mostert and Marais, 1982. It would, therefore, be logical that detasselling would relieve the increased plant density effects imposed by the bean companion crop by the same mechanisms described above and explain why detasselling nullified the cropping system effect in Experiment 1.

When the maize crop is subjected to moisture stress during the season, the rate of senescence of the lower leaves is increased. Results from this study indicate that the intensity of leaf stripping should take this into account. In Experiment 3, stripping of six leaves reduced maize grain yield compared to stripping of four leaves (Fig. 1b). During the leaf stripping exercise it was noticeable that leaves just below the cob were being removed when six leaves were stripped. Experiment 3 was located on granitic sandy soils with low inherent fertility (Grant, 1981) and this contributed to the lower number of leaves surviving at anthesis. Therefore, there was greater likelihood of leaves that were actively contributing to net photosynthesis during the crucial grain formation and grain filling process being removed when six leaves were stripped leading to the observed reductions in grain yield in Experiment 3. The effect of stripping six leaves in reducing assimilate supply to the cob compared to removing four leaves were echoed in the cob weight, grain mass cob^{-1}, grain number cob^{-1} and cob length data (Table 2). Although not always statistically significant, the trend shown by the grain yield component data is compelling in pointing out that in this Experiment the stripping of six leaves was detrimental to yield formation in the maize.

Severity of intensity of leaf stripping may explain cropping system and leaf

stripping interaction observed in Experiment 2 (Fig. 2b). It was only when six maize leaves were stripped that sole maize had higher maize grain yield than the maize-bean intercrop in Experiment 2. It is conceivable that the stripping of six leaves removed some leaves that were still contributing to net photosynthesis in the intercrop owing to lower number of leaves being alive than in the monocrop. The results indicate that the optimum leaf-stripping intensity is four leaves. This avoids the danger that leaves that are not senescing are removed during the leaf stripping exercise especially in situations where environmental conditions that hasten senescence are at play.

There was an inadvertent delay of leaf stripping and detasselling from 50% silking in Experiment 2, which accounted for the lack of effects of leaf stripping and detasselling on maize grain yield observed in this experiment. Previous studies (Mashingaidze *et al.*, Chapter 4) have shown that leaf stripping at anthesis was crucial to obtain the increase in maize grain yield from the removal of senescing leaves before they competed with the developing cob for assimilates. Delays in detasselling from the time of tassel emergence at 50% anthesis have been shown to nullify the detasselling effect on maize grain (Subedi, 1996). The results from Experiment 2 confirm that farmers would need to get their timing of leaf stripping and detasselling right on cue, at 50% silking, to enjoy the yield benefits that potentially accrue after these interventions.

Bean yields

Results of this study show no significant increase in intercropped bean yields with leaf stripping and detasselling of maize, in contrast to results previously obtained with pumpkin (Mashingaidze *et al.*, Chapter 4). The bean crop was observed to mature too early to benefit from the increase in PAR penetrating into the intercrop canopy after leaf stripping and detasselling, as the indeterminate pumpkins did. It was observed that beans tended to begin flowering and pod development about 60 days after emergence. This time is more than three weeks before detasselling and leaf stripping at 84 days and at 94 days after emergence for short season and long season maize varieties, SC 513 and SC 701, respectively, which were used in this study. Detasselling and leaf stripping is likely to benefit a companion crop grown under the canopy of the maize that continues to grow and reproduce long after the detasselling and leaf stripping interventions are implemented. For Natal Sugar, the bean variety that was used in our study, this was clearly not the case. For the smallholder farming community, besides pumpkins, local landraces of cowpeas that have been observed to be indeterminate appear another likely candidate to exhibit yield benefits from leaf stripping and detasselling. Perhaps the use of ultra-short season maize varieties such as SC 401 (Seed Co®, Zimbabwe) that flower at 70 days after emergence with long season and

indeterminate varieties of common beans would finally show the benefits of leaf stripping and detasselling maize in maize-bean intercropping. The statistically insignificant positive trends in the bean yield in Figs 4b and 4c with leaf stripping and detasselling, respectively, show that leaf stripping and detasselling may well prove beneficial to bean yield in the future. This would be contingent upon the correct match of maize and bean variety in terms of timing of phenological growth stages. For now, with the short season variety of beans commonly intercropped with short season maize, this study has shown that there are no clear and significant benefits on the bean crop yield that would be gained by leaf stripping and detasselling.

The large bean yield reduction that was measured in the intercrop when compared to the monocrop in Experiment 2 is reflective of peculiar conditions that occurred during the bean development and maturity. High residual fertility of the UZ farm site resulted in luxuriant vegetative growth of the beans and the 30 cm row spacing between maize rows in the maize-bean intercrop resulted in greater levels of bean lodging than in sole bean crop. Very heavy rainfall during the pod development maturity stages resulted in rotting of the beans that were in contact with the damp ground and this together with reduced light interception caused by lodging, reduced yield components (Table 4) and yield (Fig. 4a) in the maize-bean intercrop.

Weed density and biomass

Maize-bean intercropping, at the bean densities used in this study, effectively suppresses the germination and growth of late weeds. The combined foliage of the maize and bean attenuated incoming radiant energy by absorbing the red and green wavelengths, leaving far-red rich light to reach the ground. Far-red rich light is known to be inhibitory to the germination of seeds of some annual weed species (Radosevich *et al.*, 1997). Weed growth is reduced much more in the intercrop because of the reduction in percentage of total incoming PAR recorded in the intercrop than in the sole maize crop (Mashingaidze *et al.*, Chapter 4). The 5% difference in PAR reaching the ground in sole maize and the maize-bean intercrop in Experiment 1 (Fig. 6a) is misleading because the PAR measurements were taken late in the season (at 15 WAE) after the beans were beginning to senesce. Earlier in the season when beans were growing, the luxuriant bean vegetative growth completely covered the ground, explaining the 43.7% and 72.1% reductions in weed biomass that was recorded in the intercrops compared to the maize monocrop in Experiments 3 and 1, respectively (Table 6). The interaction between cropping system and weeding regime (Fig. 5) in Experiment 3 shows that maize-bean intercrop required a single hoe-weeding at 3 WAE to achieve the same weed biomass as in the sole maize crop weeded twice at 3 and 6 WAE. There is, therefore, potential to reduce the labour commitment of smallholder farmers in

weeding by maize-bean intercropping similar to what has been shown with maize-pumpkin intercropping (Mashingaidze *et al*., Chapter 2). The fecundity of weeds has been shown to be linearly related to biomass (Baumann *et al*., 2001; Thompson *et al*., 1991). It would, therefore, be expected that maize-bean intercropping will reduce weed seed addition to the soil seedbank by the same percentage as the reduction in weed biomass in comparison to the sole maize. Such a scenario could well prove to be useful in harnessing intercropping as a strategy to increase productivity of cropping systems in smallholder agriculture while at the same time reducing weed infestation in the long term by seedbank management.

Productivity of the maize-bean intercrop

The results of the LER analysis in Experiment 1 showed that detasselling and leaf stripping of a maize monocrop are capable of increasing the efficiency of land utilization by increasing maize yield above that of the tasselled and unstripped sole maize crop. This means that as a technology, detasselling and leaf stripping could be used to increase monocrop maize grain yield and achieve LER ratios of between 1.21-2.01 when compared to the normal farmer practice of monocropping unstripped and tasselled maize. Results obtained from previous studies indicated LER ratios that ranged from 1.17-1.50 in monocropped maize (Mashingaidze *et al*., Chapter 4) when it was detasselled and/or leaf stripped. The observation that maize grain yields in the intercrop when leaf stripped or detasselled were not reduced by intercropping enhanced the efficiency of land use by the two crops as shown by LERs recorded for the maize-bean intercrop in Experiment 1. The LER of 1.92-2.16 (Table 7) recorded for the maize-bean intercrop with leaf stripping and detasselling in Experiment 1 is higher than the 0.93-1.12 (Santalla *et al*., 2001), 1.13-1.34 (Li *et al*., 1999), 1.61 (Pandita *et al*., 2000) quoted in the recent publications on maize-bean intercropping. The bean yield that could potentially accrue to the farmer would be additional to an unchanged maize yield and would add to the productivity of the cropping system financially and nutritionally. Late leaf stripping and detasselling in Experiment 2 that sabotaged their effects on maize grain yield made the LER of the intercrop similar to the results of Santalla *et al*. (2001) and Li *et al*. (1999). The LER when 6 leaves were stripped in Experiments 2 and 3, show that this leaf stripping intensity maybe too severe and can lead to a reduction in productivity of the maize-bean intercrop.

The maize density of 37,000 plants ha^{-1} used in the three experiments was shown to be optimum for the environment in which the experiments were carried out. Increases in maize grain yield above 30,000 to 37,000 plants ha^{-1} were accompanied by decreases in maize grain yield (Mashingaidze *et al*., Chapter 6). Use of the optimum density of the cereal crop in cereal-legume or cereal-cucurbit intercropping ensures

that productivity gains that are measured using the LER method are not a result of the minor crop exploiting the empty space, unoccupied by a sub-optimal cereal density. Sub-optimal cereal densities in intercropping experiments lead to the wrong conclusions on the complementarity of the two crops in resource use (Kropff and Goudriaan, 1994).

Narrow rows reduce density, biomass and seed production of weeds and increase maize yields

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Abstract

Experiments were carried out in Zimbabwe during the 2001/02 and 2002/03 seasons to assess the effect of maize density and spatial arrangement on the emergence, growth and seed production of weeds and the yield of maize. Narrow row planting (60 cm rows) produced the highest maize grain yield at the lowest maize density (30,000 plants ha^{-1}) and the lowest yield at the highest maize density (60,000 plants ha^{-1}) in Experiment 1. Maize grain yield was lower with wide row planting (90 cm rows) than narrow planting at 30,000 plants ha^{-1} and decreased to a lesser extent than in narrow row (60 cm rows) as plant density was increased to 60,000 plants ha^{-1}. When maize density was maintained at 37,000 plants ha^{-1} in Experiment 2 and 3, the narrow row maize spatial arrangements (60 cm × 45 cm and 75 cm × 36 cm) out-yielded the wide row spatial arrangement (90 cm × 30 cm) traditionally used by farmers in semi-arid areas. The duration of the weed-free period required to attain maximum grain yield increased from 6 to 9 WAE with increase in row spacing from 60 cm and 75 cm to 90 cm in Experiment 2. Maize grain yield suffered less reduction from increased delays in starting the hoe weeding process in the narrow row spatial arrangements than in the 90 cm × 30 cm spatial arrangement in Experiment 3. An increase in maize density from 30,000 to 45,000 plants ha^{-1} reduced weed biomass by 25% in Experiment 1. Weed density, biomass and seed production were reduced by 20-80% by using narrow rows, when compared to the 90 cm row spacing. Weeding was more effective in curtailing weed seed production in the narrow row spatial arrangements than the wide row planting. Maize intercepted 16-20% and 15-24% more of the incoming PAR when planted in 60 cm and 75 cm rows, respectively, compared to the 90 cm row spacing, explaining the greater maize yields and reduced weed growth and fecundity that were observed with narrow row planting.

Key words: Maize, plant density, narrow rows, weeds, critical weed-free period, cultural weed control.

INTRODUCTION

Competition from weeds early in the development of maize remains one of the most serious and widespread production problems faced by smallholder maize producers in southern Africa (Vernon and Parker, 1983; Low and Waddington, 1990; Waddington and Karigwindi, 1996). Shortages of labour and reliance on the slow and laborious hoe weeding method mean that smallholder farmers invariably weed a large proportion of their crop late, after the crop has already suffered significant yield damage from early weeds (Chivinge, 1990). In Mangwende, a communal area typical of the high yielding sub-humid smallholder maize production zones of Zimbabwe, 42% of the farmers started weeding their early maize more than 30 days after crop emergence. This was calculated to reduce maize grain yield by 28% from a grain yield target of 5 t ha^{-1} (Shumba *et al.*, 1989). In Zambia, Vernon and Parker (1983) reported that 38% of the total labour in maize was devoted to weed control and in southern Zambia (Vernon and Parker, 1983) the inefficiencies inherent in hoe weeding resulted in maize yield loss of up to 30%. Despite the disproportionate effort expended by smallholder farmers in hoe weeding their crops, weeds still cause the greatest amount of yield loss, as much as diseases and pests combined (Labrada *et al.*, 1994). Weeds cause more crop losses in the tropics and farmers spend more of their time weeding than in any other part of the world (Akobundu, 1991).

The critical period of weed control is determined by the maximum period of time weeds can exist in a crop at the beginning of the season without significantly reducing yield (Hall *et al.*, 1992; Weaver and Tan, 1983). For smallholder farmers, the critical weed-free period, determines the number of times the maize crop has to be weeded to avert yield loss and, therefore, the labour requirement for weeding maize for that season. Weed suppression through augmentation of the competitive ability of the crop is one of the cheapest and most useful methods of weed control that is also technically feasible for smallholder farmers (Klingman, 1961). Crops can be favoured in competition against weeds by use of narrow rows and higher planting rates or crop densities (Stoller *et al.*, 1987; Teasdale, 1995). Narrow row planting and high plant densities reduce weed germination and growth by decreasing and changing the spectral composition of the incoming radiant energy incident on the weed seeds and weed seedlings under the maize canopy (Zimdahl, 1999; Swanton and Wiese, 1991; Tollenaar *et al.*, 1994). Higher plant densities and narrow rows achieve full ground cover earlier in the season than lower plant densities and wide rows. Since the critical weed-free period coincides with the time it takes for the crop to produce a closed canopy (Zimdahl, 1999), narrow planting and high plant densities should reduce this period and, therefore, the number of times the maize crop needs to be weeded to avert yield loss.

Historically in smallholder farming areas, crops are planted in rows spaced wide enough to allow passage of draft animals pulling cultivator equipment during weed control despite the fact that they use hoe weeding on a significant proportion or all of their planted maize. Where soil moisture and fertility are not limiting, light, as influenced by interplant shading, would be a major factor in inter- and intra-species competition and an equidistant planting arrangement within and across rows might be expected to give the highest yields. Interference between adjacent maize plants is postponed as long as possible in this arrangement, whereas complete shading of the inter-row spaces (and presumably most of the weeds) is achieved at the earliest possible date. Any deviation from the equidistant pattern to a more rectangular planting arrangement might be expected to decrease early maize interference with weed growth whilst increasing competition between adjacent maize plants (Weil, 1982).

Despite the potential shown by narrow planting and higher plant densities for suppressing weed growth, research on maize plant densities and spatial arrangements has concentrated on their effects on lodging and maize yield (MacRobert, 1986). Using different combinations of crop densities and row width in weed management systems is yet to be exploited in a systematic and widespread manner (Murphy *et al*., 1996). There are numerous studies on the effect of narrow row planting on weed interference and/or maize grain yield in the literature (Yao and Shaw, 1964; Tollenaar *et al*., 1994; Murphy *et al*., 1996: Andrade *et al*., 2002). However, no studies have yet addressed this subject in the context of the critical weed-free period and weed seed production in maize at plant densities that are optimal for smallholder farmers in semi-arid regions. The objective of this study was to determine the effects of plant density and spatial arrangement on weed emergence, growth and seed production, photosynthetically active radiation (PAR) interception by the maize canopy and maize grain yield. The hypotheses tested were (a) increasing the maize density above the recommended 37,000 plants ha^{-1} will decrease maize yield in semi arid regions (b) planting maize in narrower rows than the traditionally recommended 90 cm × 30 cm spacing will increase radiation interception by the maize, increase maize yields and reduce weed growth and fecundity (c) narrow row spatial arrangements will require a shorter weed-free period to attain maximum yields than wide row spacings.

MATERIALS AND METHODS

Experiment 1 was carried out at the University of Zimbabwe farm in the 2001/02 season and Experiments 2 and 3 at Rio Tinto Agricultural College in the 2002/03 season. The University of Zimbabwe site lies 14 km to the north-west of Harare, at an altitude of 1500 m above sea level, on red fersiallitic clay soils with more than 40%

clay and an annual rainfall of 800 mm to 1000 mm. Average temperatures during the growing season range from 20 to 25 °C. The Rio Tinto Agricultural College site lies between 29°30′ East and 19°20′ South in the Zhombe district, in the rain shadow area of the Mapfungautsi plateau in the middle of Zimbabwe. The site is characterized by sandy clay loams of shallow depth (30 cm), derived from granite and dolorite parent material. Growing season temperatures are fairly high, on average about 30 °C. Frequent mid season droughts characterize the rainy season and total seasonal rainfall that is received from the end of November to March ranges between 450 and 600 mm.

The land was ploughed and disced to a fine tilth and plots were marked. The between row spacing was marked using a tape measure according to treatment, and planting furrows were opened using hoes. Planting stations, within the planting furrows, were marked with a tape measure. Compound D fertilizer (8% N, 14% K_2O and 7% P_2O_5) was banded into the opened planting furrows at 300 kg ha^{-1}, before seeding at both sites. Two maize seeds were dropped per planting station and the maize was thinned to one plant per planting station, one week after emergence (WAE). The maize crops were top-dressed with ammonium nitrate (34.5% N) at 300 kg ha^{-1}, half of which was applied at 4 WAE and the other half at 8 WAE.

Experiment 1: Effect of maize density and row spacing
The experiment was set up to determine the effect of maize density (plant population) and spatial arrangement on the germination and growth of weeds, the radiant environment of the crop and maize grain yield. The experiment was laid out as a 3 × 3 factorial in a randomized complete block design, replicated three times. Maize density was 30,000, 45,000 and 60,000 plants ha^{-1} and spatial arrangements were 90, 75 and 60 cm row spacing and the corresponding in-row spacing for each maize density as shown in Table 1. Each plot was made up of eight rows 8 m long, and the net plot from which measurements were made was six maize rows of 6 m length. A long season, high yielding maize variety, recommended for the high rainfall areas of Zimbabwe, SC 701 (Seed-Co®, Zimbabwe) was used in this experiment.

Weeds were counted in five randomly selected 30 cm × 30 cm quadrants $plot^{-1}$ at 5, 8 and 22 WAE (maize physiological maturity). A stone was randomly thrown into the net plot and the quadrant positioned with the stone in the centre. Counted weeds were cut at ground level, oven dried to a constant mass and weighed. Photosynthetically active radiation (PAR) incident at two positions, adjacent to the maize row and in the middle of the maize inter-row was measured above the crop, at crop mid-height and on the ground, at 5, 8 and 12 WAE using 191-SA line quantum sensors (Li-Cor, Lincoln, Nebraska, USA). Three replicate measurements were taken at 2, 4 and 6 m along the middle rows of each plot and the average of the three positions was used in data

Table 1. Maize inter-row and in-row spacing treatment combinations in Experiment 1.

Plant density (plants ha^{-1})	Row spacing		
	90 cm	75 cm	60 cm
30,000	90×37	75×44	60×56
45,000	90×25	75×30	60×32
60,000	90×19	75×22	60×28

analysis. Maize was hand harvested at 30 WAE, shelled and grain moisture content measured. Grain yield was standardized to 12.5% moisture content and expressed per ha before statistical analysis.

Experiments 2 and 3: Maize spatial arrangements and weedy/weed-free period
Experiment 2 was set up as a 3 × 4 factorial in a randomized complete block design to measure the effect of maize spatial arrangement and weed-free period on the emergence, growth and fecundity of weeds and maize grain yield in the 2002/03 season. The spatial arrangement factors were planting maize at 90 cm × 30 cm, 75 cm × 36 cm and 60 cm × 45 cm spacing to maintain a density of 37,000 plants ha^{-1}. The weed-free periods were from emergence up to 3, 6, 9 or 12 WAE and then weedy for the rest of the season. Experiment 3 was similar in structure to Experiment 2, the only exception was that the weed-free periods were replaced by weedy periods (then weed-free for the rest of the season) for 3, 6, 9, 12 WAE. Experiment 3 was planted at the same time and adjacent to Experiment 2, to enable the results of the two experiments to be compared. A short season maize variety SC 513 (Seed-Co®, Zimbabwe), recommended for the semi-arid areas of Zimbabwe, was used in Experiments 2 and 3.

PAR measurements were conducted adjacent to maize rows and in the centre of the inter-row at 2 and 4 WAE. Weed density and dry mass were determined as in Experiment 1, at 3, 6 and 9 WAE, before the weeding treatments scheduled for that time were implemented. Weed seed capsules were counted, for major weed species as assessed by visual estimates of ground cover: *Commelina benghalensis* L., *Amaranthus hybridus* L., *Leucas martinicensis* (Jacq.) R. Br., *Rottboellia cochinchinensis* (Lour.) W.D. Clayton and other minor weed species (*Bidens pilosa* L., *Tagetes minuta* L., *Acanthospermum hispidum* DC. and *Ipomoea plebeia* R. Br.) at maize physiological maturity.

Maize was hand harvested at 20 WAE after drying down in the field and moisture content measured. A random sample of five cobs was taken from each plot and cob length, cob mass, number of kernel rows cob^{-1} and number of kernels row^{-1} determined.

Data analysis

All weed density and weed seed capsule data sets were square root of (x + 0.5) transformed (Steel and Torrie, 1984) and maize grain yield was standardized to 12.5% moisture content before statistical analysis. Data from the experiments was subjected to analysis of variance (ANOVA) using the SAS statistical package (SAS Institute 1999, Release 8, Cary NC, USA). Standard errors of the difference were calculated and used for mean separation when P<0.05.

RESULTS

Maize grain yield

Experiment 1 There was a significant (P<0.001) decrease in maize grain yield as maize density was increased, but the extent of the decrease of maize grain yield with increasing maize density was not similar for the three maize spatial arrangements as indicated by a significant (P=0.008) maize density and spatial arrangement interaction in Experiment 1 (Fig. 1). For the narrowest row spacing (60 cm), maize grain yield significantly decreased by 25% and 41% when maize density was increased from 30,000 to 45,000 and 60,000 plants ha^{-1}, respectively (Fig. 1). There was no difference in yield between the 45,000 and 60,000 plants ha^{-1} maize densities at 60 cm row spacing. For the 75 cm and the 90 cm spacing, maize density did not significantly (Fig. 1) affect maize grain yield, despite there being a trend of decreasing maize yield with increase in maize density that was more pronounced for the 90 cm than the 75 cm row spacing. At 30,000 plants ha^{-1}, the narrowest row spacing (60 cm) yielded 26% and 15% more grain yield than the 75 cm and 90 cm row spacing, respectively (Fig. 1). At 45,000 and 60,000 plants ha^{-1}, maize grain yield did not differ among the three maize spatial arrangements (Fig. 1). Overall, the 60 cm × 56 cm spacing at the lowest
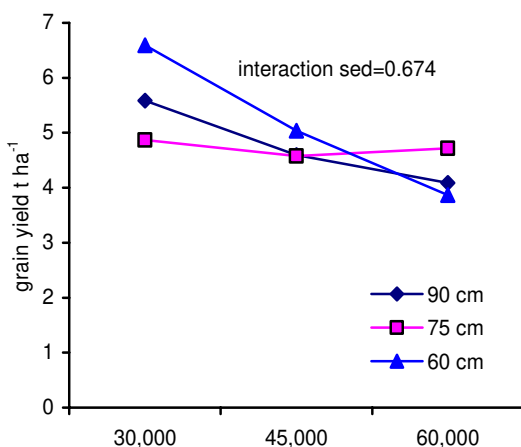
Figure 1. Interaction between maize spatial arrangement and density (maize plants ha^{-1}) on maize grain yield in Experiment 1.

maize density, that was closest to square planting, out-yielded all other treatments and the 60 cm × 28 cm spacing, at the highest maize density, had the lowest grain yield (Fig. 1).

Experiment 2 There was a significant maize spatial arrangement and weed-free period interaction (P=0.002) on maize grain yield (Fig. 2a). Maize grain yield increased with increased duration of the weed-free period for the three maize spatial arrangements but the extent of the increase varied with the maize spatial arrangement. Maize grain yield increased much more with increased duration of weed-free period in the narrow row spatial arrangement such that maximum maize grain yield for the 60 cm × 45 cm maize spatial arrangement was achieved by keeping the crop weed-free for 6 WAE. Maximum grain yield was only achieved by keeping the crop weed-free for the 9 WAE in the 75 cm × 36 cm and 90 cm × 30 cm maize spatial arrangements (Fig. 2a). Maize grain yield was consistently higher in the 60 cm × 45 cm spatial arrangements than in the 90 cm × 30 cm spatial arrangement as the weed-free period was increased (Fig. 2a).

Experiment 3 The duration of the weedy period (P<0.001) and the maize spatial arrangement (P<0.001) had highly significant effects on maize grain yield but their effects are contained in the significant (P<0.001) interaction between the two factors (Fig. 2b). Maize grain yield was reduced as weeding was delayed from the first

Figure 2. (A) Effect of maize spatial arrangement and duration of weed-free period (then weedy) on maize grain yield in Experiment 2. (B) Effect of maize spatial arrangement and duration of weedy period (then weed-free) on maize grain yield in Experiment 3.

weeding at 3 WAE, but the degree of the yield reduction was not similar among the maize spatial arrangements (Fig. 2b). Maize grain yield was similar in the narrow row spatial arrangements (75 cm × 36 cm and 60 cm × 45 cm) but higher than in the wide row spatial arrangements when weeding was started at 3 and 6 WAE (Fig. 2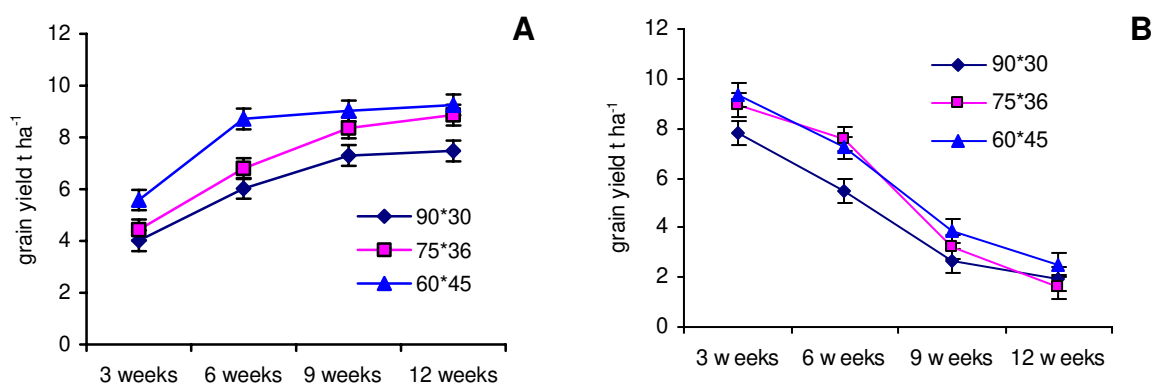b). Maize grain yield did not decline when weeding was delayed from 3 to 6 WAE in the 45 cm × 60 cm and 75 cm × 36 cm spatial arrangements but declined by 42% in the 90 cm × 30 cm spatial arrangement (Fig. 2b). Grain yield was similar among the treatments when weeding was delayed to 9 and 12 WAE (Fig. 2b).

Maize yield components

Maize spatial arrangement significantly affected maize cob length and cob mass (Table 2) but had no effect on number of kernel rows cob^{-1} and number of kernels per kernel row^{-1} (data not shown) in Experiment 2. The 60 cm × 45 cm spatial arrangement produced a longer cob than the 75 cm × 36 cm and 90 cm × 30 cm arrangements (Table 2). The 75 cm × 36 cm and 60 cm × 45 cm spatial arrangements had higher cob mass than the 90 cm × 30 cm spatial arrangement in Experiment 2 (Table 2). In Experiment 3, cob length and number of kernels row^{-1} significantly increased from 90 cm × 30 cm, 75 cm × 36 cm to 60 cm × 45 cm spatial arrangements (Table 2). Cob mass was similar for the 90 cm × 30 cm and 75 cm × 36 cm spatial arrangements but lower than the 60 cm × 45 cm spatial arrangement in Experiment 3 (Table 2).

The duration of the weed-free period did not significantly affect ($P>0.05$) any of the maize yield components in Experiment 2 (data not shown). The duration of the weedy period, on the other hand, significantly affected the cob length, cob mass and number of kernels row^{-1} in Experiment 3 (Table 3). Cob length, cob mass and number of kernels row^{-1}, significantly and consistently decreased as the duration of the weedy period was increased (Table 3).

Table 2. Effect of maize spatial arrangement on maize grain yield components in Experiments 2 and 3.

Maize spatial	Experiment 2		Experiment 3		
arrangement (cm)	Cob length (cm cob^{-1})	Cob weight (kg cob^{-1})	Cob length (cm cob^{-1})	Cob weight (kg cob^{-1})	Number of kernels row^{-1}
90×30	17.1	0.28	13.0	0.25	28.8
75×36	17.2	0.35	14.9	0.25	33.2
60×45	18.1	0.35	16.8	0.30	36.0
P-value	P<0.05	P<0.01	P<0.001	P<0.001	P<0.001
Sed	0.21	0.005	0.30	0.003	0.77

Table 3. Effect of duration of weedy period (then weed-free) on maize grain yield components in Experiment 3.

Duration of weed period	Cob length (cm cob^{-1})	Cob weight (kg cob^{-1})	Number of kernel rows per cob	Number of kernels per row
3 weeks	17.2	0.31	15.3	38.9
6 weeks	16.6	0.29	15.1	36.7
9 weeks	13.6	0.24	15.1	28.7
12 weeks	11.4	0.29	15.1	26.3
P-value	P<0.001	P<0.001	P>0.05	P<0.001
Sed	0.24	0.004	0.16	0.60

Table 4. Effect of maize spatial arrangement on weed density (number m^{-2}) and biomass (g m^{-2}) at 8 WAE in Experiments 1 and 3.

Row spacing (cm)	Experiment 1		Experiment 3	
	Weed density (number m^{-2})	Weed biomass (g m^{-2})	Weed density (number m^{-2})	Weed biomass (g m^{-2})
90	9.3 (85.73)[1]	8.5	7.1 (56.00)	259.1
75	8.1 (65.61)	3.3	5.9 (41.25)	151.7
60	8.9 (79.21)	3.0	5.1 (32.08)	104.8
P-value	P<0.05	P<0.001	P<0.01	P<0.01
Sed	0.48	0.89	0.18	14.28

[1] Numbers in brackets are untransformed weed numbers.

Table 5. Effect of maize density on weed density (number m^{-2}) and weed biomass (g m^{-2}) at 22 WAE (maize physiological maturity) in Experiment 1.

Maize density (plants ha^{-1})	Weed biomass (g m^{-2})	Weed density (number m^{-2})		
	All species	*R. scabra*	*G. parviflora*	All species
30,000	67.4	8.2 (66.39)[1]	6.3 (39.64)	12.6 (158.57)
45,000	50.7	6.7 (44.44)	4.4 (19.75)	11.5 (131.82)
60,000	38.2	5.9 (34.81)	5.6 (30.86)	10.4 (107.00)
P-value	P<0.01	P<0.01	P<0.01	P<0.01
Sed	8.81	0.59	0.55	0.67

[1] Numbers in brackets are untransformed weed numbers.

Weed density and biomass

Weed biomass was 65% and 61% lower in the 60 cm and 75 cm than in the 90 cm row spacing in Experiment 1, respectively (Table 4). Weed density at 9 WAE was reduced by 27% and 43% and biomass by 41% and 60% from 90 cm × 30 cm to 75 cm × 36 cm and 60 cm × 45 cm maize spatial arrangements, respectively, in Experiment 3 (Table 4). An increase in maize density from 30,000 to 45,000 plants ha^{-1} significantly reduced weed biomass at maize physiological maturity by 25% in Experiment 1 as well as the density of *Richardia scabra* and *Galinsoga parviflora* and the total of all weed species (Table 5).

The density of *A. hybridus*, *R. cochinchinensis*, other minor weed species and all species was significantly reduced by using narrower row planting than the traditionally used 90 cm × 30 cm spacing at 6 WAE, in Experiment 2 (Fig. 3a). Weed biomass was significantly reduced (P<0.001), by 69%, 75% and 89% in *A. hybridus*, all species and *L. martinicensis* when maize spatial arrangement was changed from 90 cm × 30 cm to the narrow row spatial arrangements of 75 cm × 36 cm and 60 cm × 45 cm (Fig. 3b). For other minor weed species, weed biomass decreased by 68% and 85% in the
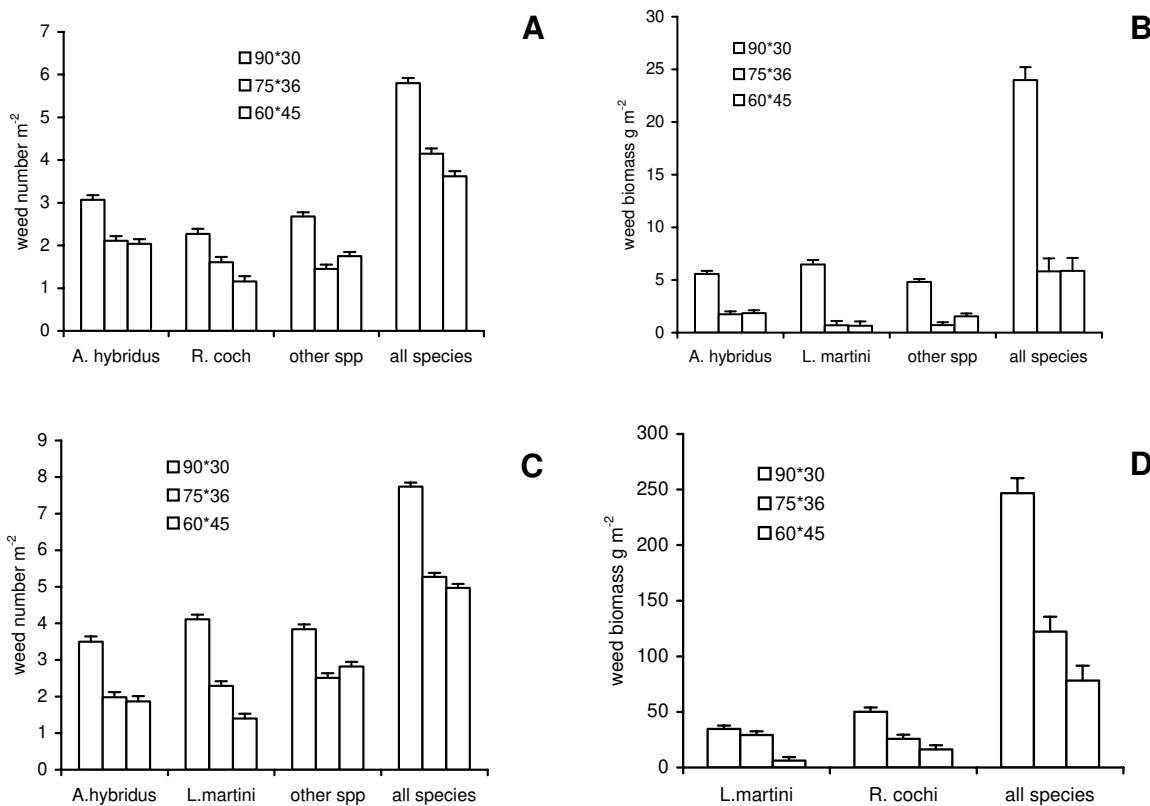

Figure 3. Effect of maize spatial arrangement on weed density (A) and weed biomass (B) at 6 WAE in Experiment 2. Effect of maize spatial arrangement on weed density (C) and weed biomass (D) at 6 WAE in Experiment 3.

60 cm × 45 cm and 75 cm × 36 cm spatial arrangements, compared to the 90 cm × 30 cm spatial arrangement, respectively (Fig. 3b).

Weed density decreased when the weed-free period was longer for total density of all weed species, other minor weed species and for *L. martinicensis* (Fig. 4a). For *R. cochinchinensis* and *A. hybridus*, the density for the plots kept weed-free for 9 WAE was higher than in plots kept weed-free for 6 WAE (Fig. 4a). Weed biomass was virtually non-existent in the plots kept weed-free for 9 WAE. Weed biomass was reduced by 77%, 80%, 91% and 98% for *L. martinicensis*, total weed biomass of all weed species, *A. hybridus* and other minor weed species by keeping the plots weed-free for 6 WAE compared to 3 WAE (Fig. 4a).

Total weed density and density of *L. martinicensis* significantly decreased as row spacing was narrowed in Experiment 3 (Fig. 3c). *A. hybridus* had a significantly higher density at 90 cm × 30 cm than at 75 cm × 36 cm and 60 cm × 45 cm maize spatial arrangements (Fig. 3c). Total weed biomass of all weed species decreased by 50% and 68%, biomass of *R. cochinchinensis* by 50% and 68% and that of *L. martinicensis* by 15.4% and 82% at 75 cm × 36 cm and 60 cm × 45 cm, respectively, compared to the 90 cm × 30 cm spatial arrangement (Fig. 3d). There was a significant duration of weedy period and maize spatial arrangement interaction (P=0.004) on *L. martinicensis* density at 6 WAE (Fig. 5a). The density of *L. martinicensis* was similar when the crop was left weedy for 3 WAE. When the crop was left weedy for 6 WAE, the 90 cm × 30 cm spatial arrangement had 78% higher weed density than the 75 cm × 36 cm and the 60 cm × 45 cm spatial arrangements. A similar interaction was recorded on total density of all species (Fig. 5b). There was no difference in total weed density when the crop was left weedy for 3 WAE. When the crop was left weedy for 6 WAE, the narrow row spatial arrangements achieved a 42% greater suppression of weed emergence than the 90 cm × 30 cm maize spatial arrangement (Fig. 5b).
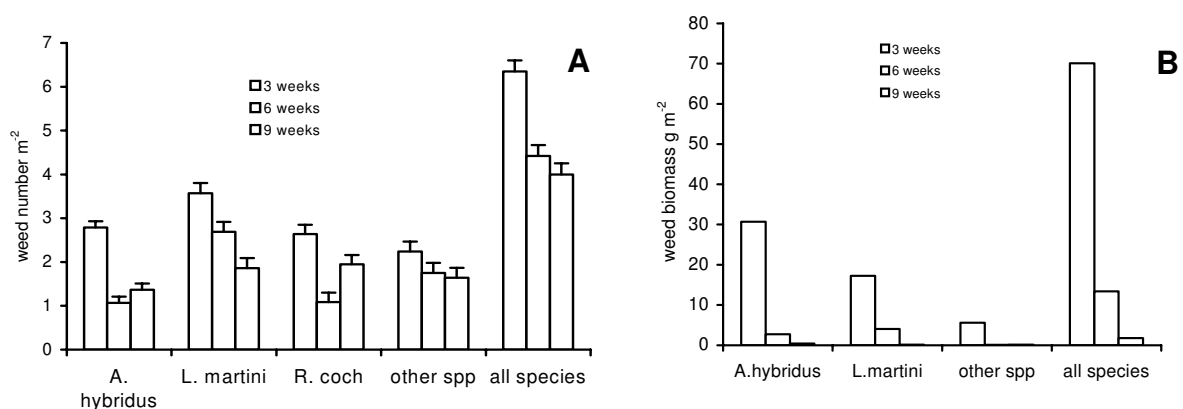
Figure 4. Effect of duration of weed-free period on weed density (A) and weed biomass (B) at 9 WAE in Experiment 2.
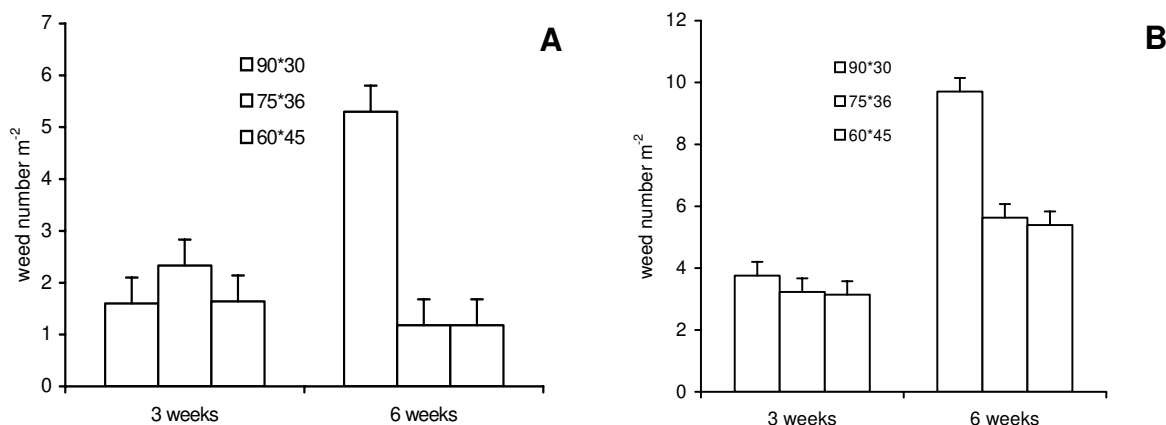
Figure 5. Interaction between duration of weedy period and maize spatial arrangement on the density of *L. martinicensis* (A) and total weed density (B).

Table 6. Effect of maize spatial arrangement on weed seed capsule production (number m^{-2}) at 12 weeks after emergence in Experiment 2.

Maize spatial arrangement	*C. benghalensis*	*A. hybridus*	*L. martinicensis*	Other species	All species
90×30	3.8a (18.49)	7.9a (70.56)	6.1a (43.56)[1]	3.1a (12.96)	11.7a (148.84)
75×36	2.8b (10.81)	3.2b (13.69)	3.6b (16.31)	2.3b (7.84)	6.2b (45.02)
60×45	1.5c (4.00)	1.4c (3.61)	2.1c (6.76)	1.4c (3.61)	3.4c (14.82)
P-value	P<0.01	P<0.001	P<0.01	P<0.05	P<0.001
Sed	0.20	0.34	0.35	0.17	0.37

[1] Numbers in brackets are untransformed weed seed capsule numbers.

Seed production by weeds

Seed capsules produced m^{-2} significantly decreased with narrower rows spatial for *C. benghalensis*, *A. hybridus*, *L. martinicensis*, other weed species and for total seed capsule production by all species in Experiment 2 (Table 6). Weed seed capsule production also consistently and significantly decreased with increase in duration of the weed-free period (Table 7). There was a significant interaction of duration of weed-free period and maize spatial arrangement on seed capsule production by *A. hybridus* (P=0.03), other minor weed species (P=0.002) and total seed capsule production by all species (P=0.04). Weeding was more effective in curtailing weed seed production in the narrow rows than in wider rows. It took a weed-free period of 9 or 12 WAE to stop the weed seed production of all species in the 60 cm × 45 cm, 75 cm × 36 cm and 90 cm × 30 cm spatial arrangements, respectively (Fig. 6a). Similar results were

Table 7. Effect of duration of the weed-free period on weed seed capsule production (number m^{-2}) at 12 weeks after emergence in Experiment 2.

Duration of weed-free period	*C. benghalensis*	*A. hybridus*	*L. martinicensis*	Other species	All species
3 WAE	6.6a (51.41)	9.5a (100.00)	7.5a (64.00)[1]	6.4a (47.61)	16.2a (218.89)
6 WAE	2.6b (9.61)	3.8b (18.49)	5.2b (32.49)	1.2b (2.89)	7.9b (70.56)
9 WAE	0.9c (1.96)	2.7c (10.24)	1.7c (4.84)	0.7c (0.00)	2.9c (11.56)
12 WAE	0.7c (0.00)	0.7d (0.00)	0.7d (0.00)	0.7c (0.00)	1.3d (3.24)
P-value	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
Sed	0.26	0.44	0.47	0.22	0.50

[1] Numbers in brackets are untransformed weed capsule numbers.

observed for *A. hybridus* and other minor weed species. For *A. hybridus* and other minor weed species, a weed-free period of 6 WAE was required to bring the weed seed production to zero for the 60 cm × 45 cm and the 75 cm × 36 cm maize spatial arrangements, respectively (Figs 6b and 6c). The 90 cm × 30 cm spatial arrangement only managed to completely curtail weed seed production when the weed-free period was extended to 12 and 9 WAE, for *A. hybridus* and other minor weed species, respectively (Figs 6b and 6c).

There was an interaction between the duration of the weedy period and maize spatial arrangement on seed capsule production by all weed species (P<0.001), *A. hybridus* (P=0.03) *and C. benghalensis* (P<0.001) and *L. martinicensis* (P=0.046). The interactions in all cases show that in treatments that were left weedy for 3, 6 and 9 WAE and then weed-free, no weed seeds were produced by the time of assessment, 12 WAE. It was only in the treatments that remained weedy for the whole season that large numbers of seed capsules were produced, with the number of seed capsules decreasing with the narrowing of the row spacing in the maize spatial arrangements (Figs 7a, 7b, 7c). Similar results were obtained for *L. martinicensis* (data not shown).

The radiant environment of the crop
Of the total incoming radiation, 69, 74 and 77% was intercepted by the maize foliage above the cob leaf in the 30,000, 45,000 and 60,000 plants ha^{-1} at 12 WAE, in Experiment 1 (Fig. 8a). Total radiation interception (RI) was 75, 81 and 88% for the 30,000, 45,000 and the 60,000 plants ha^{-1} maize densities at 12 WAE (Fig. 8a). Maize spatial arrangement significantly affected IPAR on the cob leaf (P=0.04) and the ground (P=0.03) at 12 WAE in Experiment 1 (Fig. 8b). As a result, RI was 81, 86 and 87% of total incoming PAR in the 90, 75 and 60 cm row spatial arrangements,
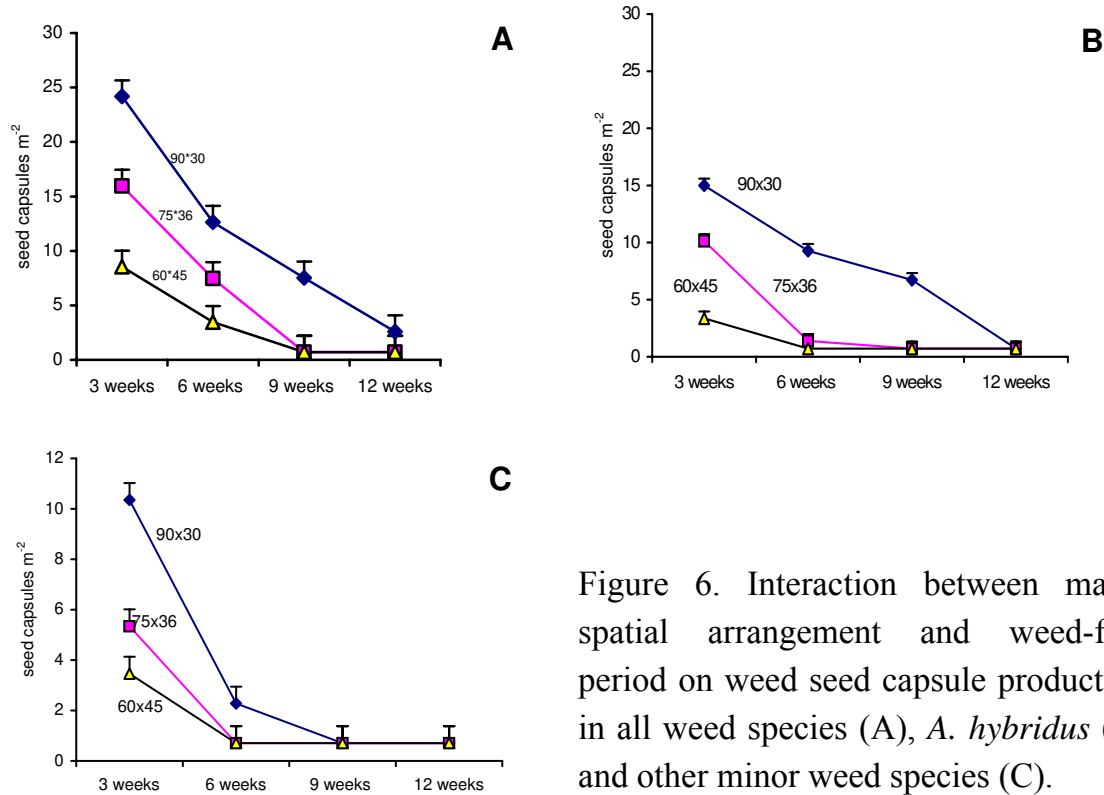
Figure 6. Interaction between maize spatial arrangement and weed-free period on weed seed capsule production in all weed species (A), *A. hybridus* (B) and other minor weed species (C).
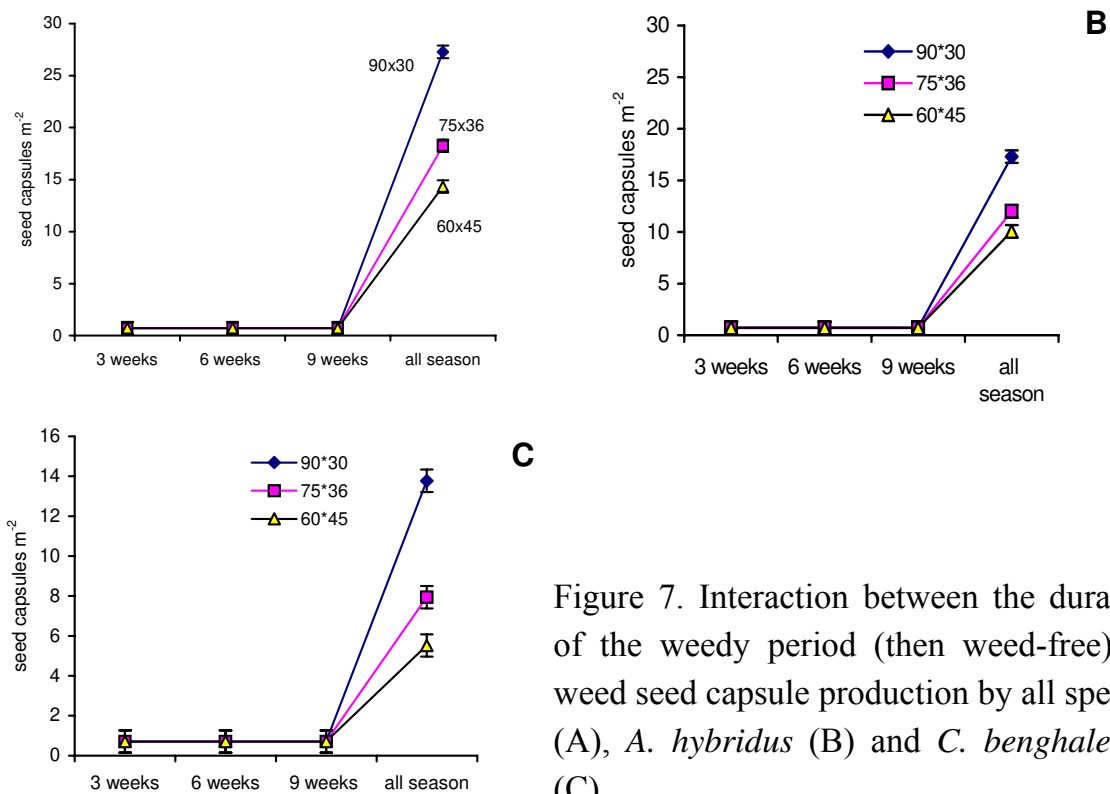
Figure 7. Interaction between the duration of the weedy period (then weed-free) on weed seed capsule production by all species (A), *A. hybridus* (B) and *C. benghalensis* (C).

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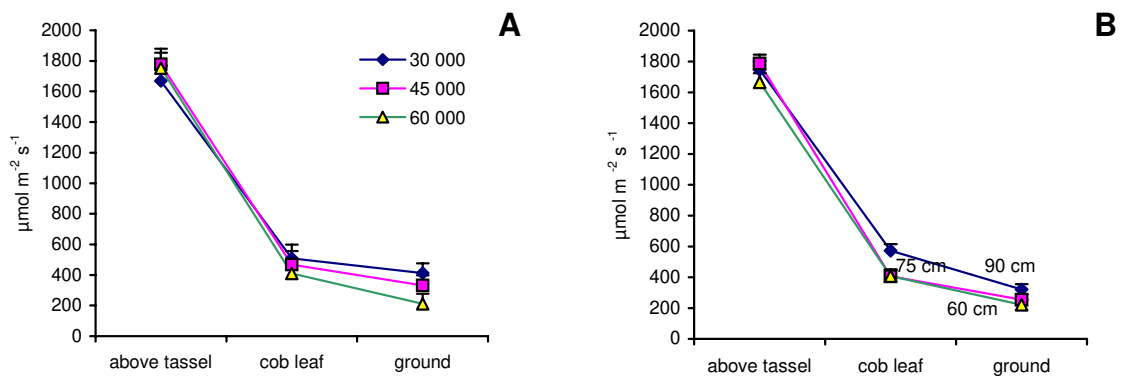
Figure 8. (A) Effect of maize density on PAR extinction in the maize canopy adjacent to the maize row at 12 WAE in Experiment 1. (B) Effect of maize spatial arrangement on PAR extinction in the maize canopy adjacent to the maize row at 12 WAE in Experiment 1.
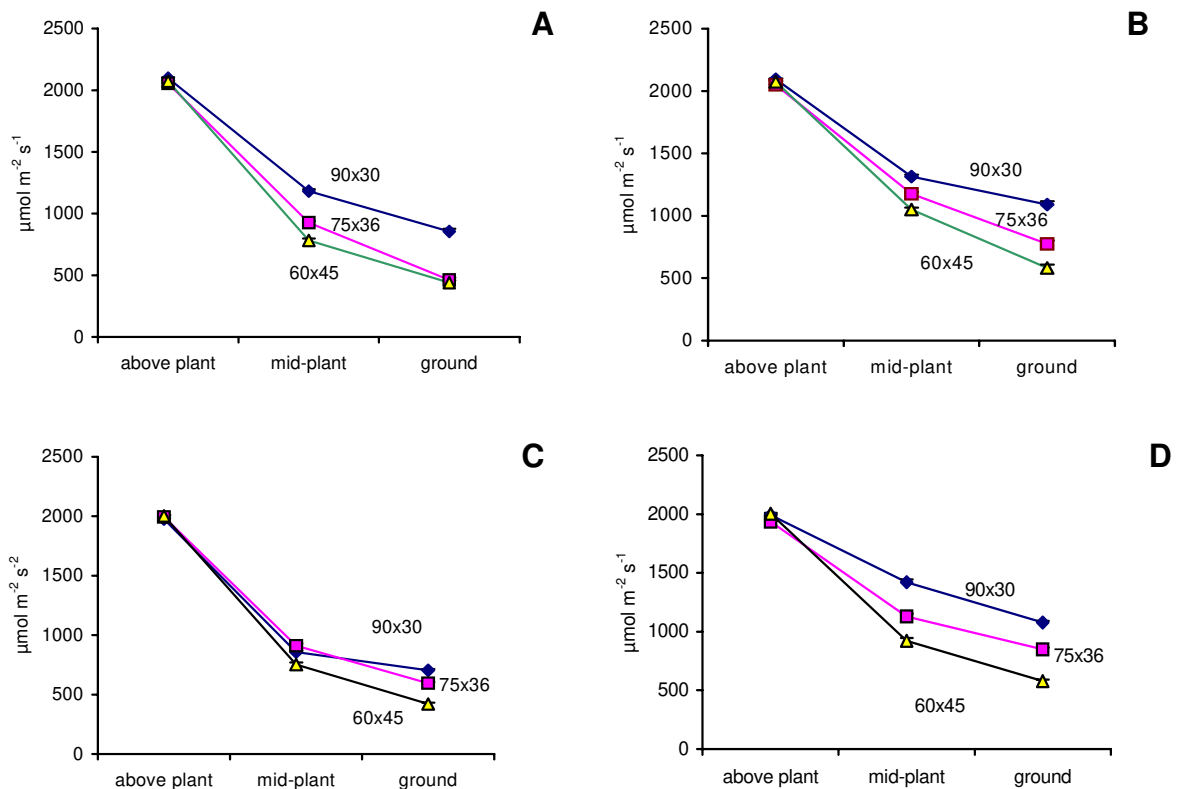
Figure 9. Effect of maize spatial arrangement on PAR extinction in the maize canopy adjacent (A) and in the middle of the maize inter-row (B) at 4 WAE in Experiment 2. Effect of maize spatial arrangement on PAR extinction in the maize canopy adjacent (C) and in the middle of the maize inter-row (D) at 4 WAE in Experiment 3.
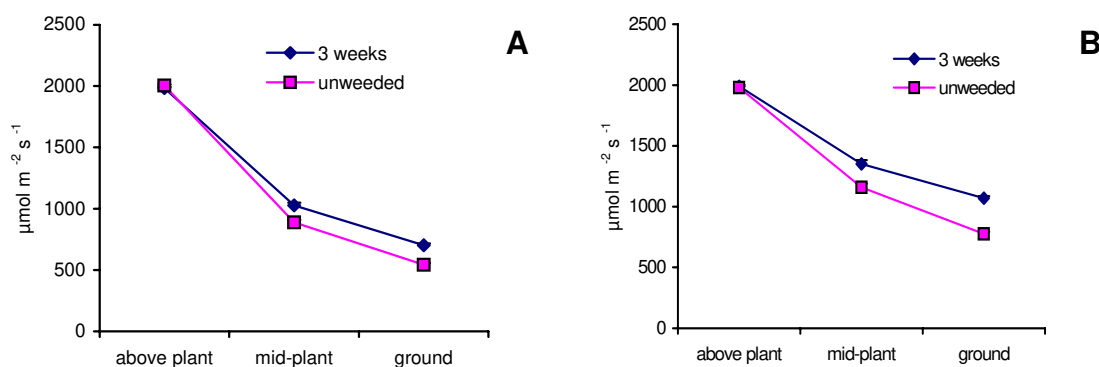
Figure 10. Effect of duration of weedy period on PAR extinction adjacent (A) and in the middle of the maize inter-row at 4 WAE in Experiment 3.

respectively, in Experiment 1 (Fig. 8b).

In Experiment 2, the narrow row maize spatial arrangements significantly intercepted more incoming PAR than the conventional 90 cm × 30 cm row spacing at 4 WAE (Figs 9a and 9b). Adjacent to the maize row, 41%, 23% and 21% of the total incoming PAR reached the ground, meaning that RI was 59%, 77% and 79% in the 90 cm × 30 cm, 75 cm × 36 cm and 60 cm × 45 cm maize spatial arrangements adjacent to the maize row. There was thus no difference in RI between the 75 cm × 36 cm and 60 cm × 45 cm spatial arrangements (Fig. 9a). In the middle of the maize row, RI was 48%, 63% and 72% in the 90 cm × 30 cm, 75 cm × 36 cm and 60 cm × 45 cm maize spatial arrangements, respectively. Similar RI results as in Experiment 2, among the three maize spatial arrangements, were recorded in Experiment 3 (Figs 9c and 9d).

The presence of weeds increased the amount of incident PAR intercepted by the combined weed and crop canopy in the unweeded plots compared to the plots kept weed-free from 3 WAE onwards (Figs 10a and 10b). The difference in the areas above the PAR extinction curve in Figs 10a and 10b, between the 3 WAE weedy treatment and the unweeded plots is the amount of radiation intercepted by the weeds.

DISCUSSION

Maize grain yield

Grain yield per unit area in a maize crop generally shows a curvilinear response to plant population density, with a maximum yield at the optimum plant population density above the optimum. Maize grain yield increases with increased plant population density until the increase in yield attributable to the addition of plants is not greater than the decline in mean yield per plant due to increased inter-plant

competition (Tollenaar and Wu, 1999). Teasdale (1998) found that the response of maize grain yield to increasing maize density was curvilinear except in dry years when there was a linear decline in maize grain yield with increasing maize population density. In Experiment 1 in this study, there was a linear decline in maize grain yield as maize density was increased beyond the recommended maize density but it was confounded within an interaction between maize density and spatial arrangement. The spatial arrangement and maize density that was closest to square planting (60 cm × 56 cm) had the highest maize grain yield suggesting that it had the least intra-specific competition. The results also suggest that the greatest interplant competition occurred in the plant density and spatial arrangement with narrowest row spacing and closest spacing of plants within the row (60 cm × 28 cm) as it had the lowest maize grain yield. An interaction between plant arrangement and maize density on maize grain yield was reported by Weil (1982) in Malawi, similar to results found in this study. Weil (1982) found that the highest maize grain yields at 20,000 plants ha^{-1}, occurred with equidistant spacing, but at 80,000 plants ha^{-1}, the highest yield was found at the widest row spacing.

When narrow rows were used with the recommended maize density for smallholder farmers in semi-arid areas of Zimbabwe, 37,000 plants ha^{-1} (MacRobert, 1986) in Experiments 2 and 3, they consistently produced higher maize grain yield than 90 cm row spacing which is widely used in Zimbabwe. Decreasing row spacing at equal plant densities produces a more equidistant plant distribution which decreases plant-plant competition for available water, nutrients and light and increases radiation interception (RI) and biomass production and economic yield (Shibles and Weber, 1966; Bullock *et al*., 1988; Johnson and Hoverstad, 2002; Barbieri *et al*., 2000; Andrade *et al*., 2002). In this study, the 60 cm × 45 cm and 75 cm × 36 cm maize spatial arrangement intercepted 16-25% more incoming PAR at 4 WAE, than the 90 cm × 30 cm maize spatial arrangement resulting in higher crop growth rates and biomass accumulation. Because of earlier canopy closure, the narrow row spatial arrangements reduce the leaf area index (LAI) required to intercept 95% of the incident radiation (Flenet *et al*., 1996). It is known that canopies that intercept 95% of the incident PAR when maximum leaf area is achieved at flowering achieve maximum grain yield (Westgate *et al*., 1997). In a wide (90 cm) row spacing, 95% radiation interception at maximum LAI at flowering, may never be achieved (Andrade *et al*., 2002). There was generally no difference in maize grain yield between the 60 cm × 45 cm and 75 cm × 36 cm narrow row spatial arrangements at a maize density of 37,000 plants ha^{-1}. Westgate *et al*. (1997) observed that decreasing row spacing beyond the 76 cm had relatively little impact on overall canopy PAR interception. Our results on the interception of PAR by the 75 cm × 36 cm and 60 cm × 45 cm maize spatial arrangements concur with the

observations by Westgate *et al.* (1997) and explain the similarity in maize yields between these narrow spatial arrangements.

The significant increase in number of kernels per row on the maize cob (and, therefore, number of kernels per cob), cob mass and cob length as row spacing was decreased as observed in Experiments 2 and 3 of this study, explains the maize yield differences between the maize spatial arrangements. Kernel number per unit area is the most important yield component determining maize grain yield (Tollenaar, 1977; Hawkins and Cooper, 1981; Fischer and Palmer, 1984). Kernel number per unit area is strongly correlated to crop growth rate during the critical period bracketing silking (Aluko and Fischer, 1987; Cirilo and Andrade, 1994; Uhart and Andrade, 1995). The crop growth rate depends on the amount of radiation intercepted by the crop and the efficiency with which it is converted into photosynthates (Gardner *et al.*, 1985). Recent studies (Barbieri *et al.*, 2000; Andrade *et al.*, 2002) have shown that grain yield increases with narrow rows were correlated with increases in radiation interception during the critical grain-setting period in maize. Barbieri *et al.* (2000) were able to show that narrow maize rows increased kernel number per unit area thereby increasing maize yield. The radiation interception, yield component and grain yield results of this study as row spacing was narrowed concur with explanations provided by the studies of Barbieri *et al.* (2000) and Andrade *et al.* (2002) of how narrow rows increase maize grain yield.

Maize grain yield has not always increased with the use of narrow rows in maize as reviewed by Andrade *et al.* (2002). Plant stresses that limit leaf area expansion and radiation use efficiency such as nitrogen deficiency and water stress would increase the probability of yield response to narrow rows (Barbieri *et al.*, 2000; Andrade *et al.*, 2002). Under the low rainfall conditions that were prevailing during the period of the study in Zimbabwe, it is conceivable that this phenomenon magnified the differences in maize grain yield that were observed between the narrow row and the 90 cm × 30 cm spacing conventionally used by farmers in Southern Africa. In the context of most smallholder farmers producing maize in semi arid-area of annual rainfall of between 450-800 mm per annum with frequent mid-season droughts, it would be foolhardy to recommend that they increase their planting densities beyond the 37,000 plants ha^{-1} currently recommended. The results of this study have shown that this will decrease yields particularly in drier seasons. The results have however shown that radiation interception by the maize crop can be improved and maize grain yields increased by using narrower spatial arrangements than the 90 cm × 30 cm currently in use.

Weed density, biomass and seed production
The higher radiation interception that was recorded at higher maize densities and

narrow row spatial arrangements account for their superior suppression of weed emergence and growth compared to the lowest maize population density (30,000 plants ha^{-1}) and the wide row maize spatial arrangements. The suppression of growth (dry weight) of weeds by high maize densities and/or narrow rows has been reported in a number of studies (Teasdale, 1995, 1998; Murphy *et al*., 1996; Weil, 1982; Begna *et al*.; 2001, Shrestha *et al*., 2001). The reduction in weed biomass was associated with reduced PAR transmittance to the weeds under the maize canopy when the maize density was increased and/or maize rows narrowed (Teasdale, 1995; Tollenaar *et al*., 1994; Begna *et al*., 2001; Tharp and Kells, 2001). These studies largely concurred with the observations made in this study. Teasdale (1995) showed that narrow row/high population density canopies closed a week earlier than wide row/low population maize canopies. Westgate *et al*. (1997) reported that increasing the maize density increased the total amount of light intercepted by the canopy and caused the canopy to close earlier in the season. Earlier canopy closure in the high maize density and the narrow row planting was indicated by higher PAR interception that was measured in these treatments early in the season (4 WAE) than in the lower plant densities and wider row planting patterns, in this study. Other studies (Johnson and Hoverstad, 2002; Johnson *et al*., 1998) have reported no beneficial effect of using narrow rows to suppress weeds in maize. These studies combined the use of reduced herbicide dosages and narrow rows and the effective weed control provided by the herbicide treatments probably nullified the effect of narrow rows on weed density and biomass.

Weed density was not only reduced because of the absolute reduction in the incident radiation reaching the ground under the maize canopy, but by the canopy absorbing the PAR (400-700 nm) wavelengths, leaving far-red rich radiation (over 700 nm) to reach ground level where weeds germinate from. Far red-rich light is known to be inhibitory to the germination of most annual weed species (Radosevich *et al*., 1997). The extent to which the germination of successive cohorts of weeds were affected by the maize canopy attenuating incoming radiation, as the season progressed, depends on how rapidly the canopy closed in the maize density and spatial arrangement treatments. It would be logical to expect lower weed densities in canopies that closed earlier, as observed in the higher maize plant population densities and narrow row maize spatial arrangements, in this study.

There is a linear relationship between the biomass of weeds at the end of the season and the amount of weed seeds produced (Baumann *et al*., 2001; Wilson *et al*., 1988; Thompson *et al*., 1991). The higher biomass that was observed for the individual weed species and all species was reflected as higher seed capsule production in the conventional spatial arrangement (90 cm × 30 cm) than in the narrow row spatial arrangements in Experiments 2 and 3 of this study. Higher maize densities that

restricted the amount of PAR intercepted by velvetleaf (*Abutilon theophrasti*) reduced its seed production (Lindquist *et al*., 1998; Teasdale, 1998) as observed with narrow rows in this study. The reduction in weed seed production by narrow row planting has potential to be integrated with other cultural weed management strategies to formulate sustainable and long-term strategies of weed seedbank management to reduce the weeding burden of smallholder farmers in Southern Africa.

The critical period for weed control

The critical period for weed control (CPWC) is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses (Nieto *et al*., 1968). Implicit in the above definition is the period of time the crop can exist with weeds (the weedy period) just after emergence without yield loss (Hall *et al*., 1992). In the context of smallholder farmers, any delay in implementing the first weeding beyond this point will be accompanied by yield loss. The second component of CPWC is the period of time the crop has to be kept weed-free to avert yield loss (Hall *et al*., 1992). For smallholder farmers this means the period of time weeding must continue in the crop to keep it weed-free to avoid yield loss. The CPWC, therefore, determines when weeding must begin and the number of times the crop must be weeded to avert yield loss. Results of Experiments 2 and 3 of this study, show that narrow row maize spatial arrangement reduce the duration of the CPWC and, therefore, potentially reduce the number of times the maize crop needs to be weeded to attain maximum yields. Rodgers *et al*. (1967) reported that the required weed-free period to avert yield loss in wide and narrow planted cotton corresponded to the time it took for the cotton to form a closed canopy. The maintenance of maximum yield with a shorter weed-free period observed in this study can be interpreted as being a result of the reduced emergence and growth rates of weeds in the maize narrow row spatial arrangements. Teasdale (1995) and DeFelice *et al*. (1989) observed that reduced herbicide dosages were more effective in narrow row spatial arrangements of maize and soya bean, respectively. This study has indicated that a reduced frequency of hoe weeding was more effective in controlling weed and averting yield loss in narrow than wide row spatial arrangements. Forcella *et al*. (1992) found that narrow row maize competed well enough with weeds to effectively eliminate the need for cultivation. In as much as high plant densities and narrow planting have been successfully integrated with reduced herbicide dosages, the results of this study suggest that combining high plant densities and narrow planting with reduced frequency of hoe-weeding may produce similar results.

From a long-term weed seedbank management perspective, the critical period of weed control concept can be extended to weed seed production by weeds. The duration

of the weed-free period required to eliminate weed seed production by a population of annual weed species was shorter in the narrow spatial arrangements compared to the wide row spatial arrangements in this study. This indicates that there is potential in using narrow rows to reduce the addition of weed seeds to the soil seedbank and in the long term reduce weed emergence and the effort expended by smallholder farmers in weed control. In the context of smallholder agriculture, cultural weed control tactics that reduce weed biomass and, therefore, seed production at the end of the season, such as mixed cropping, use of narrow row spatial arrangements, use of high plant densities where the environment permits and precise fertilizer placement have potential to contribute to long term weed seedbank management. Weed seedbank management using cultural weed management tactics will require sustained application and integration with other methods of control to be produce the desired results. With the advent of increased societal pressure to reduce the quantities of herbicides that are used in weed control world-wide (Cousens and Mortimer, 1995), there is a renewed interest in weed containment strategies. Containment is a strategy where weeds are kept at a low level by applying quantitative knowledge on the behaviour of weeds, their effect on the agro-system and the dynamics of weed populations across seasons (Kropff *et al*., 1996). Low input cultural weed management tactics such as those discussed in this study appear to lend themselves to this approach.

Fertilizer placement method affects emergence and growth of weeds and maize grain yield in Zimbabwe

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Abstract

Three experiments were conducted in Zimbabwe in the 2001/02 and 2002/03 seasons to study the effects of rate of application and method of placement of basal fertilizer on the emergence and growth of weeds and early growth, radiation interception and grain yield of maize. Compound D fertilizer (8% N, 14% K_2O, 7% P_2O_5) was applied at 75, 150 and 225 kg ha^{-1} using three placement methods viz. spot placement, banding and broadcasting in Experiment 1. Compound D (100 kg ha^{-1}) was applied using the three placement methods combined with a weed-free period or a weedy period of 3, 6, 9 and 12 weeks after emergence (WAE) in Experiments 2 and 3, respectively. Maize grain yield was increased by 30% when fertilizer application rate was increased from 75 to 150 kg ha^{-1} but decreased when the fertilizer rate was increased to 225 kg ha^{-1}. Spot placement and banding increased maize yield by 6% and 19%, 4% and 17%, and 0% and 52%, respectively, above that of the broadcasting fertilizer placement method in Experiments 1, 2 and 3, respectively. High fertilizer concentrations around the root zone of the crop probably increased the severity of water deficits at the highest fertilizer application rate and in the spot fertilizer placement treatments under drought condition prevailing during the study. Spot and band placement of fertilizer reduced the emergence, growth and seed production of weeds and increased early growth and radiation interception of the maize when compared to broadcasting. Maximum grain yields were obtained when weeding was started 3 WAE and the weed-free period maintained up to 6 WAE. This critical period of weed control was not affected by fertilizer placement method.

Key words: Fertilizer application, placement, rate, maize growth and grain yield, weed density, weed biomass, fecundity of weeds.

INTRODUCTION

Weed control is the dominant labour demanding occupation of smallholder farmers in semi-arid regions of Africa during the cropping season (Akobundu, 1991). Farmers invest large amounts of labour in weeding each season, approximately 35% to 70% of the total agricultural labour needed to produce crops which frequently exceeds the labour demand of all other livelihood operations for smallholder farmers (Chivinge, 1984; Ransom, 1990; Waddington and Karigwindi, 1996). Severe labour bottlenecks are common during peak weeding, resulting in delayed weeding in large portions of the planted crops, well after they have suffered significant damage from weeds (Chivinge, 1990).

Attempts to reduce the yield losses caused by weeds for smallholder farmers have been focused on technological improvements for weed control such as adoption of ox-driven mechanical implements and chemical weed control (Mashingaidze and Chivinge, 1995). A paradigm shift from weed control to weed management is required to effectively address the problems caused by weeds for smallholder farmers. Weed control emphasizing the control of existing weed problems is a curative approach that produces short-term results but may create or worsen long-term problems (Buhler, 1999). Weed management places greater attention on the prevention of propagule production, reduction of weed emergence in a crop and minimizing weed interference with the crop through the integration of techniques, knowledge and management skills (Buhler, 1999; Zimdahl, 1991). Cultural weed management techniques such as narrow planting, use of competitive crop varieties, mixed cropping and precise placement of fertilizers and manures have potential to reduce emergence, growth and competitiveness of weeds (Swanton and Wiese, 1991). There is a need to systematically integrate these weed management tactics into the production practice of smallholder farmers to tackle problems caused by weeds in a sustainable manner within the context of Integrated Weed Management (Mashingaidze and Chivinge, 1998).

A number of studies have shown that weeds accumulate substantial amounts of mineral nutrients, much more than crops themselves, thus pre-emptively depleting soil nutrients and reducing crop yields (DiTomasi, 1995; Qusem, 1992; Sibuga and Bandeen, 1980; Teyker *et al.*, 1991). Application of mineral fertilizer especially nitrogen can break the dormancy of certain weed species (Agenbag and De Villiers, 1989; DiTomasi, 1995; Fawcett and Slife, 1978) and, thus, increase weed densities, increasing competitive pressure on the crop. N fertilizer application has been shown to increase the competitive ability of weeds more than that of the crop which may lead to a decrease in crop yield (Carlson and Hill, 1986; Okafor and De Datta, 1976). In high weed density situations, added nutrients have often favoured weed growth while

providing little added benefit to crop yield (Liebman, 1989; Lintell-Smith *et al.*, 1991; Sindel and Michael, 1992). Fertilizers or manures can, thus, alter the crop-weed competition dynamics and worsen the weed problem and its deleterious effects on crop yields.

The weed competition dynamics for applied fertilizer nutrients can be changed in favour of the crop by the method of placement of the fertilizer (Blackshaw *et al.*, 2002). Fertilizer placement in narrow bands below the soil surface in the crop row has been found to reduce the competitive ability of weeds compared to broadcast placement of fertilizer (Blackshaw *et al.*, 2000, 2002; Kirkland and Beckie, 1998; Mesbar and Miller, 1999). In the context of smallholder agriculture in semi-arid areas, fertilizer is a scarce and expensive resource whose benefits must be maximized by precisely placing it in the root zone of the crop (Jonga *et al.*, 1996). Most smallholder farmers cannot afford to apply the recommended fertilizer application rates and frequently apply 30-50% of the recommended application rates (Chivinge and Mariga, 1998). Previous research on fertilizer placement methods in Zimbabwe has concentrated on nutrient uptake and early growth by the crop without a concomitant look at the weed crop competition dynamics (Tanner, 1984). No studies have been done in Zimbabwe to optimize fertilizer practices combined with reducing weed emergence and growth in the crop (Chivinge and Mariga, 1998).

The objective of this study was to determine the effect of fertilizer rate of application and placement methods on weed emergence and growth of weeds, early growth, radiation interception and yield of the maize crop. Hypotheses tested were (a) precise placement of fertilizer will increase early growth, radiation interception by the maize crop and reduce weed emergence and growth (b) precise placement of fertilizer will reduce the weed-free period required to avert yield loss in maize.

MATERIALS AND METHODS

Experiment 1 was carried out at the University of Zimbabwe campus in the 2001/02 season and Experiments 2 and 3 at the Rio Tinto Agricultural College in the 2002/03 season. The University of Zimbabwe campus site is found in Harare (17°50′ South and 31°30′ East) at an altitude of 1500 m above sea level, on red fersiallitic clay soils with an average annual rainfall of 800 mm that falls between the month of November and May. Daily average temperatures during the growing season range from 20 to 25 °C. The Rio Tinto Agricultural College site lies between 29°30′ East and 19°20′ South in the Zhombe district, in the rain shadow area of the Mapfungautsi plateau in the middle of Zimbabwe. The site is characterized by sandy clay loams of shallow depth (30 cm), derived from granite and dolorite parent material. Growing season temperatures are

fairly high, on average about 30 °C. Frequent mid season droughts characterize the rainy season and total seasonal rainfall that is received from the end of November to March ranges from 450 to 600 mm per annum. For the crop to be carried through the season supplementary irrigation was needed at the Rio Tinto site. For all the three experiments, the land was ploughed and planting was done in November after the first effective rains.

Experiment 1: Rate and placement method of fertilizer

The experiment was set up to determine the effect of fertilizer application rates and placement methods on the emergence and growth of weeds, early growth and maize grain yield at the University of Zimbabwe (UZ) campus. The experiment was laid out as a 3×3 factorial in a randomized complete block design replicated three times. Fertilizer application rates were 75, 150 and 225 kg ha^{-1} of basal granular compound D fertilizer (8% N, 14% P_2O_5, 7% K_2O). The three placement methods were spot placement, banding and broadcasting. Spot placement was achieved by placing the fertilizer into an opened planting station of about 5 cm depth. Banding was achieved by opening planting furrows approximately 5 cm deep using hoes and dribbling the required fertilizer in along the planting furrow, as evenly as possible, by hand. Broadcasting was achieved by evenly spreading the fertilizer onto the plot and incorporating it to 5-10 cm depth using hoes. Maize was planted at 90 cm $\times$ 30 cm spacing to achieve a final density of 37,000 plants ha^{-1}. Two maize seeds were placed into each planting station and covered. Maize plants were thinned to one plant per station, two weeks after crop emergence (WAE). A short season maize variety, SC 513 (Seed-Co®, Zimbabwe) was planted.

Weeds were counted at 5 and 8 WAE in three randomly placed 30 cm $\times$ 30 cm quadrants each, at two positions, in the maize row and in the middle of the maize inter-row. Counted weeds were cut at the ground level, oven-dried at 80 °C and weighed.

Four maize plants were randomly selected per plot (outside the net plot) and used for leaf number, plant height and biomass determination. The gross plot was 4.5 m $\times$ 7 m with 5 maize rows. The net plot was 2.7 m $\times$ 5.0 m.

Photosynthetically active radiation (PAR) incident above the crop, at mid crop height and the ground was measured using 191-SA line quantum sensors (Li-Cor, Lincoln, Nebraska, USA). Measurements were taken at two positions, against the maize stems along the maize row and in the middle of the maize inter-row. Three replicate measurements were taken at 2, 4 and 6 m along the maize row in the net plot. The average PAR measurement for the three positions was used in the data analysis. Maize was hand harvested from the net plot and moisture content measured. Grain yield was standardized to 12.5% moisture content and expressed ha^{-1} before statistical analysis.

Experiments 2 and 3: Fertilizer placement methods and the weedy/weed-free period

Experiment 2 was set up as a 3 × 4 factorial in a randomized complete block design at the Rio Tinto Agricultural College to measure the effect of fertilizer placement method and duration of weed-free period on the emergence, growth and fecundity of weeds and maize grain yield in the 2002/03 season. The fertilizer placement methods were spot placement, banding and broadcasting as described for Experiment 1. One fertilizer application rate, 100 kg of compound D was used. The weed-free factors were keeping the crop weed-free for 3, 6, 9 and 12 WAE and then unweeded for the rest of the season. Experiment 3 was similar in structure to Experiment 2, the only exception was that the weed-free periods were replaced by weedy periods (then weed-free for the rest of the season) for 3, 6, 9 and 12 WAE. Experiment 3 was planted at the same time and adjacent to Experiment 2, to enable the results of the two experiments to be compared.

PAR measurements were conducted as in Experiment 1, at 2 and 4 WAE. Maize early growth was assessed on five randomly selected maize plants which were harvested from outside the net plot area at 2 and 4 WAE. Maize height was measured using a tape measure from the ground to the tip of the maize funnel. Leaf area was measured using a LA-3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA). The maize plants were oven dried to a constant weight and weighed. Weed density and dry mass were determined as in Experiment 1, at 3, 6 and 9 WAE, before the weeding treatments scheduled for that time were implemented. Weed seed capsules were counted for the major species of weeds as indicated by visual assessment of percent ground cover at maize physiological maturity at 15 WAE. High day and night temperatures at the Rio Tinto site account for the rapid phenological development shown by the maize crop.

Maize was hand harvested from the net plots at 20 WAE and moisture content of shelled grain measured. A random sample of five cobs was taken from each plot and cob length, cob mass, number of kernel rows cob^{-1} and of kernels row determined.

Data analysis

All weed density and weed seed capsule data were expressed m^{-2} and square-root transformed (x + 0.05) transformed (Steel and Torrie, 1984) while maize grain yield was standardized to 12.5% moisture content before statistical analysis. Data from the experiments were subjected to analysis of variance (ANOVA) using SAS statistical package (SAS Institute 1999, Release 8, Cary NC, USA). Means were separated using Fisher's protected Least significant difference (Lsd) at P<0.05.
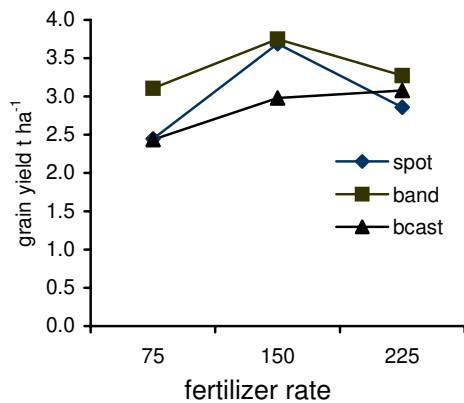
Figure 1. The effect of rate of application (kg ha^{-1}) and method of placement of basal compound fertilizer on maize grain yield in Experiment 1.

RESULTS

Maize grain yield

Maize grain yield was higher in the banded fertilizer placement treatment than in the broadcast placement treatment at all fertilizer application rates (Fig. 1), however, the overall effect of fertilizer placement was not statistically (P>0.05) significant in Experiment 1 (Table 2). Maize grain yield increased by 30% when fertilizer application rate was increased from 75 to 150 kg ha^{-1} but decreased on further increasing the fertilizer rate to 225 kg ha^{-1} (Table 1).

Maintaining the crop weed-free for the first three weeks achieved 74, 86 and 87% of the maximum grain yield in the spot, band and broadcast treatments, respectively (Fig. 2a). Fertilizer placement did not, therefore, significantly affect the grain yield response to increasing the weed-free period as indicated by the insignificant fertilizer

Table 1. Effect of rate of application (kg ha^{-1}) of basal compound fertilizer on maize plant dry weight, leaf number and height at 5 WAE and maize grain yield in Experiment 1.

Fertilizer application rate	Plant dry weight (g plant^{-1})	Height (cm plant^{-1})	Leaf number	Grain yield (kg ha^{-1})
75	18.3	65	7.4	2,664
150	20.2	74	8.6	3,471
225	19.0	70	8.1	3,069
P-value	P>0.05	P>0.05	P<0.05	P<0.05
Sed	2.89	4.47	0.44	347.16
Lsd$_{0.05}$	NS	NS	0.93	735.95

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Table 2. Effect of placement method of basal compound fertilizer on maize dry weight, leaf number and height at 5 WAE and maize grain yield in Experiment 1.

Fertilizer placement method	Plant dry weight (g plant^{-1})	Height (cm plant^{-1})	Leaf number	Grain yield (kg ha^{-1})
Spot	21.0	74	8.2	2,998
Band	19.6	72	8.1	3,376
Broadcast	16.9	62	7.8	2,831
P-value	P>0.05	P<0.05	P>0.05	P>0.05
Sed	2.89	4.74	0.44	341.50
Lsd$_{0.05}$	NS	10.048	NS	NS
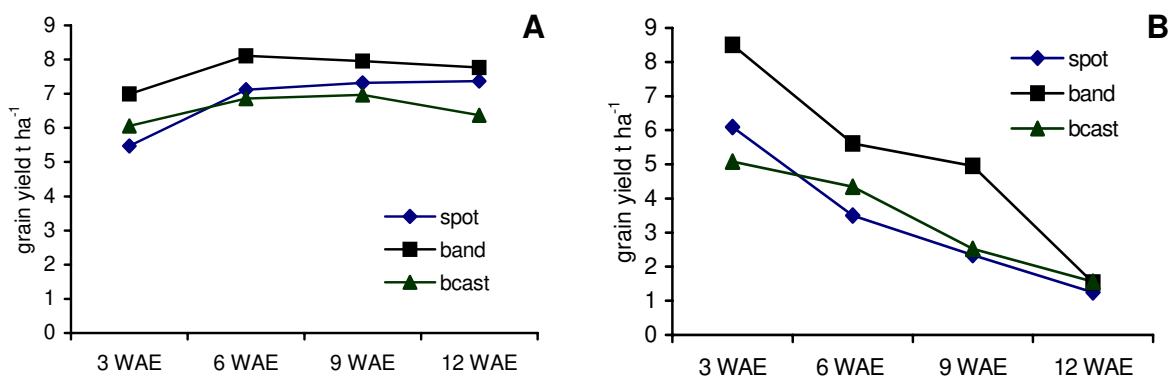
Figure 2 (A) Effect of weed-free period (then weedy) and fertilizer placement on maize grain yield in Experiment 2. (B) Effect of weedy period (then weed-free) and fertilizer placement method on maize grain yield in Experiment 3.

placement × weed-free period interaction (P>0.05). The banded treatment produced significantly higher maize grain yield than the broadcast treatment, averaged across the weed-free period treatments. The maize grain yield from the spot placed fertilizer treatment was not significantly different from the banded and broadcast fertilizer placement treatments (Fig. 2a).

In Experiment 3, the fertilizer placement method (P<0.01) and the duration of the weedy period (P<0.001), had a significant influence on maize grain yield. The two factors did not interact indicating that the nature of maize yield reduction with an increased weedy period was essentially similar across the fertilizer placement methods (Fig. 2b). The banding of fertilizer produced higher maize grain yield than spot and broadcast placement methods, averaged across the weedy periods (Fig. 2b).

Growth of maize

The effect of rate of fertilizer application on biomass, leaf number and height of the maize plant at 5 WAE in Experiment 1 is shown in Table 1. Leaf number was significantly higher at 150 kg ha^{-1} than at 75 kg ha^{-1} application rate. Plant height and biomass showed a similar trend as the leaf number data but was not significantly affected by rate of fertilizer application (Table 1).

Plant height was the only variable that was significantly affected by fertilizer placement method in Experiment 1 (Table 2). Plant biomass and height followed a similar trend as plant height but the effect of fertilizer placement on these variables was not statistically significant (Table 2). Measurements of plant biomass, height and LAI generally showed that maize plants were smaller with a reduced leaf area in the broadcast treatment compared to the banded and spot fertilizer placement methods at 3 and 6 WAE (Figs 3a, 3b and 3c). Similar results were obtained in Experiment 3 (data not shown).

Maize grain yield components

There was no significant fertilizer placement × weed-free/weedy period interaction on all maize grain yield components and, therefore, the main effects are presented. Table 3 shows the effects of fertilizer placement on maize yield components in Experiments 2 and 3. Spot and band placement of fertilizer resulted in significantly bigger cobs
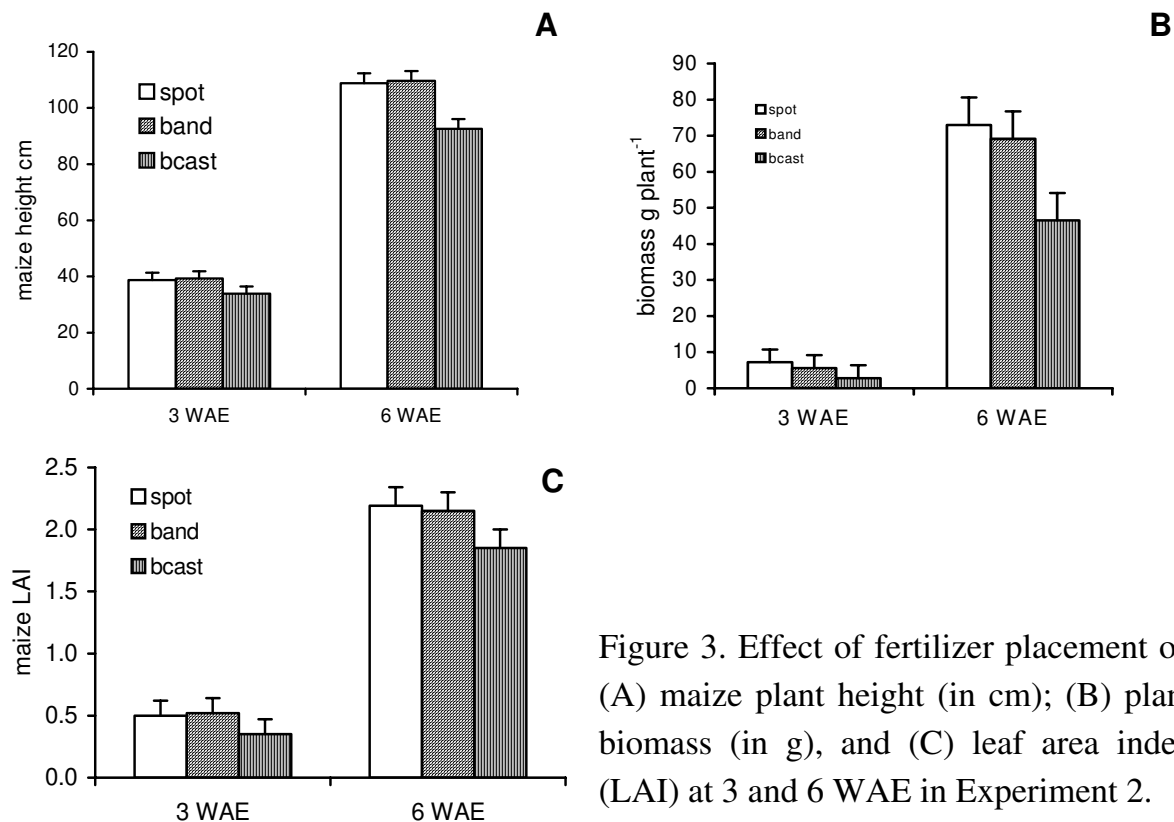

Figure 3. Effect of fertilizer placement on (A) maize plant height (in cm); (B) plant biomass (in g), and (C) leaf area index (LAI) at 3 and 6 WAE in Experiment 2.

Table 3. Effect of fertilizer placement on maize grain yield components in Experiments 2 and 3.

Fertilizer placement	Cob length cm cob^{-1}		Cob mass kg cob^{-1}		Number of kernel rows cob^{-1}		Number of kernels row^{-1}	
	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3
Spot	15.4b	13.8b	0.23b	0.17b	15.0a	14.8a	37.3a	30.6b
Band	16.1b	16.1c	0.25b	0.20c	15.0a	15.3ab	37.8a	34.0c
Broadcast	10.1a	10.0a	0.14a	0.11a	14.7a	15.8b	34.9a	23.8a
P-value	P<0.001	P<0.001	P<0.001	P<0.001	P>0.05	P<0.05	P>0.05	P<0.001
Sed	0.481	0.602	0.016	0.011	0.506	0.355	1.253	1.079
Lsd$_{0.05}$	0.998	1.248	0.033	0.023	NS	0.737	NS	2.239

Table 4. Effect of weeding regime (weeks after emergence, WAE) on maize grain yield components in Experiments 2[1] and 3[2].

Weeding regime	Cob length cm cob^{-1}		Cob mass kg cob^{-1}		Number of kernel rows cob^{-1}		Number of kernels row^{-1}	
	Exp 2	Exp 3	Exp 2	Exp 3	Exp2	Exp 3	Exp 2	Exp 3
3 WAE	13.8a	15.9c	0.20a	0.22d	15.1a	15.1a	36.0a	33.9c
6 WAE	13.6a	15.0c	0.20a	0.19c	14.9a	15.6a	37.2a	31.6c
9 WAE	14.3a	12.1b	0.23a	0.14b	15.1a	15.3a	37.6a	28.1b
12 WAE	13.8a	10.3a	0.19a	0.10a	14.4a	15.3a	35.9a	24.3a
P-value	P>0.05	P<0.001	P>0.05	P<0.001	P>0.05	P>0.05	P>0.05	P<0.001
Sed	0.556	0.695	0.018	0.013	0.584	0.410	1.447	1.246
Lsd$_{0.05}$	NS	1.441	NS	0.026	NS	NS	NS	2.585

[1] Weeding regime refers to duration of weed-free and then weedy period in Experiment 2 in Table 2.

[2] Weeding regime refers to duration of weedy period and then weed-free in Experiment 3 in Table 2.

(cob length and cob mass) than broadcasting in Experiment 2. In Experiment 3, all yield components increased from broadcasting to spot and band placement treatments, respectively (Table 3).

Increasing the duration of the weed-free period beyond three weeks did not significantly affect maize yield components in Experiment 2 (Table 4). Increasing the duration of the weedy period reduced all grain yield components except number of kernel rows cob^{-1} in Experiment 3 (Table 4).

Weed density and biomass

Weed density was generally not significantly affected by fertilizer placement or rate of application in Experiment 1. The exception was at 8 WAE in the middle of the maize inter-row. A higher density of weeds was recorded in the broadcast (6.6 m^{-2}) compared to the banding (5.88 m^{-2}) placement method ($Lsd_{0.05}$=0.657; n=9). There was no difference in weed density between the spot and banding fertilizer placement methods. There was a significant interaction ($P \leq 0.01$) between fertilizer placement method and rate of application on weed biomass within the maize row at 5 WAE (Table 5). The biomass of weeds within the row decreased in the broadcast treatment with increased quantity of fertilizer applied. With spot and band placement methods of fertilizer application, the weed biomass increased in the row with increased quantity of fertilizer applied (Table 5).

In Experiment 2, there was a consistently higher weed density and biomass in the broadcast compared to the spot and band fertilizer placement treatments (Figs 4a and 4b). In Experiment 3, weed density tended not to statistically differ between the banding and broadcasting treatments with spot placement having the lowest weed density at 3, 6 and 9 WAE (Fig. 4c).

There was a fertilizer placement method × weed-free period interaction on weed biomass in Experiment 2. It required a weed-free period of 6 WAE for the broadcast treatment to attain the same weed biomass as the spot and band placement treatments with a weed-free period of 3 WAE (data not shown).

A higher weed density and biomass were measured in the row than the middle of the inter-row in Experiment 2 (Figs 5a and 5b). In Experiment 3, there was an interaction (P<0.05) between fertilizer placement and sampling position on weed

Table 5. Interaction between fertilizer application rate and method of placement on weed biomass (g m^{-2}) in the row in Experiment 1.

Placement method	Fertilizer applications rates in kg ha^{-1}		
	75	150	225
Spot	16.52a[1]	23.31a	25.32a
Band	16.43a	14.52a	32.54b
Broadcast	30.43b	18.72ab	14.31a
	P-value	Sed	$Lsd_{0.05}$
Effect of fertilizer placement method	P>0.05	3.440	NS
Effect of rate of fertilizer application	P>0.05	3.440	NS
Rate × placement interaction	P<0.01	5.985	12.305

[1] Means followed by the same letter in a row are not significantly different at P<0.05.
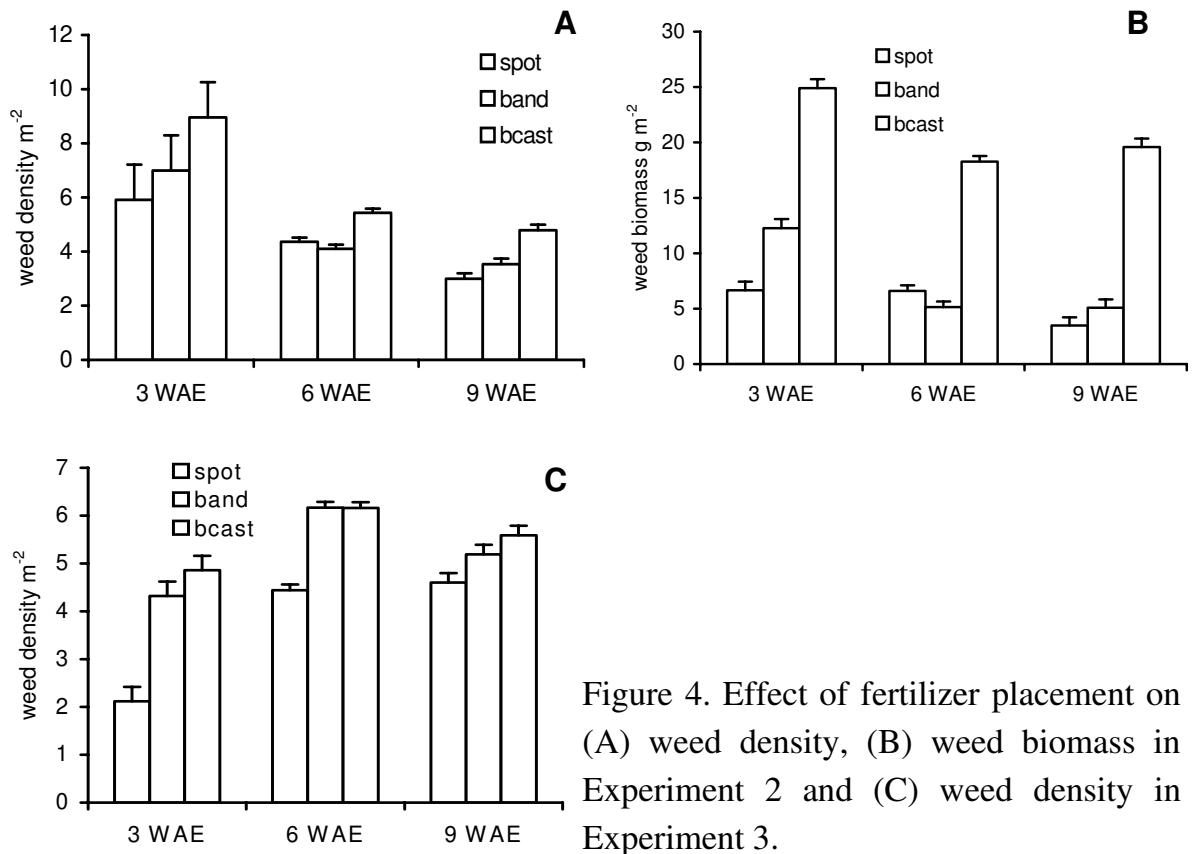
Figure 4. Effect of fertilizer placement on (A) weed density, (B) weed biomass in Experiment 2 and (C) weed density in Experiment 3.
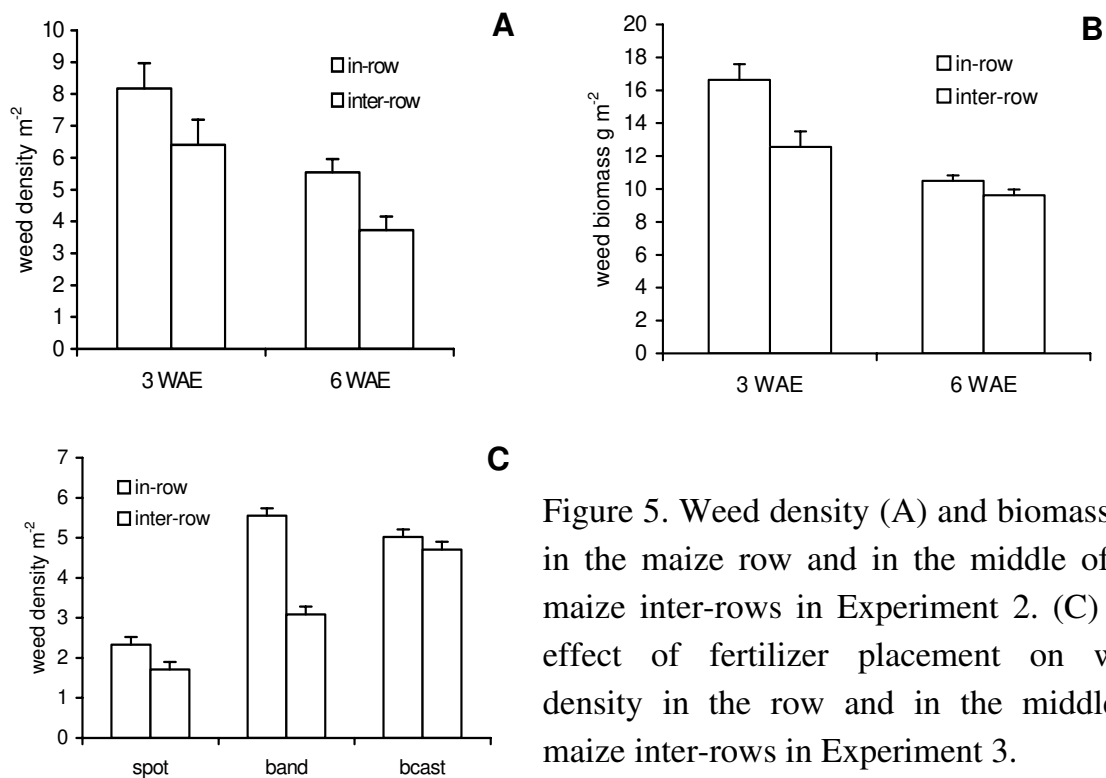
Figure 5. Weed density (A) and biomass (B) in the maize row and in the middle of the maize inter-rows in Experiment 2. (C) The effect of fertilizer placement on weed density in the row and in the middle of maize inter-rows in Experiment 3.

density at 3 WAE. Broadcasting the fertilizer produced the same weed density in the row and in the middle of the inter-row, while more weeds emerged in the row compared to the middle of the inter-row in the spot and band fertilizer placement methods (Fig. 5c).

Seed production by weeds

A significantly higher number of weed seed capsules were counted in the broadcast compared to the spot and band fertilizer placement methods for *Commelina benghalensis* L.*, Amaranthus hybridus* L. and all species (Fig. 6a). For all species, a 9 week weed-free period was required to completely stop the addition of weeds to the seedbank (Fig. 6b). For *C. benghalensis*, there was a significant interaction between fertilizer placement method and weed-free period on its seed production.
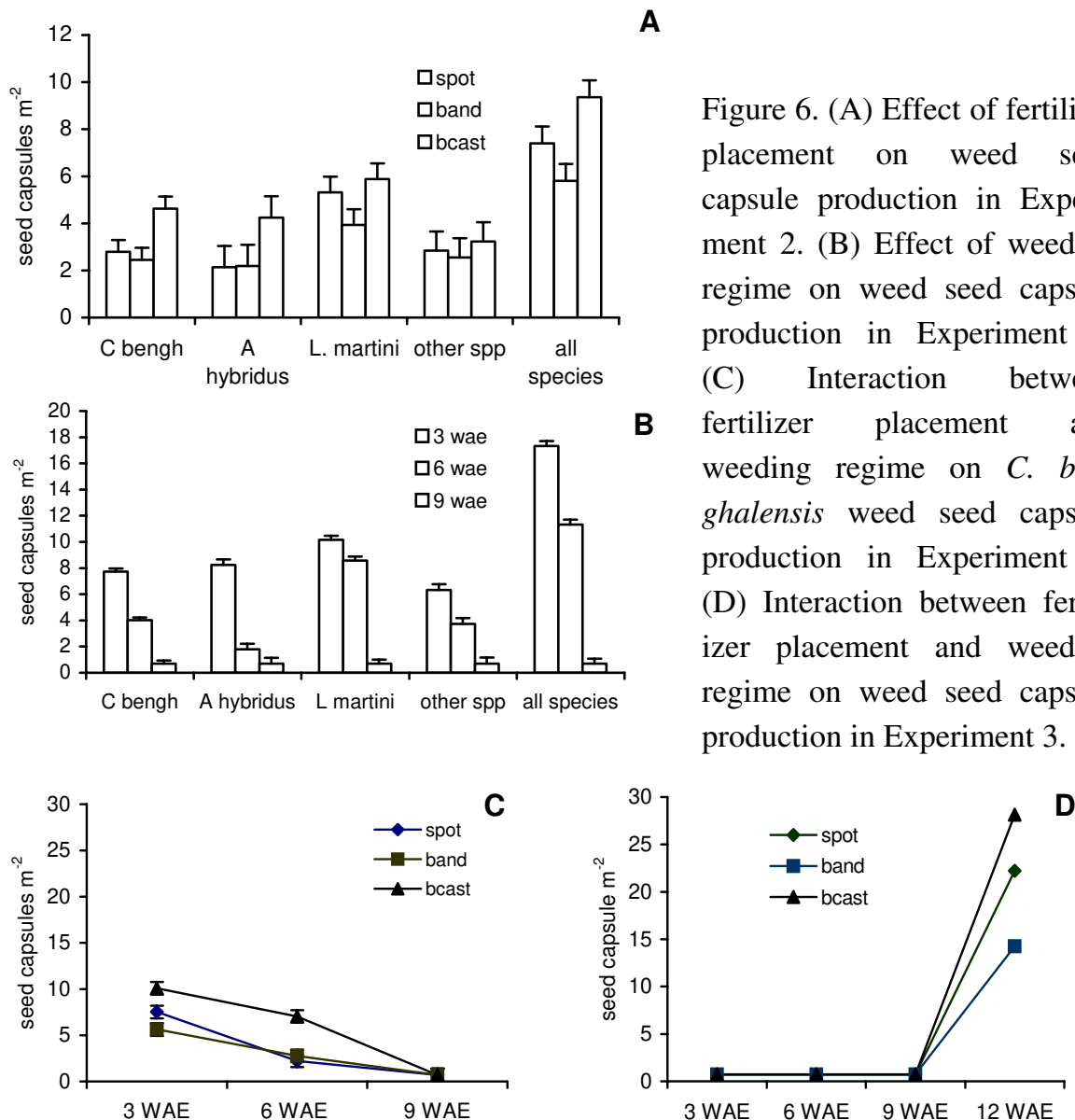
Figure 6. (A) Effect of fertilizer placement on weed seed capsule production in Experiment 2. (B) Effect of weeding regime on weed seed capsule production in Experiment 2. (C) Interaction between fertilizer placement and weeding regime on *C. benghalensis* weed seed capsule production in Experiment 2. (D) Interaction between fertilizer placement and weeding regime on weed seed capsule production in Experiment 3.

For the band and spot fertilizer placement methods, a weed-free period of 6 WAE was adequate to almost stop weed seed capsule production, while the same weed-free period in the broadcast treatment only resulted in a 20% reduction of seed capsule production (Fig. 6c). A weed-free period of 9 WAE was required to stop additions of new seed by *C. benghalensis* to the seedbank in the broadcast treatment (Fig. 6c). There was a weedy period × fertilizer placement interaction on weed seed capsule production in Experiment 3. Weed seed production was nil in all the weeded treatments at 12 WAE, but in the unweeded treatment, seed capsule production decreased from broadcast, spot to band fertilizer placement method (Fig. 6d).

Radiation interception

There was no significant effect of fertilizer placement method on PAR reaching the ground in Experiment 1. PAR reaching the ground was significantly lower and concomitantly radiation interception higher at 150 kg than the 75 kg ha^{-1} fertilizer application rate at 8 WAE in Experiment 1 (Fig. 7a).
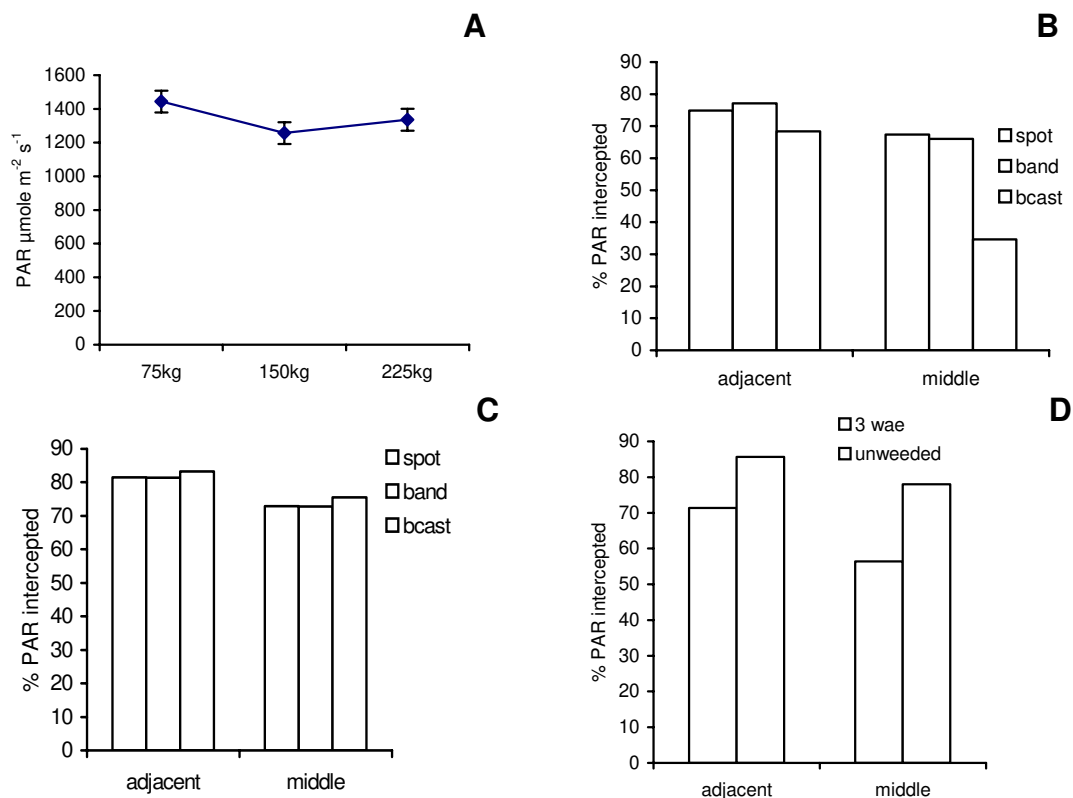
Figure 7. (A) Effect of fertilizer placement on PAR reaching the ground in the middle of the row at 8 WAE in Experiment 1. Effect of fertilizer placement on percent incoming PAR intercepted in a maize crop at 4 WAE in (B) Experiment 2 and (C) Experiment 3. (D) Effect of weeding regime on percent incoming PAR intercepted by a maize crop at 4 WAE in Experiment 3.

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Percent of total PAR intercepted was higher in the spot and band fertilizer placement treatments than in the broadcast treatment in Experiment 2 (Fig. 7b). The unweeded treatments at 4 WAE intercepted more radiation than the treatments kept weed-free from 3 weeks onwards in Experiment 3 (Fig. 7d).

DISCUSSION

Maize grain yield

Banding of fertilizers within the crop row has been shown not only to reduce weed populations but also to increase crop yields when compared to broadcasting in beans (*Phaseolus vulgaris* L.) (Ottabong *et al.*, 1991), soybean (*Glycine max* Merr.) groundnuts (*Arachis hypogaea* L.) (Everaarts, 1992) and wheat (*Triticum aestivum* L.) (Cochran *et al.*, 1990). The banding of fertilizer below the seed or to one side of the seed concentrates mineral nutrients in the root zone of the crop. It also restricts access of weeds to the fertilizer by spatial separation and by virtue of the shallow depth of soil exploited by most annual weed roots (DiTomasi, 1995; Ottabong *et al.*, 1991; Moody, 1981). The advantages of precise placement of fertilizer are most likely to be shown in nutrient deficient soils because it minimizes dilution effect of spreading the mineral nutrients over the whole soil surface that invariably occurs with broadcasting of fertilizer. It also reduces the fixation of applied nutrients by restricting contact of the applied nutrients with large volumes of soil constituents that react with the mineral nutrients, especially phosphate, to form insoluble products that are unavailable for plant uptake. Nyamangara *et al.* (2000) reported on the general acidification and decline in nutrient status of sandy soils where maize is grown, soils similar to those found at the Rio Tinto site. Under such conditions, the beneficial effects of placement of applied fertilizer near the root zone of the crop become more likely.

The response of maize grain yield to fertilizer placement and rate of application in Experiment 1 reflects the high fertility of the soil at this site. The University of Zimbabwe site has a history of high fertilizer applications running for the previous 20-30 years and, therefore, a build up of residual fertility at this site is expected. Coupled with the inherent high fertility of the fersiallitic clay soils (Nyamapfeni, 1991), the accumulated residual fertility dulled the effects of more precise placement of fertilizer compared to broadcasting on maize grain yield in Experiment 1. Spot and band application of fertilizers only accounted for a statistically insignificant maize grain yield increase of 6% and 19%, respectively, above that of the broadcast treatment Experiment 1. By comparison, banding had an overall 52% yield advantage over the broadcast treatment in Experiment 3. The Rio Tinto site is located on less fertile granitic sandy soils (Grant, 1981) and the advantages of banding fertilizer on maize

grain yield were, therefore, more pronounced than in Experiment 1.

Early growth of the maize in the banding and spot placement treatments was generally greater than in the broadcast treatment, agreeing with results of Tanner (1984), in an experiment on similar soils as in Experiments 2 and 3. However, in all cases in this study, the trend in maize grain yield showed a consistent superiority of banding over spot placement, albeit not statistically significant in Experiments 1 and 2. These results may be indicative of the droughty conditions that characterized the two seasons in which these experiments were held. Tanner (1984) explained that spot placement maybe more beneficial in seasons with adequate rainfall than banding and broadcasting but the opposite can be true in dry seasons as high concentrations of fertilizer around the root zone of the crop where fertilizer has been spot placed increases the severity of moisture stress episodes much more than in the broadcast and band treatments. The apparent superior maize grain yield of the banding treatment over the spot placement treatment may be attributable to this phenomenon. This should hold given rainfall totals of 667 mm in 2001/02 season at UZ campus and 450 mm in the 2002/03 season at Rio Tinto, and the fact that rainfall was poorly distributed at both sites.

To some extent the results of the rate of fertilizer application on maize grain yield in Experiment 1 lend support to the hypothesis that high concentrations of fertilizer were somewhat damaging to maize grain yield. Maize grain yield showed a distinct trend of decreasing from the 150 kg ha^{-1} to the 225 kg ha^{-1} application rate, more so in the spot than in the band fertilizer placement treatments and no response in the broadcast treatment (Fig. 1). Early maize growth data also displayed similar trends (Table 1). These results suggest that at 225 kg ha^{-1} of compound D fertilizer, the high concentrations of fertilizer in the root zone of the spot and band placed fertilizer probably predisposed the plants to more severe episodes of drought stress to which maize plants were subject to because of droughty conditions.

Weed density, biomass and seed production

Broadcasting of fertilizer and its incorporation into the soil mean that the applied mineral nutrients will be distributed more or less uniformly across the soil surface and in the soil depth to which the fertilizer is incorporated. In contrast, with spot and band placement of fertilizer, the fertilizer is placed below the soil surface nearest to the root zone of the crop. The dormancy of some annual weed species is broken by increased levels of nitrates in the soil (DiTomasi, 1995; Agenbag and De Villiers, 1989) and this may explain the higher densities of weeds observed in the broadcasting treatment compared to banding and spot placement treatments. Banding of fertilizer reduced weed density compared to broadcasting in a number of studies (Ottabong *et al.*, 1991;

Everaarts, 1992; Cochran *et al.*, 1990; Kirkland and Beckie, 1998) similar to our results. It would seem, therefore, that weeds tend to emerge in greater number where fertilizers are spread and incorporated throughout the whole soil surface in comparison to more precise placement of fertilizer nearest the crop roots. The relative degree to which this occurs must be related to the general fertility of the soil. The expectation would be that in a nutrient deficient soil, similar to the sandy soil in Experiments 2 and 3, the magnitude of weed emergence stimulation by broadcasting fertilizer in comparison to precise fertilizer placement methods, would be greater than in a fertile soil as in Experiment 1. Weed density was higher by 11%, 16% and 51% in the broadcast compared to the banding treatment in Experiments 1, 2 and 3, respectively, in this study. In Experiment 3, the data includes successive cohorts of weeds over a long period since it involved weedy then weed-free treatments. This magnified the weed density differences in the broadcasting compared to the banding treatment much more than for Experiment 2.

Access to applied fertilizer nutrients is promoted for the crop and restricted for the majority of the shallow rooted weeds found in the mid-row area when fertilizer is banded or spot placed nearest the crop seed at planting. The opposite would be true when fertilizer is broadcast and incorporated in the soil. This would explain why higher weed biomass was recorded from the broadcast compared to the spot and band fertilizer placement treatments in this study. Higher levels of nutrient uptake by weeds have been recorded when fertilizer was broadcast compared to more precise fertilizer placement methods into the soil nearest to the crop rooting zone (Blackshaw *et al.*, 2002). To some extent this may partly explain the higher rates of growth of weeds in the broadcast treatments recorded in this study and others in the literature. Kirkland and Beckie (1998) reported that broadcast applied fertilizer was more effective than banded fertilizer in promoting wild oat and broadleaf weed emergence and growth over the season in a wheat crop. Weeds are generally more efficient in accumulating soil nutrients than crop plants (Vengris *et al.*, 1953; DiTomasi, 1995; Sibuga and Bandeen, 1980; Teyker *et al.*, 1991; Qusem, 1992, 1993; Ampong-Nyarko and De Datta, 1993; Moody, 1981). It is, therefore, expected that weeds will win the competition battle with the crop for applied fertilizer nutrients unless access to the nutrients promoted for the crop and discouraged for weeds by precise placement of the fertilizer.

The effects of precise fertilizer placement in denying access of weeds to applied nutrients and, therefore, reducing the competitiveness of weeds against the crop is confounded with its effects in promoting higher rates of crop growth and attainment of earlier canopy closure which achieve the same effect. Results of this study generally showed that band and spot placement of fertilizer increased early maize growth and PAR interception compared to maize grown in the broadcast treatment. Competition

for light tends to give an increasing advantage to the plants that have a starting position advantage (bigger and leafier plants at the start of the dynamic process of competition). Weiner *et al.* (1997) observed that larger plants were able to obtain a share of resources that was disproportionate to their relative size and to suppress the growth of smaller individuals. The lower weed biomass attained by weeds in the spot and band placed fertilizer treatments compared to the broadcast treatment in this study is, therefore, partly explainable in terms of these placement methods increasing the size and competitiveness of the maize crop against weeds. Van Delden *et al.* (2002) found that in wheat, *Stellaria media* growth, seed production and nitrogen uptake increased with soil nitrogen supply while in a potato crop, its growth was light limited and decreased with increased soil nitrogen supply. The effects of increased nutrient supply to the crop as would be promoted by banding and spot placement of fertilizer, are, therefore, likely to depend on the competition dynamics of the crop and the weed for light and mineral nutrients.

Our results also show that there is likely to be increased weed growth within the row when fertilizer is spot or band placed compared to broadcasting and such weed growth may increase in the row with increased rates of fertilizer application. Munguri (1996) reported similar results in sandy soils. It may, therefore, mean that fertilizer placement should be integrated with weed management tactics that remove weeds within the row soon after crop emergence before they cause crop damage. Weeds that are within the row are nearest to crop plants and if they grow together with the crop, are more damaging than those in the middle of the row especially early on, soon after crop emergence.

The interaction between the weed-free period and weed biomass in Experiment 2 shows that the broadcast treatment required a weed-free period of six weeks to attain the same weed biomass as the band and spot fertilizer placement with a weed-free period of only three weeks. This result indicates a possibility that precise placement of fertilizer near the crop rooting zone has potential to reduce the weeding burden of smallholder farmers. Integrating fertilizer and manure placement into the cropping practices of smallholder farmers is, therefore, likely to contribute to the aggregate reduction of the weed problem that they have to deal during the season.

The lower seed production by weeds in the band and spot fertilizer placement treatments compared to the broadcast treatments is reflective of the linear relationship between weed biomass and fecundity of annual weeds found in other studies (Thompson *et al.*, 1991; Baumann *et al.*, 2001). The reduction in seed production with precise placement of fertilizer compared with broadcasting means that these methods will not only be potentially beneficial in increasing crop yields and reducing weed competition, but could affect weed propagule numbers in the soil seedbank in the long term.

The critical period of weed control

Results of this study show that the maize crop must be weeded at 3 WAE to achieve maximum yields and that there is no yield advantage to be gained by continuing to weed the crop after 6 WAE. These results were consistent for all fertilizer placement methods as there were no interactions between the fertilizer placement methods and weed-free/weedy period in Experiments 2 and 3. Tanveer *et al*. (2001) tested the effect of weed-free periods of 3, 4, 5, 6, 7, 8 WAE and full season competition combined with side placement side placement and broadcasting of fertilizer in wheat. The highest dry weights and N uptake by *Chenopodium album* were recorded in the broadcasting and full season competition treatments. Higher wheat yields were obtained with side placement of the fertilizer and the critical weed-free period that produced yields equal to no weed competition throughout the season was 3WAE, in general conformity with our results. It would seem, therefore, that although weed density and biomass were reduced by precise placement of fertilizer in the rooting zone of the crop, the reduction in weed competitiveness was not adequate to effectively reduce the overall weeding requirements of the crop for attainment of maximum yields.

Implications for smallholder farmers in semi-arid areas

Increased precision in the placement of fertilizer nearest to the rooting zone of the crop had been shown to enhance the competitiveness of the crop against weeds in this study. Weed emergence and growth were reduced and crop growth was enhanced significantly more in the banding and spot placement methods than in the broadcast method of fertilizer application. For smallholder farmers, precise placement of fertilizer makes sure that the little fertilizer that is applied literally 'goes a long way' because it produces similar yields to higher fertilizer application rates applied using the broadcasting method (Jonga *et al*., 1996; Munguri, 1996). Chivinge and Mariga (1998) showed that half the recommended fertilizer application rates (44 kg N ha^{-1}) produced maize grain yield similar or higher than full application rates provided that adequate weed control (hoe-weeding at 3 and 5 WAE or application of 1.75 kg a.i. atrazine full cover spray) was carried out in the smallholder sector in a semi-arid area of Zimbabwe. Munguri (1996) showed that the same similar benefits were derived when fertilizer or manure was banded or spot placed in comparison to broadcasting, meaning that precision of placement technology is also available to those farmers with cattle and access to cattle manure. A systems approach implies that each weed control decision must be evaluated in terms of its impact on the performance of the farming system as a whole (Ikerd, 1993).

Increased precision of application of fertilizers is, therefore, beneficial to cropping

systems from two fronts, reduced weed competitiveness and increased crop yield, more with band than spot application in this study. Our results seem to indicate that high fertilizer application rates and/or spot placement of fertilizer may nullify any expected yield gains from the supply of mineral nutrients by a greater predisposition of the crop to moisture stress in semi-arid regions. The fertilizer placement decisions must, therefore, be tempered by the soil moisture conditions that are likely to prevail during the growing season.

CHAPTER 8

Reduced dosages of atrazine and nicosulfuron provide adequate weed control in maize in Zimbabwe

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Abstract

Field and glasshouse experiments were carried out to determine the efficacy of below label recommended dosages of nicosulfuron and atrazine in maize in the 1995/96 and 1996/97 seasons in Zimbabwe. Atrazine and nicosulfuron were applied at 33.3, 66.7 and 100% of the label recommended dosage (LRD) at the 2-3 and 5-6 leaf stage of weeds. Reduced herbicide dosages were significantly more effective in controlling weeds at the 2-3 leaf stage than at the 5-6 leaf stage. Species exhibiting tolerance to atrazine (*Eleusine indica* (L.) Gaertn., *Setaria homonyma* (Stead.) Chiov., *Setaria verticillata* L. Beauv., *Cyperus rotundus* L.) or to nicosulfuron (*E. indica*, *Galinsoga parviflora* Cav. and *Portulaca oleracea* L.) increasingly survived the herbicide application and produced more seeds at lower dosages or when treated at the 5-6 leaf growth stage. Long-term use of reduced dosages alone would, therefore, select for these tolerant weed species. Reduced dosages of atrazine and nicosulfuron mixtures as low as 25% of the LRD of each of the herbicides, had equal levels of weed control as LRDs of atrazine and higher levels of weed control than the LRD of nicosulfuron. Maize grain yield was consistently similar at all dosages of atrazine, nicosulfuron or their mixtures. The results indicate that below LRDs sufficiently suppressed the competitiveness of weeds during the critical first 4-5 weeks after maize emergence to avert yield loss but not survival and weed seed production by tolerant weed species. Reduced dosages of atrazine and nicosulfuron were more effective against tillage-damaged weeds resurrecting under wet soil conditions than on undamaged weeds. Reduced dosages of atrazine and nicosulfuron have to be integrated with hand hoeing or mechanical weeding to remove herbicide escapes after their application and prevent the inadvertent selection for tolerant species in the long term.

Key words: Nicosulfuron, atrazine, reduced doses, weed growth stage, weed biomass, weed seed production, tank mixtures, sequential application, maize grain yield.

INTRODUCTION

Weed control is a major contributor to the total labour input in the production of crops in Zimbabwe. Smallholder farmers spend more than 75% of their time struggling to control weeds during the peak weeding period from December to March (Chivinge, 1990). Ellis-Jones *et al.* (1993) observed that weeding was the most labour intensive pre-harvest operation, accounting for about 80% of the labour hours in crop production in the smallholder sector of Zimbabwe. Smallholder farmers in Southern Africa largely rely on the hand hoeing and ox-cultivation for weed control (Chivinge, 1990; Parker and Vernon, 1982). Hoe-weeding is a slow labour intensive method of weed control which involves considerable physical drudgery for smallholder farmers (Akobundu, 1987). Most of the burden of hoe-weeding falls on women and children because of gender related division of labour where men work with animals and rural urban migration (Sibuga, 1999).

The labour shortages for weeding are being worsened by the increase in morbidity wreaked by the AIDS (Acquired Immune Deficiency Syndrome) pandemic that is sweeping sub-Saharan Africa (Sibuga, 1999). The average HIV (Human Immuno-deficiency Virus) infection rate in the 15-49 age group in Zambia and Zimbabwe is 28.7%, South Africa 20.1% and Botswana 38.8% (Ngom and Clark, 2003). The impact of the HIV/AIDS on age related mortality is striking and very focused at the reproductive ages (15-49 years) and takes a grim toll on the able bodied members of rural communities that work on the land. The ability of smallholder farmers to effectively control weeds is not only threatened by the HIV/AIDS subtracting the able bodied weeders from the households but also by farmers neglecting their weeding chores to tend to the sick and attend funerals (Mashingaidze *et al.*, 2003).

The efficacy of hoe-weeding and ox-cultivation is often compromised by continuously wet conditions characteristic of the beginning of the growing season in November/December. Hoe-weeded weeds often re-root and re-establish when hoe-weeding and ox-cultivation are carried out during wet conditions, necessitating several rounds of weeding to keep the crop weed-free and avert yield losses (Mashingaidze and Chivinge, 1995). Under continuous wet soil conditions, smallholder farmers often fail to cope with their weeding requirements and abandon a portion of the crop to weeds, incurring losses of inputs such as labour, fertilizers and draft power previously committed to the crop. In resettlement areas in Zimbabwe that were opened up after 1980, the average arable land holding per household is 6-10 ha (Jonga, 1998), an area too large for households to adequately cope with its weeding requirements using hoe-weeding and ox-cultivation. By 1996, 71,000 households were resettled on 2.7 million hectares of former commercial farmland (Palmer, 1990; Moyo, 1995, 2000).

The adoption of herbicide technology in the smallholder sector has traditionally been low because of lack of technical knowledge of the farmers and extension agents, lack of funds to purchase herbicides, fear of crop phytotoxicity and lack of equipment (Chivinge, 1984; Johnson and Adesina, 1993). Reduced herbicide dosages of herbicides would reduce the aggregate cost of the herbicide option and render the use of herbicides more attractive to smallholder farmers. Reduced herbicide dosages reduce the risk of carry-over phytotoxicity problems to susceptible crops in a rotation (Chivinge and Mpofu, 1990; Burnside and Schultz, 1978). Hanson *et al.* (1997) showed that below label dosages of atrazine were less liable to be leached into underground water sources than full label rates. Smallholder agriculture was booming in the immediate post-independent Zimbabwe (Rukuni, 1994), however, there was a growing realization that if newly resettled farmers would not acquire the means to manage weeds on large pieces of land, productivity would remain at pre-settlement levels (Rupende *et al.*, 2000). Chemical weed control was seen as a viable option for a new breed of smallholder farmers who have the resources and the land for commercial production of maize and other crops (Mashingaidze and Chivinge, 1995).

The objective of this study was to determine the efficacy in terms of weed kill, weed biomass, grain yield, economic return and weed seed capsule production of below label dosages of atrazine and nicosulfuron applied alone, in mixture or sequentially. The hypothesis tested in this study was that below label dosages of herbicides would sufficiently suppress weed growth during the critical period for weed competition for maize, before full ground cover, and avert yield losses. The study also examined the efficacy of weed control of these herbicides when combined with simulated tillage in the glasshouse and the field. The hypothesis tested was that re-establishing weeds recovering from the tillage damage will be more susceptible to below label rates of herbicides than weeds that have not been subjected to a prior tillage treatment.

MATERIALS AND METHODS

Field operations

In all field experiments in this study, the land was disc-ploughed in October/November and disc-harrowed to a fine tilth, before planting. Planting was achieved by placing two maize seeds 0.3 m apart into opened planting furrows at 0.9 m spacing. The maize was thinned 2 weeks after emergence (WAE) to one plant per station to a final maize density of 37,000 plants ha^{-1}. Planting occurred in November after the first effective rains. A short season maize variety, SC 501 (Seed Co®, Zimbabwe) was planted in Experiments 1 and 2 while for the rest of the experiments Pan 67 (Pannar®, Zim-

babwe), a medium season maize variety was planted. Compound D (8% N, 14% P_2O_5, 7% K_2O) was dribbled as a basal fertilizer at a rate of 200 kg ha^{-1} into the planting furrows before planting and the maize was top-dressed with 200 kg ammonium nitrate (34.5% N) at 5 WAE. Gross plot size was 5.4 m × 8 m consisting of six maize rows of 8 m length and measurements were taken from a net plot of 3.6 m × 6 m consisting of four middle maize rows of 6 m length. In all cases label recommended dosages (LRDs) refer to the dosages of the herbicides when they are used as single herbicides.

Experiments 1 and 2: Reduced dosages of atrazine and nicosulfuron and weed growth stages

Two experiments, one with atrazine (Experiment 1) and the other with nicosulfuron (Experiment 2), were carried out at the Crop Science Department plots, University of Zimbabwe campus, in the 1995/96 season. The experiments were laid out as a split plot randomized complete block design with stage of growth of the weeds at which herbicide was applied as the main plot and herbicide dosage as the sub-plot. The treatments were replicated three times. Two stages of growth, the 2-3 leaf and the 5-6 leaf stage of the majority of weeds, constituted the main plot treatments. Three dosages 750, 1,500 and 2,250 g active ingredient (a.i.) atrazine ha^{-1}, respectively representing 33%, 67% and 100% of the label recommended dosage (LRD) of atrazine for a medium heavy clay (30-40% clay content) were the sub-plot treatments in Experiment 1. In Experiment 2, the sub-plot treatments were 11.25, 22.5 and 33.75 g a.i. nicosulfuron ha^{-1}, respectively, representing 33%, 67% and 100% of the label recommended dosage. A control treatment hoe-weeded at 3 and 6 WAE was included in both experiments. The LRD for post emergence application of Atrazine®500 (500 g a.i. atrazine litre^{-1}) Flowable is 4.5 litres for a medium heavy soil (30-40% clay). The LRD of nicosulfuron is 45 g of the Accent®75 (75 g a.i. nicosulfuron kg^{-1}) Dry Flowable Granule in maize in Zimbabwe.

The herbicide was applied at 2.5 WAE for the 2-3 leaf stage and at 4 WAE for the 5-6 leaf stage main plot treatments. The weeds were counted by species in five randomly placed 30 cm × 30 cm quadrants just before herbicide application (BHA). Four wire pegs with a red flag marker were placed at the corners of each quadrant to enable subsequent counts at the same locations. The herbicides were applied using a knapsack sprayer calibrated to apply 200 litres of the herbicide spray mixture ha^{-1}. The herbicide applicator was timed for each run to make sure that a constant application rate was maintained throughout herbicide dosage treatments. Three weeks after herbicide application (WAHA), surviving weeds within the marked quadrants were counted by species, cut at ground level, and oven-dried to a constant weight at 80 °C and weighed. At maize physiological maturity, three 1 m × 1 m quadrants were randomly placed into

the net plots and seed capsules carried by each weed species counted. Maize cobs were hand harvested in May from the net plot and grain yield was standardized to 12.5% moisture content before analysis.

Percent weed kill were arc-sine square root transformed for mean separation (Steel and Torrie, 1984), however, the actual percentages are presented. Partial budgets were worked out to analyse the net economic benefit (NEB) of each treatment using the methods of CIMMYT (1988). Variable costs to construct the budget were the cost of the herbicide, the cost of labour to apply the herbicide and the cost of hand weeding. The gross crop yield benefit was obtained by multiplying the market prices for maize and the grain yield ha^{-1}. The NEB was the difference between the variable costs and the gross crop yield benefit in US dollars.

Experiments 3 and 4: Reduced dosages of atrazine and nicosulfuron applied as a tank mixture

Experiment 3 was carried out at the University of Zimbabwe (UZ) Farm in the 1996/97 season to determine the efficacy of below label rates of atrazine and nicosulfuron when applied as a mixture on the percent weed kill, weed biomass and maize yield. Herbicide application was similar to Experiment 1, except that the herbicides were applied as a tank mix. Dosages were 280 g a.i. atrazine + 4.24 g a.i. nicosulfuron (12.5% LRD), 560 g a.i. atrazine + 8.84 g a.i. nicosulfuron (25% LRD), 750 g a.i. atrazine + 11.25g a.i. nicosulfuron (33% LRD), and 1,130 g a.i. atrazine + 16.88 g a.i. nicosulfuron (50% LRD) applied as tank mixes. Herbicide was applied when the median growth stage of the weeds was the 2-3 leaf stage as assessed visually. These treatments were compared among themselves and to the full dosage of each herbicide applied alone. The treatments were laid out as randomized complete block design replicated four times. Percent weed kill and weed biomass were determined as in Experiments 1 and 2. The transformed percent weed kill data was pooled and analysed as a factorial with species and herbicide treatment as the factors.

Experiment 4 was carried out at the Crop Science Department, UZ in Harare in the 1997/98 season. The experiment was similar to Experiment 3 except for the herbicide dosages that were tank mixed. A quarter (560 g a.i. atrazine + 8.84 g a.i. nicosulfuron), a third (750 g a.i. atrazine + 11.25 a.i. nicosulfuron), two thirds (1,500 g a.i. atrazine + 22.5 g a.i nicosulfuron) and the full LRDs (2,250 g a.i. atrazine + 33.75 g a.i. nicosulfuron) were compared with an unweeded control and hand-weeded control (hand-weeded at 3 WAE). Herbicide application and measurements were as in Experiment 3.

Experiment 5: Sequential applications of nicosulfuron

The experiment was carried out at the University of Zimbabwe Farm in the 1996/97

season to compare the efficacy of a quarter and a third of the LRDs of nicosulfuron applied twice (sequentially), at 3 and 6 WAE. These treatments were compared to half, two thirds and the full LRD applied at once, at 3 WAE. Percent weed kill, weed bio-mass and maize yield were treated in the same manner as in Experiments 3 and 4.

Experiment 6: Reduced nicosulfuron and atrazine dosages and simulated tillage
Two experiments, one with atrazine, the other with nicosulfuron, were carried out in a glasshouse kept at 25/15 °C day/night temperatures, respectively, at the Crop Science Department in the 1995/96 season. *Eleusine indica* (L.) Gaertn., *Ipoemia plebeia* R. Br., *Portulaca oleracea* L., and *Commelina benghalensis* L. were used for the atrazine trial while *Amaranthus hybridus* L*., E. indica* (L.) Gaertn., *I. plebeia* and *Nicandra physaloides* Gaertn. were used in the nicosulfuron trial. Seeds of each species were sown three rows 10 cm apart in asbestos trays (40 cm length × 30 cm width × 5 cm depth) filled with a medium heavy (30-40% clay) fersiallitic red soil.

At 2 WAE, each species was thinned to 25 uniform spaced and sized seedlings per species row per tray. At 3 WAE, after watering, the prongs of a garden fork were inserted between the rows of weed seedlings, now at the 4-5 leaf stage, and dragged across the tray in the tilled treatments. The roots were, therefore, gently lifted and dis-lodged from the soil and allowed to settle back into the soil to mimic the effect of tillage in wet soil on weeds which are likely to re-establish and re-grow (Caseley *et al*., 1993).

The experiments were set up as split plot design with tillage treatments as the main plot and the dosage of the herbicides as the sub-plot. The main plot had two levels: tilled and not tilled. The sub-plot herbicide dosage factor had four levels. 12.5%, 25%, 50% and 100% of the LRDs of atrazine and nicosulfuron. The herbicides were applied with a knapsack sprayer, 2 days after application of the tillage treatments. The treatments were replicated five times. The number of surviving weeds was counted at 3 WAHA for the assessment of percent weed kill.

RESULTS

Weed density and spectrum at research sites.
The initial weed population, before spraying varied among the experiments (Table 1). *Galinsoga parviflora* and *Eleusine indica* were ubiquitous at all sites. *Setaria homonyma* was present at high density in Experiments 1 and 2 in the 1995/96 seasons, while *Setaria verticillata* had a high density in Experiment 1 in the 1995/96 season. The UZ farm (Experiments 3 and 5) had a very high density of *Richardia scabra* and moderate densities of *Bidens pilosa* and *Amaranthus hybridus* (Table 1). All sites had

more than ten weed species and more than 1,700 weed seedlings m^{-2} that had emerged by the time of herbicide application (Table 1).

Percent kill of weeds

Percent weed kill was significantly higher (P<0.01) at the 2-3 than at the 5-6 leaf stage in Experiments 1 and 2 (Figs 1a and 1b). There was a consistent increase in percent

Table 1. Weed species and their density per square meter at the Crop Science Department and University Farm plots before application of herbicide treatments in the 1995/96 and 1996/97season.

Weed species	Experiment 1 (1995/96)	Experiment 2 (1995/96)	Experiments 3 and 5 (1996/97)
	UZ campus	UZ campus	UZ farm[1]
Grasses			
Eleusine indica (L.) Gaertn.	476	448	526
Setaria verticillata L. Beauv.	208	-	-
Setaria homonyma (Stead.) Chiov.	161	291	18
Broad leaves			
Galinsoga parviflora Cav.	658	816	710
Commelina benghalensis L.	65	-	70
Nicandra physaloides Gaertn.	48	596	48
Amaranthus hybridus L.	35	86	169
Hibiscus meeusei Exell	32	42	19
Richardia scabra L.	-	24	837
Bidens pilosa L.	17	6	243
Sida alba L.	-	5	-
Oxalis latifolia Kunth.	4	42	-
Portulaca oleracea L.	4	86	-
Ipomoea plebeia R. Br.	2	9	18
Chenopodium album L.	-	5	-
Sonchus oleracea L.	-	3	-
Leucas martinicensis (Jacq.) R. Br.	-	-	27
Datura stramonium L.	-	-	7
Bothriocline laxa N. E. Br.	-	-	7
Sedges			
Cyperus rotundus L.	29	14	-
Total	1,729	2,473	2,699

[1] Experiments 3 and 5 were located in two adjacent plots at the UZ farm, with a similar weed spectrum and density, the average density of the two experiments is presented.
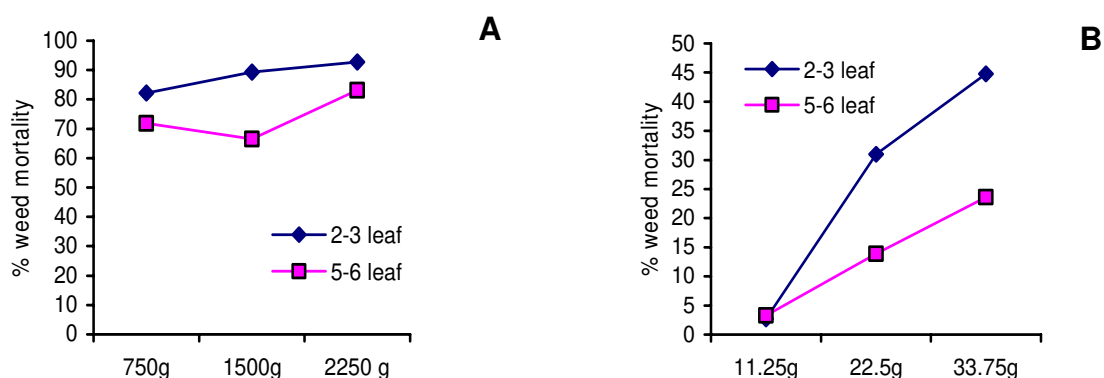
Figure 1. Effect of dosage (g a.i. ha^{-1}) of (A) atrazine (Experiment 1) and (B) nicosulfuron (Experiment 2) at two weed growth stages on percent kill of weeds.

weed kill with increase in atrazine dosage at the 2-3 leaf stage and lack of consistency at the 5-6 leaf stage (Fig. 1a). Percent kill of weeds achieved with nicosulfuron increased with dosage and was less than half that achieved with atrazine (Fig. 1b).

Percent weed kill by atrazine and nicosulfuron varied according to weed species. There was a 100% kill of broadleaf weeds *G. parviflora*, *A. hybridus*, *N. physaloides*, *H. meesuei*, *R. scabra* and *B. pilosa* by atrazine, no survivors could be counted 3 WAHA. There was a 100% kill of *S. homonyma*, *N. physaloides A. hybridus*, *H. meesuei* and *O. latifolia* by nicosulfuron in Experiment 2. Percent kill of *C. benghalensis* by atrazine was above 80% regardless of dosage or growth stage (Fig. 2a). Percent kill of *S. homonyma* significantly (P<0.01) increased with increased atrazine dosage and was higher for the 2-3 than the 5-6 leaf stage (Fig. 2a). Percent kill of *S. verticillata* was similar to that of *S. homonyma* (data not shown). *Cyperus rotundus* was the most tolerant weed species to atrazine, it appeared to have temporarily scotched its foliage but it was observed re-growing from underground rhizomes at 5 WAHA. There was a weed growth stage × atrazine dosage interaction on *E. indica* percent control (Fig. 3). At the 2-3 leaf stage, there was a consistent increase in percent kill while at the 5-6 leaf stage the lowest dosage exerted virtually no control of *E. indica* (Fig. 3).

E. indica and *G. parviflora* proved to be the most recalcitrant weed species to control by nicosulfuron (Fig. 2b). There was no effect of herbicide dosage and weed growth stage (P<0.05) on percent kill of *E. indica*. Although dosage and weed growth stage significantly affected mortality of *G. parviflora*, control of this species was generally below 20% (Fig. 2b). There was a distinct advantage in applying nicosulfuron at the 2-3 leaf stage for *P. oleracea* while for *R. scabra* similar percent kill was achieved by applying the herbicide at the 2-3 and the 5-6 leaf stage (Fig. 2b).
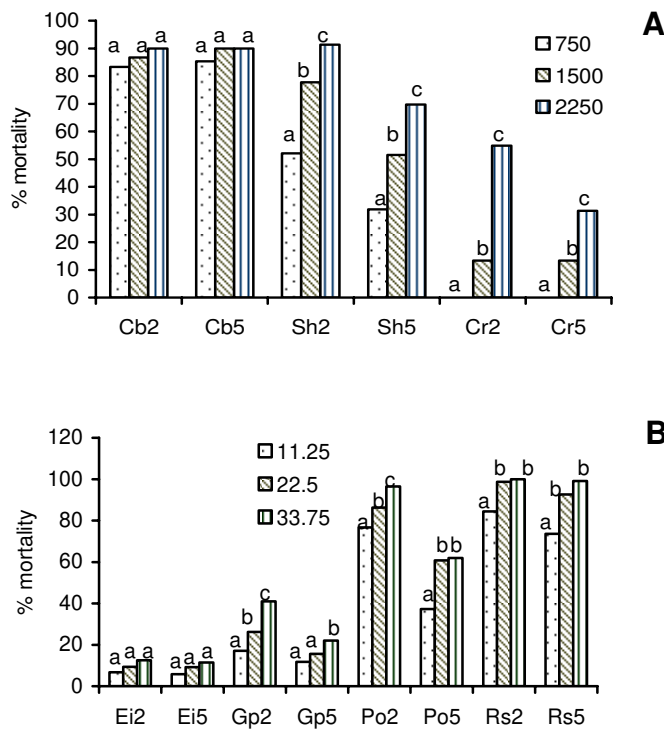
Figure 2. (A) Effect of atrazine dosage (g a.i. ha^{-1}) on percent mortality of *Commelina benghalensis* (Cb), *Setaria homonyma* (Sh), *Cyperus rotundu*s (Cr) when applied post emergence at the 2-3 leaf stage and the 5-6 leaf stage in Experiment 1. (B) Effect of nicosulfuron dosage (g a.i. ha^{-1}) on percent mortality of *Eleusine indica* (Ei), *Galinsoga parviflora* (Gp), *Portulaca oleracea* (Po), *Richardia scabra* (Rs) when applied post emergence at the 2-3 leaf stage and the 5-6 leaf stage in Experiment 2.
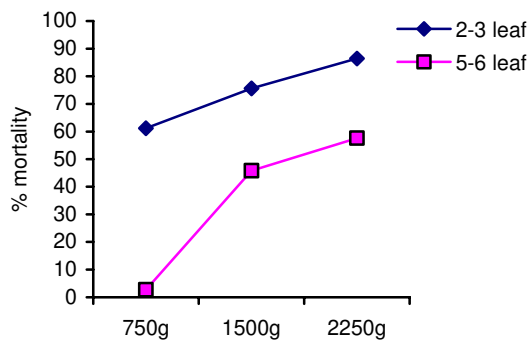
Figure 3. Interaction between dosage and weed growth stage on percent kill achieved by atrazine on *Eleusine indica* in Experiment 1.
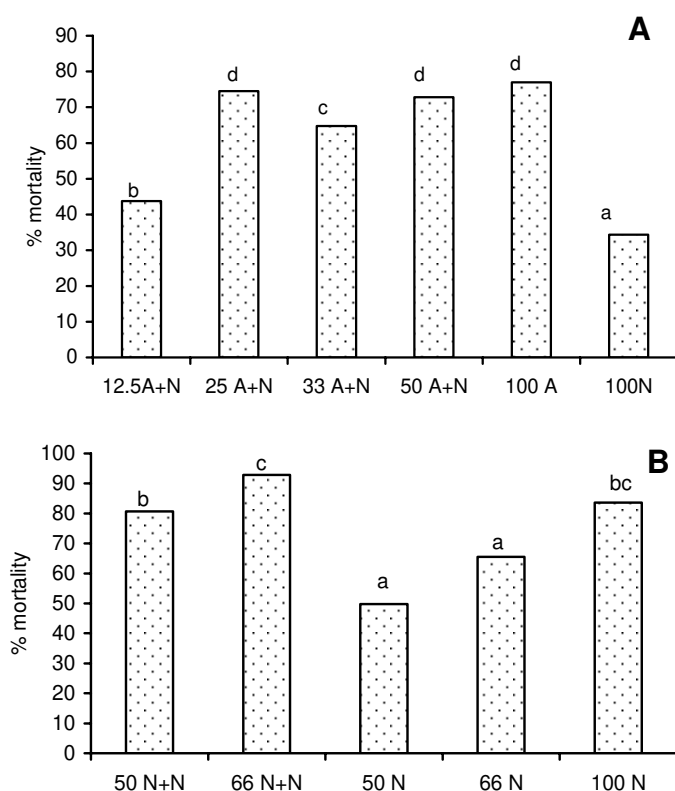
Figure 4. (A) Effect of reduced dosages of atrazine and nicosulfuron applied as a tank mixture on percent weed mortality in Experiment 3 (B) Effect of reduced dosages of nicosulfuron applied in sequence at 3 and 6 WAE and a single application at 3 WAE on percent weed mortality in Experiment 5.

Percent kill was lowest when LRD of nicosulfuron was applied alone in Experiment 3 (Fig. 4a). Tank mixtures of reduced atrazine + nicosulfuron dosages above 25% of the recommended generally provided similar weed control as the 100% recommended dosage of atrazine (Fig. 4a). Even the lowest dosage of the atrazine + nicosulfuron tank mix (12.5%) achieved greater weed kill than the LRD of nicosulfuron (Fig. 4a).

Sequential applications of nicosulfuron, half of the dosage applied at 3 WAE and the other half at 6 WAE, resulted in higher weed mortality than equivalent dosages applied once at 3 WAE in Experiment 5 and had similar percent weed kill to the nicosulfuron LRD (Fig. 4b).

Weed density and biomass

Weed biomass at maize physiological maturity was significantly less (P<0.01) when atrazine was applied at the 2-3 leaf stage than at the 5-6 leaf stage in Experiment 1 (Fig. 5a). Very little gains were made in suppression of weed biomass between the 1,500 and the 2,250 g a.i. atrazine dosage in contrast to what happened when dosage was increased from 750 to 1,500 g a.i. ha^{-1} (Fig. 5a). Weed dry weight significantly (P<0.05) decreased with an increase in nicosulfuron dosage and nearly doubled when herbicide application was delayed from 2-3 to 5-6 leaf weed growth stage (Fig. 5a).

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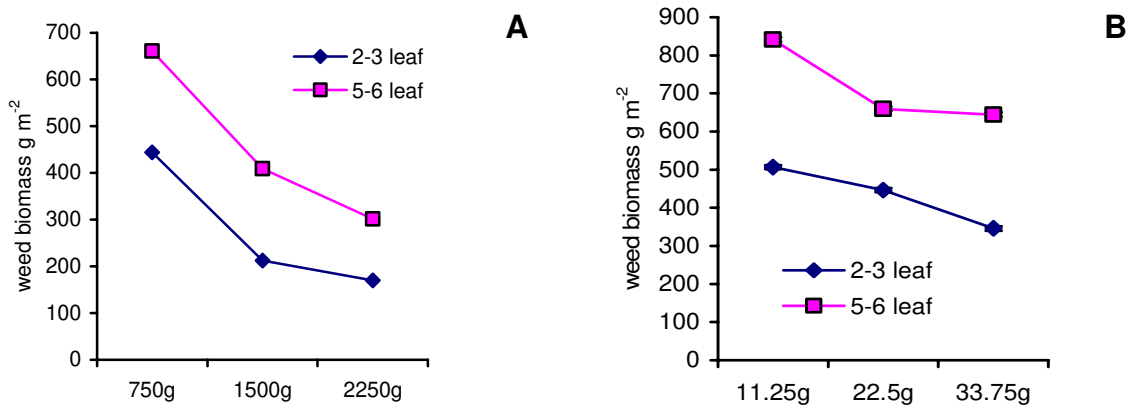
Figure 5. Effect of (A) atrazine dosage and (B) nicosulfuron dosage on weed biomass at maize physiological maturity.
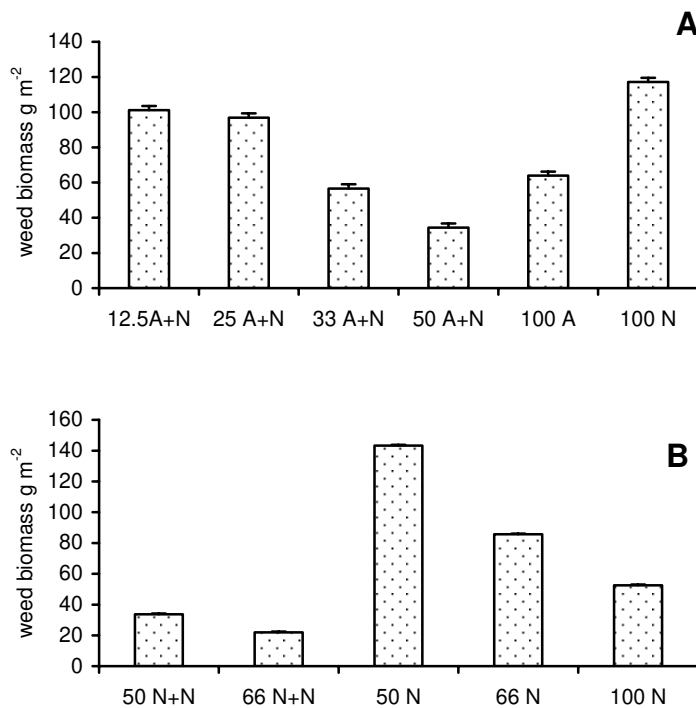
Figure 6. (A) Effect of atrazine and nicosulfuron reduced dosages applied as a tank-mix on weed biomass at maize physiological maturity in Experiment 3. (B) Effect of reduced dosages of nicosulfuron applied in sequence at 3 and 6 WAE and as single application at 3 WAE on weed biomass at maize physiological maturity in Experiment 5.

Mixing half the recommended dosages of atrazine and nicosulfuron resulted in the lowest weed biomass at the end of the season in Experiment 3 (Fig. 6a). Mixing a third of the recommended dosages of atrazine and nicosulfuron resulted in equivalent weed control to the atrazine LRD. The highest weed biomass at the end of the season was recorded after application of the LRD of nicosulfuron, followed closely by mixtures of an eighth and a quarter of the atrazine and nicosulfuron LRDs (Fig. 6a). In Experiment 4, the highest weed biomass was recorded in the unweeded control (Table 2). There

Table 2. Effect of mixtures of reduced dosages of atrazine and nicosulfuron on weed density, biomass and seed production at maize physiological maturity in Experiment 4.

Treatment	Weed density (number m^{-2})	Weed biomass (g m^{-2})	Number of seed capsules m^{-2}
Unweeded control	6.35d (42)	288.47c	559.60c
Atrazine + nicosulfuron (g a.i. ha^{-1})			
562 (25%) + 8.44 (25%)	3.99c (15)	111.93b	96.00a
750 (33%) + 11.25 (33%)	5.76d (33)	117.48b	217.00b
1500 (67%) + 22.50 (67%)	2.69b (7)	12.94a	14.00a
2250 (100%) + 33.75 (100%)	0.88a (0)	0.02a	0.00a
Hoe-weeded	7.28e (52)	76.10b	314.00b
P-value	P=0.001	P=0.007	P=0.02
Sed	0.414	24.04	57.675
LSD$_{0.05}$	0.923	53.57	128.50

was no difference in weed biomass among the hoe-weeded and a quarter and third of the LRD atrazine + nicosulfuron tank mixes (Table 2). Weed biomass was lowest in the two thirds and LRD mixtures of atrazine + nicosulfuron (Table 2).

Sequential applications of reduced doses of nicosulfuron were more effective in suppressing weed growth than equivalent doses or the full LRD applied once (Fig. 6b).

Seed production by weeds

Seed capsule production, averaged across all species, was significantly (P<0.01) lowered as atrazine dosage increased and there were more seed capsules found with late herbicide application, at 5-6 leaf stage, than the early herbicide application at 2-3 leaf stage (Fig. 7a). Although weed seed capsule production was lower when nicosulfuron was applied at the 2-3 leaf stage than at the 5-6 leaf stage, the weed growth stage effect on seed production was not significant (P>0.05). However, there was a significant decrease in weed seed capsules produced as nicosulfuron dosage was increased (Fig. 7b). Weed seed production followed the trends set by the weed biomass data in Experiment 4 (Table 2).

Maize grain yield

Grain yield was neither affected (P>0.05) by atrazine dosage nor by weed growth stage at which the herbicide was applied in Experiment 1 (Fig. 8a). In Experiment 2, the
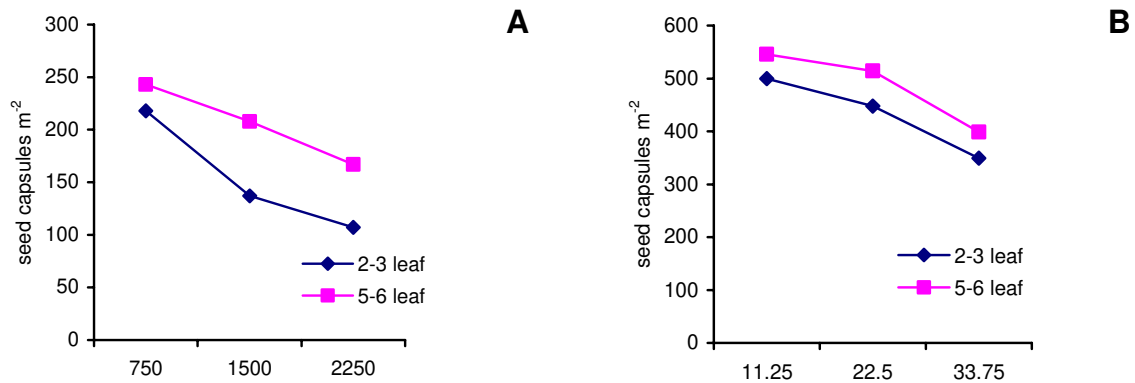
Figure 7. The effect of herbicide dosage (A) atrazine and (B) nicosulfuron applied at post-emergence at the two weed growth stages on weed seed capsule production at maize physiological maturity.
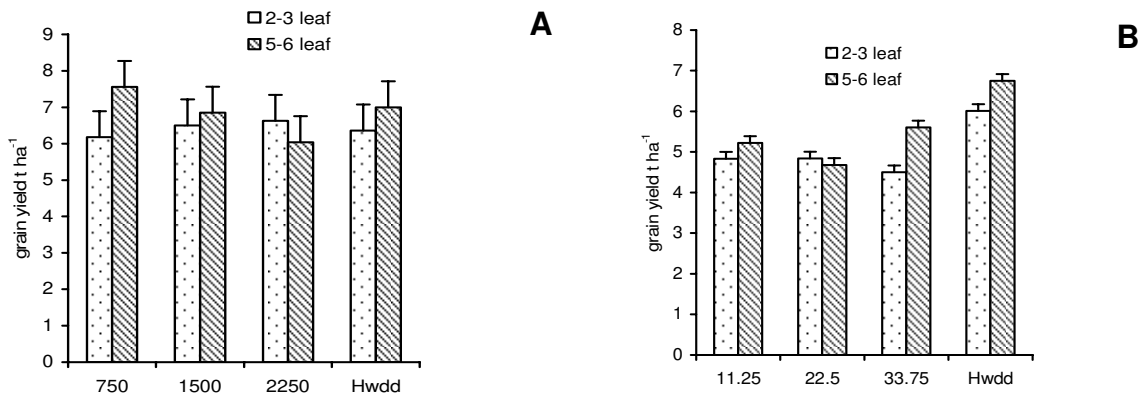
Figure 8. Effect of (A) atrazine and (B) nicosulfuron dosages applied at two weed growth stages on maize grain yield. (Hwdd = hand-weeded).

hand-weeded treatment had higher ($P<0.05$) maize grain yield than all the nicosulfuron dosages, averaged across the weed growth stages. Applying the herbicide at the 5-6 leaf stage produced higher maize grain yield than application at the 2-3 leaf stage, averaged across the herbicide dosages (Fig. 8b). There were no statistically significant differences in maize yield between the tank-mixed reduced dosages of atrazine + nicosulfuron and the LRDs of the two herbicides applied alone in Experiment 3 and 4 (Figs 9a and 9b). However, in Experiment 4, maize grain yield was reduced by approximately 75% in the unweeded control compared to other treatments (Fig. 9b). Grain yield was highest in the sequentially applied nicosulfuron reduced dosage treatments but it was not statistically different from the single applications (Fig. 9c).
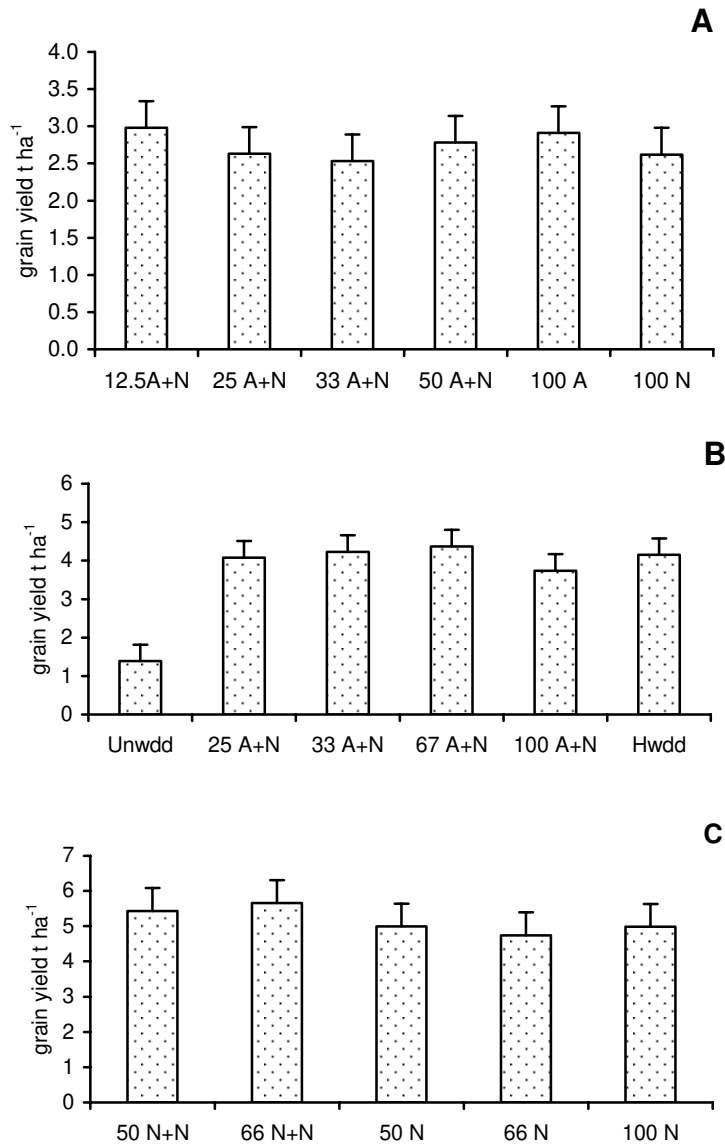
Figure 9. Effect of reduced dosages of (A) atrazine and (B) nicosulfuron applied as a tank-mix in Experiments 3 and 4, respectively, and (C) nicosulfuron applied in sequence at 3 and 6 WAE and as a single application at 3 WAE in Experiment 5, on maize grain yield.

Net economic benefit (NEB)

There was an interaction ($P<0.01$) between atrazine dosage and weed growth stage on NEB in Experiment 1. There was a distinct increase in NEB with decreases in dosage when atrazine was applied at the 5-6 leaf stage. At the 2-3 leaf stage, NEB was not significantly affected by atrazine dosage (Fig. 10a). Averaged across the herbicide dosages, NEB was highest in the clean-weeded treatment and at the lowest atrazine dosage (Fig. 10a). In Experiment 2, NEB was significantly higher in the hand-weeded

treatment than in the nicosulfuron treatments (Fig. 10b). NEB decreased with increase in dosage of the atrazine + nicosulfuron mixture in Experiment 3 (Fig. 10c). The LRD of atrazine had a higher NEB than nicosulfuron LRD (Fig. 6c). In Experiment 5, NEB was not statistically affected by the herbicide treatments (Fig. 10d).

Reduced dosages of atrazine and nicosulfuron and simulated tillage

Simulated tillage shifted the dose-response curves of weed species by increasing percent kill at low dosages in simulated tillage treatments (Figs 11 and 12). For three out of four species, in the case of nicosulfuron, simulated tillage increased the percent kill achieved by reduced dosages. The exception was *A. hybridus* which proved equally susceptible to reduced dosages of nicosulfuron regardless of tillage treatment
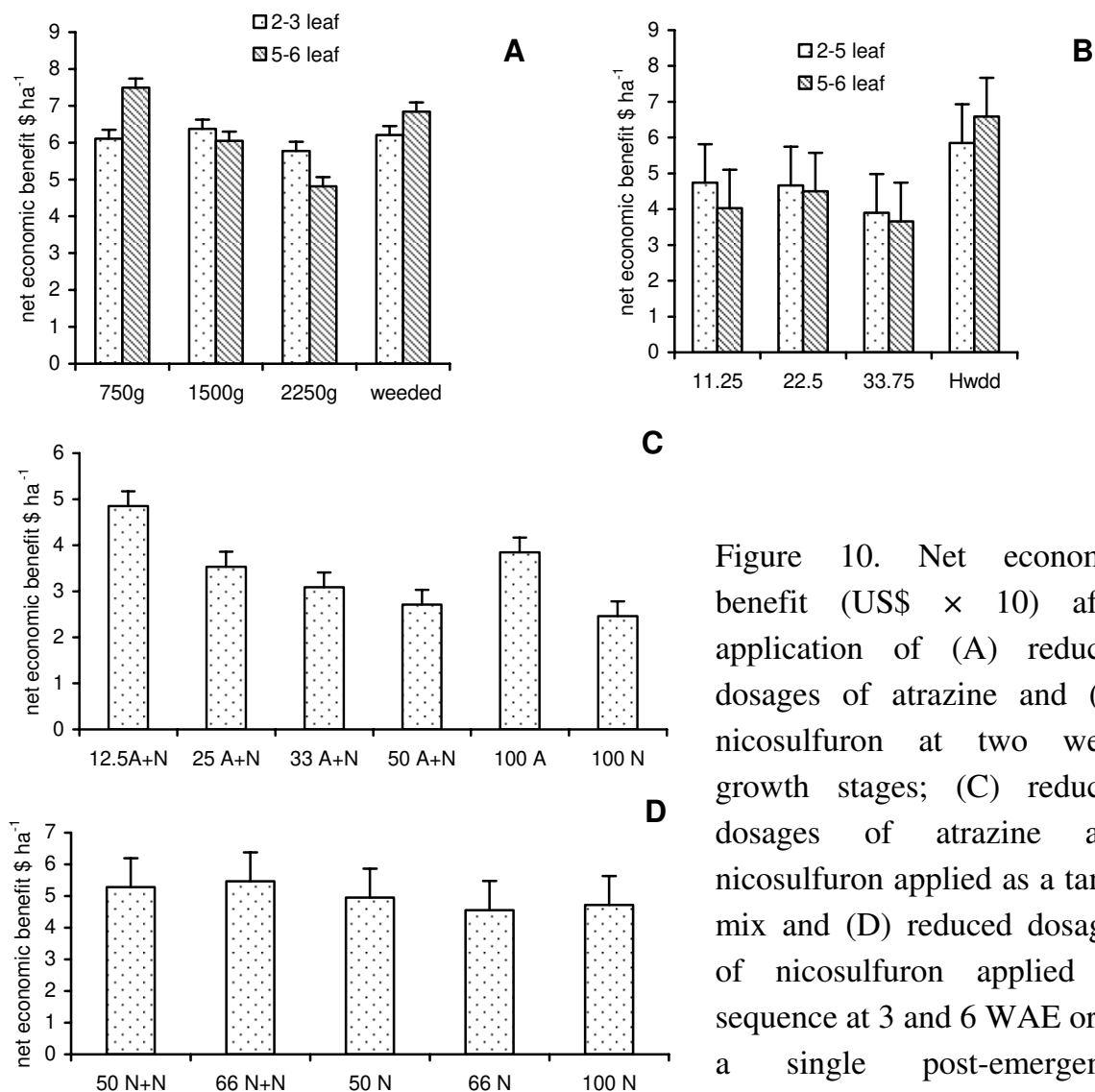
Figure 10. Net economic benefit (US\$ × 10) after application of (A) reduced dosages of atrazine and (B) nicosulfuron at two weed growth stages; (C) reduced dosages of atrazine and nicosulfuron applied as a tank-mix and (D) reduced dosages of nicosulfuron applied in sequence at 3 and 6 WAE or as a single post-emergence application.
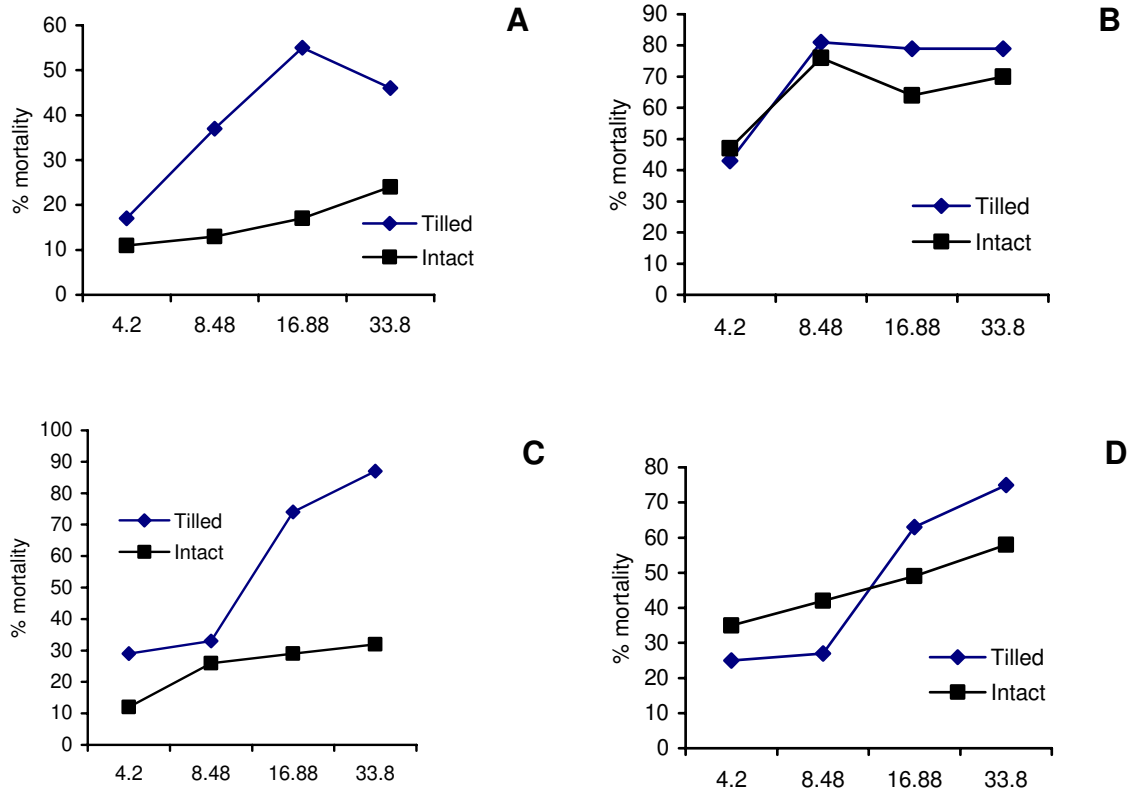
Figure 11. Effect of reduced dosages of nicosulfuron (g a.i. ha^{-1}) and simulated tillage on percent kill of (A) *E. indica*, (B) *A. hybridus*, (C) *N. physaloides*, and (D) *I. plebeia* in Experiment 6.

(Fig. 11). For atrazine (Fig. 12), weed mortality increased was consistently higher at low dosages following simulated tillage than in untilled trays in three out of the four weed species (Figs 12a, 12c and 12d).

DISCUSSION

Reduced herbicide dosages and weed control in maize

LRDs for herbicides are typically 'fail safe dosages' designed to provide adequate weed control under a variety of conditions and for as broad a spectrum of weed species tolerances to the herbicide as possible (Salonen, 1992; Proven *et al.*, 1993; Caseley, 1994). It has long been recognized that application rates below LRDs can provide similar levels of weed control as LRDs (Mashingaidze and Chivinge, 1995; O'Sullivan and Bouw, 1993; Alm *et al.* 2000). A survey by Parker and Vernon (1982) in Zambia, showed that smallholder farmers who were using atrazine mixed with metalochlor/ alachlor were often under-dosing rather than over-dosing but were still getting
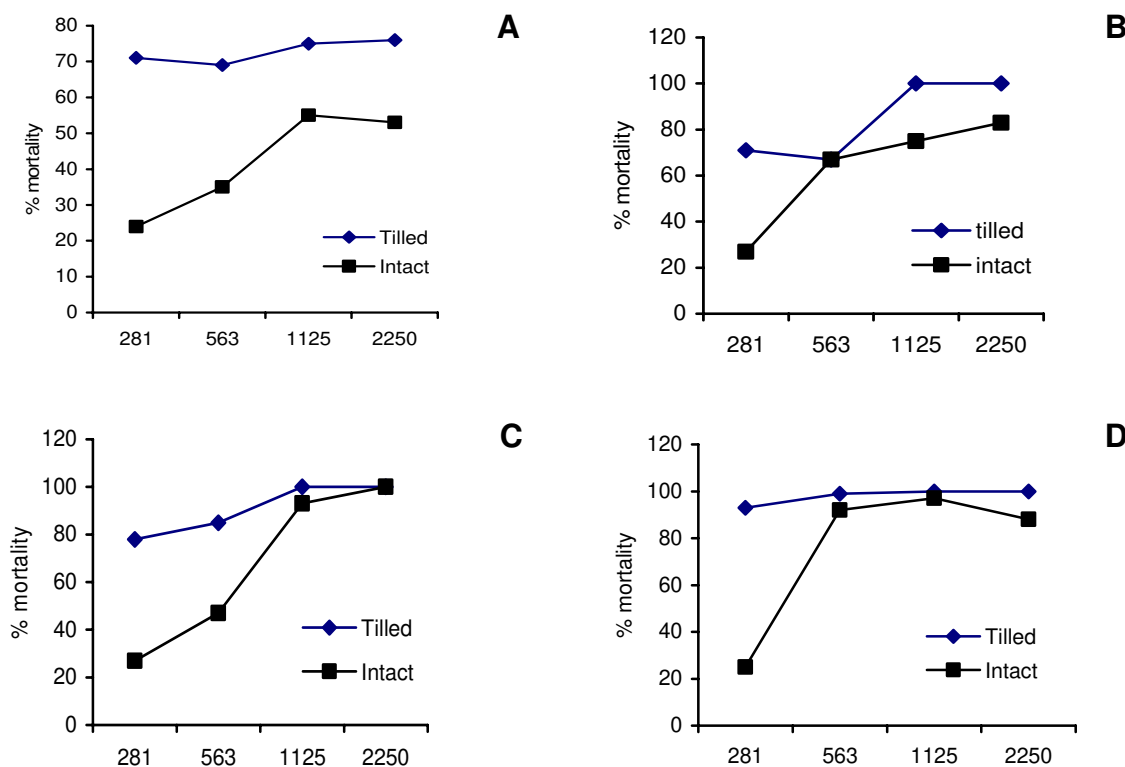
Figure 12. Effect of reduced dosages of atrazine (g a.i. ha^{-1}) and simulated tillage on percent kill of (A) *E. indica*, (B) *C. benghalensis*, (C) *I. plebeia*, and (D) *P. oleracea* in Experiment 6.

satisfactory weed control. The smallholder farmers cited cutting down costs and chances of crop damage through herbicide phytotoxicity as their primary motivation for their reduced LRD approach. Our results, in particular with atrazine (Fig. 1a), show that percent weed kill was above 80% even for a third of the LRD, when applied early at the 2-3 leaf weed growth stage.

Reduced dosages of post-emergence herbicides provide more consistent and greater levels of weed control when they are applied early, to the youngest weed growth stages possible (Feldick and Kapusta, 1986; DeFelice *et al.*, 1989; Hamill and Zhang, 1995). Results from Experiments 1 and 2 of this study generally conformed to this assertion. However, our results also indicate that this general assertion must be tempered with knowledge of the relative tolerance of the resident weed species spectrum to the herbicide or herbicide mixtures used in the below LRD approach. For very susceptible species for both atrazine and nicosulfuron, 100% control was achieved at all dosages and growth stages. However, for tolerant to moderately tolerant species to atrazine (*C. rotundus, E. indica and S. homonyma*), our results clearly show that significant gains in percent control of these species were made when the reduced

doses were applied earlier (2-3 leaf stage) than later (5-6 leaf stage). In addition, higher dosages were required to provide weed control that was less than when lower dosages were applied earlier at the 2-3 leaf stage, when the herbicides were applied at the 5-6 leaf stage (Figs 1-3).

Our results indicate that a below LRD strategy applied over a number of seasons will increasingly select for the moderately tolerant weed species to the herbicide or herbicides being applied. In the case of atrazine, moderately tolerant grasses (*E. indica* and *S. homonyma*) will be selected for by the strategy as more of these weed species escaped the herbicide treatments at low doses. The same conclusion is applicable for *E. indica*, *G. parviflora* and to some extent *P. oleracea* for nicosulfuron. The below LRD strategy, therefore, needs to be integrated with other weed control tactics that will remove herbicide escapes and prevent them from producing seed. This is clearly required despite the herbicide escapes lack of competitiveness to the maize crop (no yield effect) seen in this study, to prevent the inadvertent change in the species composition be dominated by tolerant weed species, in the long term. Our results also show that the mixing reduced dosages of atrazine and nicosulfuron provided higher percentages of weed kill when compared to application of similar or higher dosages of each individual herbicide (Fig 6a). Therefore, application of reduced dosages of mixtures of complementary herbicides in terms of target species spectrum (nicosulfuron is mainly a grass herbicide and atrazine controls mostly broadleaf weeds), rather than the individual herbicides, may reduce the need to follow up application of reduced dosages with weed control tillage to remove herbicide escapes.

It is apparent from the results of this study that despite the differences in percent kill and final weed biomass measured in various reduced doses treatments and LRD, maize grain yields (Figs 8 and 9) and NEB (Fig. 10) were marginally or not affected by herbicide dosage. The most plausible explanation for this observation is that the below LRDs were able to suppress weed competitiveness during the critical first four-five weeks after emergence and avert yield loss in maize. Willis and Stoller (1990) and Alm *et al*. (2000) tested the concept of using ultra-low rates (ULRs) of herbicides, using less than one-eighths of the LRD of sulfonylurea (including nicosulfuron) herbicides to suppress weeds without killing them, thereby giving the crop a competitive advantage to negate the effects of the weeds on crop yield. In our study, although the 12.5% and 25% of the LRD of atrazine and nicosulfuron mixed together in the tank were clearly inferior in controlling weeds, they were equally effective in preventing damage to maize grain yield as higher dosages of the mixtures and the LRDs of the single products.

Nicosulfuron phytotoxicity

There was a distinct difference in maize grain yield between the hand-weeded treatment and nicosulfuron dosage treatments in Experiment 2 (Fig. 8b) and a lack of such a difference when atrazine was applied in Experiment 1 (Fig. 8a). This result is indicative of nicosulfuron toxicity to the maize variety, SC 501, used in Experiments 1 and 2. Maize plants in the nicosulfuron treated plots in Experiment 2 were stunted with leaves emerging from the funnel chlorotic, wrinkled and puckered at 1-2 WAHA. There was no apparent yield depression in variety Pan 67 between the hand-weeded treatments and atrazine + nicosulfuron tank-mixed treatments in Experiment 4 (Fig. 9b) indicating the tolerance of this maize variety to nicosulfuron. Green and Ulrich (1993) reported that maize varieties can vary more than 40,000-fold in sensitivity to nicosulfuron. Differential tolerance of maize varieties to nicosulfuron has been widely reported (Moro *et al.*, 2000; Kang, 1993; Widstrom and Dowler, 1995; O'Sullivan *et al.*, 1995). Farmers, therefore, need to check with their hybrid seed suppliers to ascertain nicosulfuron tolerance before applying the herbicide. Nicosulfuron tolerance can be systematically increased in the available maize genetic pool by back-crossing sensitive inbreds with tolerant varieties, or using at least one tolerant hybrid parent in hybrid crosses or incorporating the acetohydroxy acid synthase modified XA-17 gene (Green and Ulrich, 1993).

Sequential applications of reduced dosages

There were superior levels of weed control exhibited by the sequential reduced doses of nicosulfuron in comparison to equivalent doses applied once and the LRD (Fig. 9c). Two sequential applications of herbicides at 0.25% of the LRD were as effective as single applications of the LRD in controlling weeds in soya beans (DeFelice *et al* 1989). The greater suppression of weed biomass in the sequential application recorded in Experiment 5 is probably explainable in terms of the exposure of more weed cohorts to reduced dosages applied at 3 and 6 WAE than by a single application at 3 WAE. Nicosulfuron has little soil activity as it is rapidly degraded in the soil by hydrolysis and microbial activity. The half-life of metsulfuron methyl, another herbicide from the sulfonylurea group, was only 2.5 days at pH 5.5 (Caseley, 1994). Roughly similar soil pH conditions are found in most soils in Zimbabwe (Nyamangara *et al.*, 2000). When a single application is made, weed cohorts that emerge later would not be affected, accounting for the higher weed biomass measured in these treatments compared to the sequential applications. Sequential applications of ULR of herbicides could potentially be used in conjunction with mechanical/hand hoeing removal of herbicide escapes as proposed for the below LRD applied once, in this chapter.

Reduced herbicide dosages and simulated tillage

Following mechanical or hoe cultivation, uprooted weeds often regenerate in moist soils by developing new roots and shoots, rapidly re-infesting previously weeded fields. The greater susceptibility of weeds with simulated tillage damage to herbicides applied at reduced rates can be potentially exploited by farmers facing resurrecting weeds in wet soil conditions. Continuously wet conditions soon after mechanical or hoe-weeding episodes frequently nullify the overall weed control efficacy of these operations and the results of the glasshouse studies suggest that below LRD could be deployed to literally 'finish off' the resurrecting weeds in wet conditions. Lower dosages of herbicides were required to kill weeds when simulated cultivations were made one to six days after herbicide application (Caseley *et al.*, 1993). A shift in the dose response curve of simulated weeds (oats and rape) occurred when 20% of the LRD of metsulfuron methyl and mecoprop was followed by cultivation (Blair and Green, 1993). These results suggest that higher levels of efficacy of mechanical or hoe-weeding are potentially realizable in the integration of below LRD and cultivation proposed in this study. Our results show that below LRD could be used to rescue the crop from a resurrecting weed population when mechanical and hoe-weeding have been used under wet soil conditions.

Implications for farmers

The results of this study raise the possibility of developing a weed management system based on the use of reduced dosages of herbicides, especially those that act on amino acid and protein biosynthesis (sulfonylureas, imidazolinones), to slow down or stop weed growth soon after application (Mashingaidze and Chivinge, 1998). This strategy will reduce the competitiveness of weeds, without necessarily killing them, before full ground cover by the crop canopy. Once full ground cover is achieved, the crop normally becomes insensitive to the presence of the weeds in its understorey (Egley and Duke, 1985). However, as shown by the greater survival of moderately tolerant species and higher seed production under reduced LRD regimes in this study, relying on the ULR approach alone as proposed by Willis and Stoller (1990) and Alm *et al.* (2000), would lead to an increase in the proportion of the moderately tolerant species in the weed population within a few seasons. This will mean that the reduced LRDs will become increasingly ineffective as a result of repeated selection pressure on the very susceptible biotypes within these moderately tolerant species and increasing dominance of the hardier biotypes. Cognisant of this inevitable eventuality as can be predicted from the results of this study, it is proposed that ULR and below LRD approaches be integrated with mechanical weed control strategies. The minimum lethal herbicide dose technique (Ketel *et al.*, 1996) uses fluorescence measurements to

determine the extent of herbicide saturation of the binding sites on the D1 protein of photosystem II, which is then used to predict weed mortality for photosystem II inhibitors such as atrazine. The use of the technique can reduce herbicide dosage by up to 70% when compared to LRD. However, it requires expensive and complicated equipment to be implemented and is, therefore, not suitable for smallholder farmers.

In the context of smallholder and emerging commercial farmers in Zimbabwe, the ULR or below LRD can be followed up by mechanical or hoe cultivation to remove the herbicide escapes. Since the weed escapes will be rendered uncompetitive against the crop by the ULRs or below LRDs, before full ground cover, the timing of the following hand hoeing or mechanical weeding becomes less crucial. The potential advantage of this strategy would be to iron out the severe labour bottlenecks at peak weeding that are mostly responsible for the inability of smallholder farmers to control weeds in time to avert significant yield loss on a large proportion of their planted crops. Since the below LRDs can be applied and are effective under wet soil conditions, the problem of poor efficacy of hoe- or mechanical weeding under continuously wet conditions will be eliminated. Mid season soil disturbance caused by mechanical or hoe-weeding has been shown to be beneficial in breaking the soil crust and increasing infiltration during high intensity but infrequent rain storms that are characteristic of semi-arid areas of Zimbabwe (Ellis-Jones *et al.*, 1993). Rupende *et al.* (2000) and Pleasant *et al.* (1994) attributed the higher maize grain yield obtained in the herbicide plus hoe-weeding/mechanical cultivation treatments compared to blanket applications of herbicides, to increased aeration and infiltration in semi arid areas. Integration of the below LRD approach with mechanical/hand hoeing as proposed will not only remove herbicide treated escapes curtailing the selection pressure driven march towards herbicide resistant weed biotypes from dominating the resident weed population in the long term, but also encourage infiltration of rainfall into the soil that will lessen the effects of drought stress on crop yields.

Atrazine and related triazine products (simazine and cyanazine) were banned in Europe in 1993 because of a perceived threat that they pose to human health and generalized presence in water supplies (Gianessi *et al.*, 2003). However, atrazine is still widely used in Zimbabwe and other countries (USA) for weed control in maize.

CHAPTER 9

General discussion

GENERAL DISCUSSION

In this thesis, cultural weed management techniques such as maize-pumpkin and maize-bean intercropping, precise fertilizer placement and narrow-row planting were studied to determine their potential to increase radiation interception (RI) by the crop and potentially increase crop growth and yield and to reduce RI by weeds in the understorey of the crop and to reduce weed growth and seed production. The effect of leaf stripping and detasselling on RI by maize and the understorey crop (pumpkins and beans) was analysed to determine its impact on improving intercrop productivity without affecting the ability of the intercrop to suppress weeds. In addition to cultural management techniques, an exploratory study was made of the potential to integrate reduced herbicide dosages with cultivation as a weed management tactic for maize. This chapter puts the findings of these studies into perspective in relation to how they can be integrated into the production practices of smallholder farmers to increase productivity and to reduce their weeding burden. Research gaps and future research directions, in relation to solving problems faced by smallholder farmers in sub-Saharan Africa, are explored.

The effect of cultural and other weed management techniques in maize systems
When smallholder farmers in Zimbabwe and elsewhere in Africa plant their crops, they probably are not thinking about whether or not the way they plant the crop, in terms of plant density, plant spatial arrangements, intercropping, fertilizer/manure application, planting date or choice of competitive varieties, will help them to manage weeds in their fields. The usual routine is that when the time comes to weed, which in most cases, begins two to three weeks after crop emergence, the toiling must begin and last, day in day out, for well over three to four months of the year, the so-called peak weeding period. The peak weeding period is a hectic weed control period in a desperate bid to avert crop yield loss from weed interference. The farmers are, therefore, locked in a perpetual cycle of labour intensive weed control operations year in and year out, condemning them to the drudgery that characterize farming life-styles of smallholder farmers in Africa. For smallholder farmers who toil without any relief in their fields it is common that they get little return for their efforts because weeding is neither done in time because of severe labour bottlenecks nor is it done efficiently because the weeds are either parasitic or difficult to control (Akobundu, 1991). Attempts to alleviate the toil and misery visited upon smallholder farmers by weeds have concentrated on improving access to technology such as animal-drawn weeders and herbicides for smallholder farmers (Mashingaidze and Chivinge, 1995; Johnson and Adesina, 1993). Little research has been focused on integrating weed management

tactics into the production cycle of smallholder farmers to reduce the weed control burden that is faced by farmers and increase their crop yields. From the observations reported in the foregoing chapters of this thesis, it can be concluded that:

- Pumpkin or bean interplanted in maize crops minimize weed problems by reducing weed growth and seed production and the intercrop is more productive than monocrops of either crop.

- Leaf stripping and detasselling of maize at anthesis increases intercrop productivity by both improving the yield of the maize and that of the minor crop as a result of their effect on dry matter distribution in the maize plant and an increased radiation interception by the minor crop.

- Decreasing the row spacing in maize while maintaining maize density at 37,000 plants ha^{-1} increases radiation interception by maize, increasing yield and suppressing weed growth and fecundity.

- Precise placement of fertilizer (banding and spot placement) increases early growth of maize, produces higher maize grain yields and promotes less weed emergence, growth and seed production than the broadcast placement method.

- Reduced dosages of atrazine and nicosulfuron applied as single, mixed or in sequence protect the maize crop from the yield-reducing effects of weeds as much as label recommended dosages. However, reduced dosages should be combined with hoe- or mechanical-weeding to remove tolerant weed biotypes that escape the effects of the reduced doses and potentially build in the weed population with continued use of this strategy.

Synthesis and future research directions

Experimental conditions: station versus on-farm

This thesis presents an exploratory study into the interactions of cultural weed management tactics, crops and weeds, which was carried out mostly at research station level (colleges and a university research farm) but with some of the studies on-farm. The observed interactions need to be tested in farmers' fields with farmers' input levels and management before any extension of the technologies developed can be confidently initiated. For that purpose co-innovation with farmers in farmers' fields is crucial. For example in Chapter 5, the effect of leaf stripping was too severe and decreased maize grain yield when six leaves were stripped on maize that had been stunted by drought and nutrient deficiency under farmer conditions. In contrast under higher rainfall and more fertile conditions stripping of six lowest leaves increased maize grain yield (Chapter 3). This shows that the interactions between the cultural weed management tactics, the crops and weeds were different when conditions varied.

This underlines the need for holding non-experimental variables at levels which correspond to those that are found at the farm level in the research station research stage (Partenhelmer, 1983). Leaf stripping and detasselling was a completely new technology that required the concomitant hypothesis to be tested before being transferred to farmer's fields in this study and hence the initial experiments were all carried out at research station level.

The principal investigator received a grant from the Rockefeller Foundation (Grant 2002 FS 174) to investigate on-farm some of the technologies that were studied at research station level. The on-farm research which is not part of the thesis involves testing the effect of leaf stripping and detasselling on maize and minor crop yield (beans) and the effect of narrow-row planting on maize grain yield, weed emergence and growth in the Chinyika Resettlement Area over a period of two seasons. The research includes both researcher-managed and farmer-managed trials carried out at input levels that reflect the general practice by smallholder farmers in the area. Farmer evaluations of treatments mid-season and at the end of the season are included in the research programme. These trials are on-going and will provide comparative data to data generated on station, which is reported in this thesis.

Manipulating crop growth through leaf stripping and detasselling
As expected in a broad based exploratory study, many new hypotheses were generated which require further research. Through a process of deduction and gathering of complementary data, we were able to show that leaf stripping at anthesis has a positive effect on the amount of dry matter allocated to the cob and through this process increases maize grain yield. Because of limited access to equipment to measure photosynthesis and respiration, photosynthesis in fully lit maize plants was measured at anthesis and generally showed a very low photosynthetic capacity in the lowest three to four leaves as a result of senescence. We hypothesized that the lowest leaves would senesce much faster in a canopy and would become a respiratory burden, requiring assimilates from other leaves for maintenance. These lowest leaves would compete for assimilates with the developing cob starting from anthesis, reducing yield, when not removed from the plant by leaf stripping. Direct measurements of photo-synthesis and dark respiration on maize plants within maize canopies are required to test this hypothesis. The higher maize yield responses to leaf stripping and detasselling that were measured in intercrops compared to in monocrops were explained as resulting from the more rapid senescence in the maize leaves in the intercrops. Measurements of nitrogen mobilization and leaf photosynthesis in intercrops and monocrops would be required to test that hypothesis. Facilitated by the afore-mentioned research grant, we are currently investigating the effects of leaf stripping

and detasselling on the growth rate of the maize cob using a destructive harvesting technique. Preliminary results indicate that leaf stripping maize at anthesis increases the growth rate of the maize cob when compared to the unstripped control.

Competitive relations

Intercropping suppresses weeds through niche pre-emption and resource competition. The intercrop occupies the ecological niche required by weeds much earlier than either of the monocrops and through this mechanism suppresses weed emergence, growth and competitiveness with the crop. From our results, it is clear that by intercepting a higher proportion of the incoming PAR earlier in the season, maize-pumpkin and maize-bean intercrops, precisely fertilized and narrow-row monocrops of maize dominated the aerial access to this resource to the detriment of weed growth and seed production. Bantilan *et al.* (1974) found that intercrops suppressed weeds by inter-cepting a higher proportion of the incoming radiation than the individual component crops. However, in the case of Bantilan *et al.* (1974), the ability of the intercrops to suppress weeds depended on the crop combinations. The rapidity with which the canopy achieved full ground cover early in the season and the completeness of that ground cover during the season, a function of the growth characteristics and morphology of the crops, determines the efficacy of the intercropping system in weed suppression. Our results have also shown that precise fertilizer placement and narrow planting suppress weed growth and fecundity through the same mechanism of rapid canopy development as intercrops. Baumann (2001) suggests that knowledge about the morphological characteristics of crops should be used to design intercropping systems for improved weed competition. He went on to further illustrate that early ground cover and height development, were the most important traits for crop competitive ability using the INTERCOM eco-physiological model for interplant competition of Kropff and van Laar (1993).

Pumpkins grow along the ground, have large flat leaves that shade a large surface area of the soil and hence they were able to consistently suppress weed growth and competitiveness with the maize crop in this study (Chapters 2 and 4). Pumpkins are part of the indigenous knowledge system of smallholder farmers and their being widely grown together with maize (Mariga, 1990; Gwanana and Nichterlein, 1995; Chigwe and Saka, 1994), made them ideal candidates for the kind of work that was carried out in this study. Using the maize density and spatial arrangement commonly used by smallholder farmers in Southern Africa (90 cm × 30 cm), it was shown that pumpkin had to be inter-row intercropped at densities of more than 33% of the maize density to suppress weed biomass more than the sole maize crop. At a pumpkin density of less than 20% of the maize density, maize-pumpkin intercrops displayed

equal weed suppression abilities as sole maize and higher than sole pumpkins (Chapter 2). These results were similar to what was observed by Shetty and Rao (1981) with mixtures of pearl millet and peanut. The results suggest that in designing mixed cropping systems for weed suppression there is also a need to optimize the plant densities of the component crops in the mixture not only to maximize productivity but simultaneously to attain maximum suppression of weeds. Increasing the density of maize in a monocrop was also found to increase radiation interception by the crop and reduced weed growth and fecundity in Chapter 6. However, when plant density was increased above the optimum, maize grain yield was decreased due to increased intra-specific competition. Narrowing the row spacing at the recommended maize density for the particular environment is a less risky strategy for use by smallholder farmers to suppress weeds and increase maize yield (Chapter 6).

Criteria for assessing yield benefits

The Land Equivalent Ratio (LER), defined by Mead and Willey (1980), was the index used for assessing the productivity from the intercropping treatments in this study. The LER is a standard index that is defined as the relative land area under sole crops that is required to produce the same yield achieved by intercrops. The LER is, therefore, a measure of the biological efficiency achieved by growing two or more crops together in a specific environment. The LER has been criticized for overstating the efficiency of the intercropping system where the dominant component crop population was sub-optimal. With a sub-optimal dominant component crop density, even in a pure stand, an increase in plant density will result in an increase in yield by additional plants simply occupying the empty space and taking advantage of unused resources (Kropff and Goudriaan, 1994). In the intercropping studies carried out, maize density was optimum, as shown by results in Chapter 6 and the calculated LERs should reflect the efficiency of resource utilization by the intercrops.

The criteria used for evaluating the productivity of intercropping systems must be consistent with that of the target group of farmers to whom the recommendations will be made (Mkamilo, 2004). In Chapter 2, it was shown that pumpkins could cause 20% yield decrease in maize grain yield when intercropped with maize. Since smallholder farmers in Zimbabwe prioritize maize grain yield and aim to maintain it similar to sole maize grain yields, this result would be undesirable to the farmers. Our results also showed that with leaf stripping and detasselling in maize-pumpkin (Chapter 4) and maize-bean intercropping (Chapter 5), maize grain yields were equal or higher than sole maize grain yields. Our results, therefore, indicate that leaf stripping and detas-selling has the potential of making maize-pumpkin and maize-bean intercropping more attractive to smallholder farmers by securing or increasing their maize grain yields.

The partial Land Equivalent Ratio (pLER) analysis that was carried out for the intercropping experiments showed the reductions in the maize and minor crop yield in intercrops versus monocrops. Such an analysis is useful in assessing the ability of the intercrop to satisfy the smallholder farmers' criteria of maintenance of maize grain yield.

Impact of cultural measures on weeding effort

In the context of smallholder farming systems that mostly rely on hand-weeding, the ability of the intercrop to reduce the number of times the crop is weeded is the criterion that is most appropriate to judge its efficacy. One would not be far from the truth in arguing that this criterion would make most sense to farmers since it addresses an aspect which occupies them, in hard labour, 65-75% of their time (Chivinge, 1990; Akobundu, 1980) during the cropping season. In this study, the reference point for evaluating the effects of the various cultural weed management tactics on weed suppression was their ability to reduce the number of times the crop was weeded without suffering yield loss. Evidence was presented in Chapter 2, that weeding once in the maize-pumpkin intercrop resulted in weed biomass similar to weeding thrice in the maize monocrop. Similar results were also found in the maize-bean intercrop (Chapter 5). The results indicate that potentially the weeding burden of smallholder farmers can be halved or cut to a third when compared to either of the monocrop. Intercropping can, therefore, substantially contribute to the reduction of the drudgery and toil that characterizes attempts by smallholder farmers to reduce the toll taken by weeds on their crop yields. However, large differences among crop species in weed suppression ability have been found in intercrop/weed experiments (Bantilan *et al.*, 1974) and reflect differences in the timing and nature of resource capture. These differences are frequently embodied in species phenology and growth form (Liebman, 1988). Genotypic differences within the same species with respect to weed suppression ability within the intercrop have been observed by Bantilan *et al.* (1974). Recommendation domains on what crops, what varieties and at what densities the crops need to be grown to effectively suppress weeds and increase productivity need to be generated through research and popularized among farmers under local conditions.

In his review of ecological suppression of weeds in intercropping systems, Liebman (1988) laments that despite the ubiquity of intercropping systems, researchers have given little attention to the use of intercrops to suppress weeds in a systematic and sustained manner. There are a number of intercropping systems that are imbedded within the traditional practices of smallholder farmers in Southern Africa that require optimization for weed suppression and productivity through sustained inquiry such as the maize/millet/sorghum (cereals)-cowpea, cereal-bean and the cereal-groundnut

intercropping systems (Mariga, 1990). The effect of species richness and its interactions with density of component crops within a multi-species mixture on weed suppression are other complex challenges that need to be tackled as smallholder farmers are known to plant more than two crops on one piece of land.

Another important benefit of cultural weed management techniques investigated in this study that would be directly relevant for smallholder farmers would be the reduction in weed seed production. We have seen in this study that the reduction in weed biomass through the suppression of the growth of late weeds, when fertilizer was precisely placed and narrow rows were used or by intercrops, was directly translatable into reduced weed seed production as determined by Thompson *et al.* (1991). It, therefore, means that sustained use of intercropping, precise fertilizer placement and narrow-row planting have potential to reduce the additions of weed seed to the soil seedbank. It remains to be seen, however, how effective intercropping, narrow-row planting, precise placement of fertilizer or combinations of these tactics applied over a number of seasons would affect the population dynamics of a resident population of weeds. Mertens (2002) points to the dearth of long-term experiments or monitoring studies of weed population dynamics. For smallholder farmers, it would be of interest for information to be provided on the long-term impact of cultural management inter- ventions on weed density and species composition within the season and over a number of seasons. How long the weed seed reserves in the soil dampen the effect of reductions in the weed seed rain brought about by cultural weed management interventions combined with hoe-weeding is of immediate relevance to the quest to reduce the weeding burden of smallholder farmers in the long term.

Towards integration to increase crop yields and suppress weeds

Smallholder farmers in sub-Saharan Africa have traditionally focused on weed control rather than weed management. Cardina *et al.* (1999) describe weed control as the basic level in weed management involving the control of weeds with a single tool or tech- nology. It has been argued that there is too much emphasis of weed control on killing weeds instead of crop protection (Vandeman, 1994). The weed control approach overlooks the possibility that positive interactions among biological components of agro-ecosystems may act to keep weed populations in check (Cardina *et al.*, 1999). These positive interactions were illustrated in this study in the reduction in weed growth and reproduction and increased crop productivity recorded with maize- pumpkin/bean intercropping, narrow-row planting and precise fertilizer placement. Weed management implies a shift away from reliance of control of existing weed problems and places greater emphasis on prevention of propagule production, reduction of weed emergence in a crop and minimizing weed competition with the

crop (Buhler, 1996; Zimdahl, 1991). The positive impact of the cultural weed management techniques on reducing weed growth and reproduction measured in this study supports the view that a paradigm shift from weed control to integrated weed management is required in the focus of research and extension in countries in sub-Saharan Africa. Integrated Weed Management (IWM) has been defined as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological and chemical methods of weed control (Swanton and Wiese, 1991). The IWM approach recognizes that a single method approach is often ineffective in long-term weed management and reliance on one method of weed control has often resulted in shifts in biotype within species and species within weed populations as weeds continuously adapt to the selection pressure imposed by the single weed control tactic (Gressel and Segel, 1990; Wrubel and Gressel, 1994).

This study has shown how various cultural weed management techniques, based on the hypothesis that crop management tactics designed to maximize radiation inter-ception by the crop at the expense of weeds, increase crop yields and reduce weed growth and reproduction (Fig. 1). These cultural management techniques potentially can reduce the weeding burden of smallholder farmers in maize-dominated cropping systems.

The integration of these techniques is expected to have a higher impact on crop yields and weeds than the use of them as single technologies. Integrating multiple tactics in weed management exploits synergistic or cumulative effects that are not evident when a single technology is used and result in a decline in seedbanks and reduction in weed populations (Cardina *et al*., 1999). In this study, each cultural weed management tactic was combined with hoe-weeding and there was evidence that sustained implementation each of these strategies will lead to a reduction in seedbanks as they all reduced weed seed production. Similar studies to ours describing the multiple tool approach have involved experimental treatments such as herbicide alone versus herbicides with cultivation (Buhler *et al*., 1993; Burnside *et al*., 1994; Poston *et al*., 1992). Fewer studies have involved a combination of three technologies and they have commonly included crop or companion crop competition (Malik *et al*., 1993; Shilling *et al*., 1995). The integration of more than two technologies within the crop management and input levels that are commonly used by smallholder farmers in sub-Saharan Africa is desirable to explore if any further synergistic and cumulative effects accrue to crop performance and weed suppression in this system.

A systems approach would require that smallholder farmers use every opportunity during the production cycle to implement measures to reduce weeds and their impact in the agro-ecosystem and to increase yields (Fig. 2). Cardina *et al*. (1999) categorize this approach as cropping system design, in which the cropping system itself is
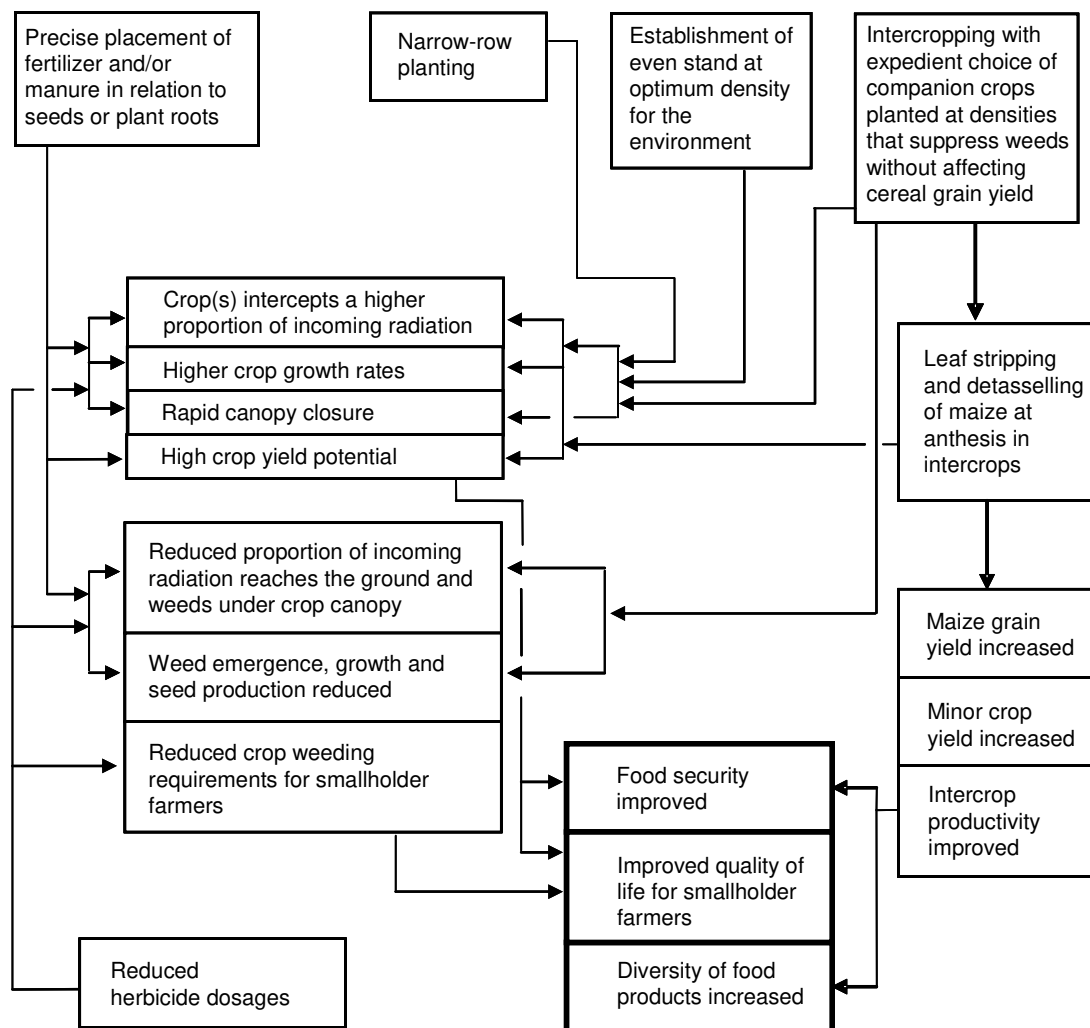
Figure 1. Mechanistic interactions among cultural weed management tactics, crop(s) and weeds that were studied in this thesis.

designed as a weed management strategy. A central ecological principle of cropping system design is that weeds occupy ecological niches not utilized by crop plants, therefore, farmers can design their cropping operations to maximize resource capture by the crops through intercropping (Burke and Grime, 1996; Thebaud *et al*., 1996), narrow planting, precise fertilizer placement (this thesis) and other tactics to suppress weeds and maximize crop growth and yield.

It is not possible to integrate all the cultural weed management techniques at the same time. However, various scenarios can be generated in which combinations of the weed management techniques that are suitable for integration for each wealth category of smallholder farmers are included. For example, for non-cattle owners with no

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┌──────────────────────┐    ┌─────────────────────┐    ┌────────────────────────┐
│ Planting date        │    │ Tillage             │    │ Choice of crops and    │
│ - Early planting     │    │ - Winter plough to  │    │ crop varieties         │
│ - High incident      │    │   dehydrate         │    │ - Choose competitive   │
│   radiation          │    │   perennials        │    │   varieties and / or   │
│ - Reliable           │    │ - Deep ploughing to │    │   crops                │
│   precipitation      │    │   bury weed seeds   │    │                        │
│ - Less weed          │    │                     │    │                        │
│   emergence          │    │                     │    │                        │
│   (periodicity)      │    │                     │    │                        │
└──────────────────────┘    └─────────────────────┘    └────────────────────────┘
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Figure 2. Components of the cropping system that can be integrated by smallholder farmers in designing cropping systems that maximize crop productivity and suppress weeds.

access to draft power, narrow-row planting (Chapter 6) with precise fertilizer placement would be an ideal choice. Narrow rows restrict the use of ox-drawn cultivators, and precise fertilizer placement or manure placement encourages weed germination and growth within the row (Chapter, 7) and these weeds can best be removed by hand-hoeing. Non-cattle owners and cattle owners can choose to intercrop maize with a cucurbit or legume crop. Intercrops restrict the farmers to use hand-weeding because mechanical cultivation will damage the minor crop in the maize inter-row.

Intercropping with legumes that fix nitrogen benefits the next crop in the rotation (Jeranyama *et al.*, 1998) and is particularly suitable for the inherently infertile and exhausted soils prone to erosion (Waddington and Heisey, 1997) common in sub-Saharan Africa. At current fertilizer costs, most smallholder farmers in Zimbabwe grow maize with little NPK fertilizer (Jeranyama *et al.*, 2000). Maintaining maize
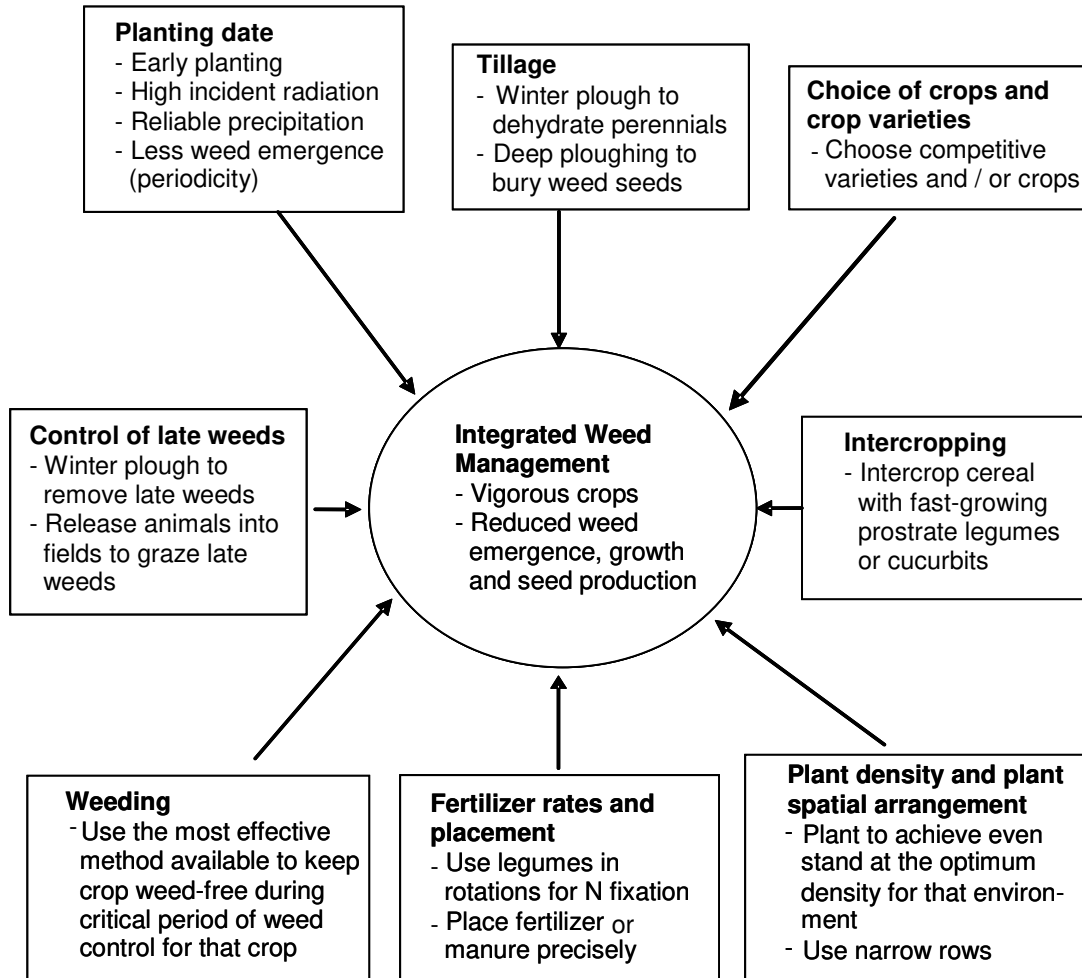
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production will require using inorganic fertilizer with a range of organic sources such as cattle manure, miombo leaf litter, herbaceous legume plant residues and compost (Kumwenda *et al.*, 1996). The combined effects of weed suppression (this thesis) and biological nitrogen fixation (Giller *et al.*, 1994) of maize-legume intercrops make maize-legume intercropping a particularly attractive option for smallholder farmers in sub-Saharan Africa. Intercrop productivity can be increased by leaf stripping and de-tasselling of the maize at anthesis (Chapters 4 and 5). There is a need to study the effects of leaf stripping and detasselling maize at anthesis in a maize-legume intercrop to measure potential benefits that might accrue to nitrogen fixation by the understorey legume. Nitrogen fixation capacity is dependent on photosynthetic production and the increase in PAR incident on the legume in the maize understorey on leaf stripping and detasselling would be expected to increase the quantities of nitrogen fixed. For wealthy farmers who can afford to buy herbicides and the necessary application equipment, reduced dosages of post-emergence herbicides can be applied to the youngest weed growth stage possible and herbicide escapes controlled by inter-row tillage (Chapter 8).

Concluding remarks

A key challenge to the management of weeds using integrated approaches that were investigated in this thesis is the level of awareness and understanding of the complex interactions among the cultural management tactics, the crops and weeds that result in increased crop yields and suppression of weeds among the key stakeholders, the smallholder farmers and extension personnel. Most extension workers were educated using a weed control and to advice farmers on single tactic methods of weed control with little recourse to integration and exploitation of the synergies that emanate from integrated weed management that includes simple cultural management technologies that can easily be implemented by smallholder farmers. A change in emphasis in the education of agricultural graduates from weed control to weed biology and ecology (Akobundu, 1991) and an emphasis, with farmer and extension personnel participation, on research on integrated weed management under smallholder farmer conditions is called for in sub-Saharan Africa.

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Summary

Chapter 1 describes the environment, the background and the objectives of the study. Weed management problems in the smallholder sector characterized by high labour requirements for weeding, low crop yields and a rapidly changing socio-economic situation in Zimbabwe characterized by a turbulent land reform programme and the HIV/AIDS pandemic that is likely to multiply the weed management and food shortage problems. The thematic boundaries of the study are laid out and objectives of the study stated.

In Chapter 2, the use of maize-pumpkin intercrops to suppress weeds and reduce hoe weeding requirements, and increase cropping system productivity were explored. The maize-pumpkin intercrop suppressed weed biomass by 50% more than sole maize crop when the pumpkin maize density was increased from 20% to 33% of the maize density of 37,000 plants ha^{-1}. Maize grain in the maize-pumpkin intercrops did not differ from the maize monocrop yields in three out of four seasons. However these three seasons were characterized by high levels of mildew infection that reduced pumpkin competitiveness to maize. In the 1996/97 season when pumpkins were protected against mildew by application of fungicides, the maize-pumpkin intercrop had 13-37% lower maize grain yield than sole maize according to weeding regime, suggesting that pumpkins unaffected by mildew can reduce maize grain yield in maize-pumpkin intercrops. Maize-pumpkin intercrops reduced weed growth more than sole crops of either of the component crops suggesting that weeding could be reduced to once in maize-pumpkin intercrops compared to twice or three times in sole maize or pumpkin.

Chapters 3, 4 and 5 explore the effect of leaf stripping and detasselling first in monocrop maize (Chapter 3), a maize-pumpkin intercrop (Chapter 4) and a maize-bean intercrop (Chapter 5). In these chapters, the hypothesis that removing lower leaves or the tassel at anthesis would increase maize grain yield as a result of more dry matter being re-directed to the female reproductive parts of maize, was tested. The results of the three studies suggested that senescing lower leaves in the maize canopy after anthesis competed for photosynthetic assimilates with the developing cob and their removal (leaf stripping) potentially relieved this competition leading to increased maize grain yield. To some extent we did show that under a denser canopy structure with more senescence, as would happen with intercropping, the relief of assimilate competition between the developing cob and the senescing lower leaves resulted in greater yield gains compared to maize monocrops. Our results suggest that leaf stripping would potentially be more beneficial under canopy conditions that have

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higher levels of shading in the lower canopy as what occurs under intercropping conditions.

Results from Chapter 2 also showed that the timing of leaf stripping, at 50% silking, was crucial to relieve the effects of lower leaf senescence on grain development and grain filling, with leaf stripping three weeks earlier or later not producing any yield benefit. Interactions between leaf stripping and detasselling on the grain test weight and cob mass in maize suggested that these interventions affected the same process of dry matter allocation to the developing and filling maize cob, post anthesis. In Chapter 4, it was shown that leaf stripping increased PAR interception by pumpkins by an average of 10% in maize-pumpkin intercrops and this resulted in pumpkin yield increases of between 40-64%. Leaf stripping and detasselling were therefore able to increase the productivity of the maize-pumpkin intercrops as indicated by land equivalent ratios that were 60 to 100% greater than unity. The coincidence of pumpkin reproductive stages with the increased radiation penetration into the canopy brought about by leaf stripping and detasselling ensured that pumpkin yield significantly responded to these interventions. In contrast when leaf stripping and detasselling was carried out in a maize-bean intercrop, bean yield marginally benefited by 5-10% because by the time leaf stripping and detasselling were carried out the beans were maturing and senescing. Leaf stripping and detasselling was therefore shown only to be significantly beneficial in increasing the yield of the minor crop when the phenology of the minor crop allowed it to benefit from the increased radiation penetration late in the season, after leaf stripping and detasselling of the maize.

Results from Chapter 6 indicate that planting maize in narrow rows increased maize grain yield by increasing radiation interception during a critical three-week period bracketing anthesis. The increased radiation capture of the narrow row planted maize crops concomitantly decreased radiation intercepted by weeds leading to reduced weed density, biomass and fecundity in narrow row planted maize. Weeding was more effective in reducing weed biomass and weed seed production in the narrow row maize spatial arrangements than the conventional 90 × 30 cm spatial arrangement currently used by smallholder farmers in Zimbabwe. There were some strong indications in the results of Chapter 6 that narrow planting could reduce the critical period when weeds have to be controlled to avoid yield loss at the beginning of the season in maize.

In Chapter 7, the effect of fertilizer placement method on maize early growth, radiation interception and yield was examined. Precise fertilizer placement methods (banding and spot placement) resulted in higher rates of early growth of the maize and therefore earlier canopy closure. As a result, higher weed biomass and seed production was recorded in the broadcast fertilizer placement method. The ability to suppress weeds in the precise fertilizer placement methods was attributable to reduced

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accessibility of the applied nutrients to weed plants and to greater suppression by more vigorously growing maize plants in the precisely placed fertilizer treatments.

In Chapter 8, reduced dosages of the herbicides nicosulfuron and atrazine applied as single applications, in mixtures and sequential applications in maize. Reduced dosages of as low as 12% of the label recommended dosages suppressed weed growth and competitiveness with the maize crop during the first critical period for weed control which is 4-5 weeks after crop emergence. As a result all the reduced herbicide dose treatments had similar maize grain yield to the full label dose and hand weeded controls. However, there was increased survival and seed production of tolerant weed species as herbicide dosage was reduced. It was concluded that reduced dosages of atrazine and nicosulfuron would need to be integrated with hand hoeing to prevent the inadvertent selection for tolerant weed species and biotypes in the long term.

Chapter 9 is the general discussion and brings into perspective the findings of the various experiments in relation to their applicability in the context of the production constraints in the smallholder sector in Zimbabwe. A scheme is devised to show how the cultural and other weed management practices that were studied can be integrated into the production practices of smallholder farmers to have a collective positive impact on weeds and crop yields in a practical implementation of an Integrated Weed Management programme. The results of the studies are used to identify research gaps that require attention so that a greater understanding of the interactions between management, crops and weeds becomes possible and ecologically sound crop and weed management tactics are designed to increase yields and suppress weeds in smallholder farming systems.

Samenvatting

Kleine boerenbedrijven in Zimbabwe worden gekarakteriseerd door een hoge arbeidsbehoefte voor het handmatig wieden, lage opbrengsten en een snel veranderende sociaal-economische situatie. Deze sociaal economische veranderingen worden veroorzaakt door een onstuimig landhervormingsprogramma en de HIV/AIDS pandemie die vooral (jonge) volwassenen treft, met desastreuze gevolgen voor de leeftijdsopbouw van de bevolking en de beschikbaarheid van arbeid.

In Hoofdstuk 2 wordt beschreven hoe mengteelt van maïs en pompoen kan bijdragen aan een vermindering van de afhankelijkheid van handmatig wieden en een verhoging van de productie. Mengteelt van pompoen in maïsgewassen leverde een bijdrage aan de onkruidonderdrukking, mits de pompoen in voldoende hoge dichtheid werd geteeld, terwijl de korrelopbrengst van maïs in mengteelt met pompoen in drie van de vier seizoenen niet verschilde van de opbrengst in monoculture. Deze drie seizoenen werden echter gekenmerkt door hoge niveaus van meeldauwaantasting in pompoen die de concurrentiekracht van het pompoengewas verminderden. In het seizoen 1996/97 werd meeldauw op de pompoenplanten bestreden met fungiciden en was de korrelopbrengst van maïs in mengteelt lager dan in de monocultuur. Door de onkruidonderdrukkende werking van de maïs-pompoen mengteelt kon het handmatig wieden met een factor twee tot drie worden teruggebracht ten opzichte van monocultures.

In Hoofdstukken 3, 4 en 5 wordt het positieve effect van het verwijderen van bladeren en de mannelijke bloeiwijze in achtereenvolgens de monocultuur van maïs (Hoofdstuk 3), de mengteelt van maïs en pompoen (Hoofdstuk 4) en de mengteelt van maïs en bonen (*Phaseolus vulgaris*) op de opbrengst aangetoond. Oudere bladeren in het maïsgewas en de mannelijke bloeiwijze concurreren met de ontwikkelende kolf om de fotosynthese-assimilaten. Het verwijderen van deze organen kan deze concurrentie opheffen en dus de opbrengst verhogen.

Resultaten van Hoofdstuk 2 lieten daarnaast zien dat het juiste tijdstip van het verwijderen van de bladeren, in dit geval bij 50% vrouwelijke bloei, cruciaal is voor een goed effect op de zaadontwikkeling en -vulling. Er was geen opbrengstvoordeel bij het verwijderen van de bladeren drie weken vóór of ná de bloei. De aangetoonde statistische interactie tussen het verwijderen van de verouderende bladeren en het verwijderen van de mannelijke bloeiwijze met betrekking tot het korrel- en kolfgewicht suggereerden dat deze ingrepen na de mannelijke bloei hetzelfde proces beïnvloeden. In Hoofdstuk 4 wordt aangetoond dat het verwijderen van bladeren de PAR interceptie door pompoenplanten in maïs-pompoen mengteelten met gemiddeld

10% verhoogt en de pompoenopbrengst met 40-64% doet toenemen. Het verwijderen van de oudste bladeren en de mannelijke bloeiwijze geeft daarom de mogelijkheid de totale productiviteit van de maïs-pompoen mengteelt te verhogen. Dit wordt kwantitatief gestaafd door Land Equivalentie Ratio's (LER) van 1,6 tot 2. Het samen-vallen van de reproductieve stadia van de pompoen met de toename van lichtpenetratie in het gewas na verwijdering van bladeren en/of bloeiwijze veroorzaakten een significante verhoging van de pompoenopbrengst. Echter, wanneer de blad- en bloei-wijzeverwijdering werd uitgevoerd in de maïs-boon mengteelt, was de opbrengst van de bonen slechts marginaal hoger, waarschijnlijk omdat deze ingrepen werden uitgevoerd terwijl de bonen reeds afrijpten en verouderden. Verwijderen van bladeren en bloeiwijze in maïs heeft kennelijk slechts een opbrengstverhogend effect op een tussengewas indien het tussengewas na deze ingrepen nog lang genoeg doorgroeit om te kunnen profiteren van de verhoogde instraling.

De resultaten van Hoofdstuk 6 geven aan dat het zaaien van maïs bij een kleinere rijafstand de korrelopbrengst verhoogt door een toename van de stralingsinterceptie gedurende een kritische periode van drie weken rond de mannelijke bloei. De toename van het invangen van straling door de kleinere rijafstand ging samen met een afname in lichtinterceptie door onkruiden, hetgeen leidde tot een lagere onkruiddichtheid, -biomassa en -reproductie. Wieden had meer effect op onkruidbiomassa en onkruid-zaadproductie bij een kleinere rijafstand dan in een maïsgewas met het gebruikelijke plantpatroon van 90 cm × 30 cm. Vernauwing van de rijafstand kan de kritische periode, waarin onkruiden moeten worden bestreden om opbrengstverliezen te voorkomen, verkorten.

In Hoofdstuk 7 werd het effect onderzocht van een gerichte toediening van be-mesting op de groei van jonge maïsplanten, lichtinterceptie en de uiteindelijke opbrengst. Toediening van de meststoffen in een band langs de gewasrij of precies op de plaats van de gewasplanten, resulteerde in hogere groeisnelheden van de jonge maïsplanten en een vroegere sluiting van het gewas. Daardoor werden er in behande-lingen met volveldse toediening van bemesting hogere biomassa en zaadproductie van onkruiden waargenomen dan bij deze precieze plaatsingsbehandelingen. Deze onkruidonderdrukking kon worden toegeschreven aan een afname in bereikbaarheid van de toegediende bemesting voor de onkruidplanten en aan een grotere onkruid-onderdrukking door weelderiger groeiende maïsplanten.

In Hoofdstuk 8 werden gereduceerde doses van de herbiciden nicosulfuron en atrazin éénmalig toegediend, in mengsels en in achtereenvolgende toedieningen. Een hoeveelheid van slechts 12.5% van de (op het label) aanbevolen dosis onderdrukte de onkruidgroei en de concurrentie met de maïs gedurende het begin van de kritische periode voor onkruidbestrijding, dit is 4-5 weken na gewasopkomst. Daardoor hadden

al de behandelingen met gereduceerde doseringen eenzelfde opbrengst als bij de herbicidenbehandeling met label-dosering en met handmatig wieden. Bij verlaging van doseringen was er echter een toename van overleving en zaadproductie van onkruidsoorten die minder gevoelig zijn voor de herbiciden. Conclusie was dat toedieningen van gereduceerde doses van atrazin en nicosulfuron zouden moeten worden gecombineerd met handwieden om sluipende selectie voor resistente onkruidsoorten en biotypen op de lange termijn te voorkomen.

Hoofdstuk 9 is de algemene discussie. In dit hoofdstuk worden de resultaten van de verschillende experimenten gekoppeld en gerelateerd aan de toepasbaarheid in de context van de kleine boerenbedrijven in Zimbabwe. Een schema werd opgesteld om te laten zien hoe teelthandelingen en andere onkruidbeheersingsmaatregelen, geïntegreerd kunnen worden in de productiepraktijken van de kleine boerenbedrijven. Kennishiaten worden geïdentificeerd om te komen tot een beter inzicht in de interacties tussen teeltmaatregelen, gewassen en onkruiden, en ecologisch verantwoorde gewas- en onkruidmanagementtactieken te ontwikkelen die leiden tot een verbetering van opbrengsten en onkruidonderdrukking op de kleine boerenbedrijven en een vermindering van de werkdruk.

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Curriculum vitae

Arnold Bray Mashingaidze was born at Saint Joseph Hospital in Chirumanju district in the Midlands Province of Zimbabwe on 13 March 1961. He obtained a BSc Agriculture Honours degree from the Crop Science Department of the University of Zimbabwe in December 1983. After graduation he taught for four years at Gwebi Agricultural College and then joined the University of Zimbabwe as a staff development fellow. The fellowship included a United States Information Service (USIS) scholarship to study at Iowa State University in the United States that he took up in August 1988. He graduated with an MSc in Crop Physiology and Production in December 1990 and rejoined the University of Zimbabwe as a lecturer in 1991. He currently holds the position of Senior Lecturer in Crop Physiology and Weed Science in the Crop Science Department, University of Zimbabwe. He has been married since 1986 to Sylvia and they have two children, Allan and Petronella who are fraternal twins and are now seventeen years old.

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