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Assessment of weed control methods for maize production by emerging farmers on commercial farms

By

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Submitted in partial fulfilment of the requirements for the degree MSc (Agric) Agronomy

In the Department of Plant Production and Soil Science, Faculty of Natural and Agricultural Sciences,

University of Pretoria

Supervisor: Prof. C. F. Reinhardt

Co-supervisor: Dr. B. J. Vorster

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DECLARATION

I, the undersigned, hereby declare that the dissertation submitted herewith for the degree MSc Agronomy to the University of Pretoria, contains my own independent work and has not been submitted for any degree at any other university. I also certify that no plagiarism was committed in writing this dissertation.

Signed ....

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ABSTRACT

Maize (*Zea mays* L) is a staple food crop grown in South Africa by both large scale commercial and smallholder farmers. During the 2013/14 cropping season maize occupied about 2.6 million hectares of the total 3.9 million hectares of arable land that was under field crops in South Africa. Maize accounted for about 12.4 million tonnes of the 14.4 million tonnes of all field crops produced. Excessive competition from weeds is a major constraint, reducing maize yield and farmer income. Resource poor and inexperienced emerging farmers who have acquired land through the government land redistribution programmes are particularly affected. To date about 5.7 million hectares of land have been transferred to about 4.2 million black (previously disadvantaged) emerging farmers. Although emerging farmers have several options available for weed control, these still need to be appraised with regards to benefits, in the form of grain yield measured against the cost of weed management. An on-farm study was carried out at two sites in the North West province of South Africa during the 2011/12 and 2013/14 cropping seasons. The objectives were:-

- To determine the effect of different weed control methods on maize yields of emerging farmers at two localities in the North West province.
- To identify the most competitive or problematic weed species at two localities in the North West province.
- To compare the economic benefit of different weed control methods at the two localities.

The experiment was laid out in a split-plot randomised block design. A stacked gene (stalk borer and herbicides resistance) and a conventional maize cultivar were planted in strips. Eight weed control methods that included hand-weeding, mechanical, chemical (herbicides) and combinations of these methods were randomly allocated across the strips. Weed species were counted and crop heights were recorded at three and eight weeks after crop emergence (WACE). Weed dry biomass was also determined. Grain yield and the yield components of ear mass and 100 kernels mass were recorded. A cost-benefit analysis of these weed control methods was carried out in the context of total production costs.

The highest maize grain yields were obtained, where weed competitive effects were satisfactorily suppressed. The clean field and pre- and post-emergence herbicides methods produced the highest grain yields in the two seasons. In the first season the highest grain yields obtained were 73% higher than the lowest yield in no-weeding method for both cultivars. The second season was characterized by below average and erratic rainfall. The stacked gene cultivar outperformed the conventional cultivar by 63% where weeds were effectively controlled. Weed competition seemed to cancel the superiority of the stacked gene cultivar over the conventional cultivar in a drier season.

The cost-benefit analysis revealed that a single cultivation operation at six WACE was the cheapest method, costing only R 495 ha^{-1} irrespective of the cultivar used. Keeping a clean field throughout the season was the most costly endeavour, at

R 2 528 ha^{-1} and R 2 174 ha^{-1} for the conventional and the stacked gene cultivar respectively. The use of both pre- and post-emergence herbicides on stacked gene cultivars can provide farmers with a return of up to R 2.60 for every R 1 invested. Controlling weeds in a conventional maize cultivar, using tractor-drawn cultivator at six WACE, can give a return of up to R 1.64 for every R 1 invested.

The weed control methods that provide the highest grain yields are not necessarily the most cost effective. It is preliminarily recommended that chemical weed control methods be considered if stacked gene cultivars are to be planted. However, mechanical weed control methods must be considered when planting conventional cultivars. The present study needs to be intensified, covering a wider geographical extent, to cater for variation that can be expected as a result of differences in climate, soil type and weed spectra.

Keywords: emerging farmers; competition; cost-benefit analysis; dominance; returns; weed control

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CONTENTS

LIST OF ABBREVIATIONS

ANOVA : Analysis of variance

CPWC : Critical period for weed competition

CWFP : Critical weed-free period

DAFF : Department of Agriculture, Forestry and Fisheries

GDP : Gross domestic product

ha : Hectares

IWM : Integrated weed management

PAR : Photosynthetically active radiation

t : Tonnes

WACE : Weeks after crop emergence

CV : Coefficient of variation

CIMMYT : The International Maize and Wheat Improvement Center

a.i. : Active ingredient

LSD : Least significant difference

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INTRODUCTION

Maize (*Zea mays L*) is a staple food crop for most African communities. It is grown by both commercial and smallholder farmers and occupies the greatest production area of all field crops in South Africa. The maize industry is one of the largest contributors to the gross domestic product of South Africa both as an employer and foreign currency earner (Department of Agriculture, 2007). Amongst South Africa's nine provinces, the North West province is the third largest maize producer after the Free State and Mpumalanga in terms of grain yield (Department of Agriculture Forestry Fisheries (DAFF), 2013). In the North West province the agricultural sector is fast-growing and newcomer farmers are being constantly included in the sector as beneficiaries of Government Land Reform programmes. These farmers are being given commercial land in a bid to empower them to become commercial farmers. Most of those who have ventured into crop production are producing maize, however, with varied degrees of success as a result of a number of challenges inter alia: low and erratic rainfall, poor soil fertility management, and limited weed management techniques (Hager *et al.,* 1998). Of these challenges, weed management is the greatest constraint to crop production.

Excessive weed competition, if not controlled, can reduce crop yield to a fraction of the true potential (Laider, 1985), reduce harvesting efficiency and add thousands of seeds to the soil-weed seed bank, thereby compounding future weed problems (Hartzler, 2003). The competitive effects of all weed infestation types on crop production have been experimentally found to be strongly dependent on the time of weed removal as well as relative time of crop-weed emergence. Research has revealed that in sub-Saharan Africa weed competition is greatly hampering crop production amongst smallholder farmers. Although 50% of labour time during farming operations is devoted to weeding (Akobundu, 1996), weed control practices are inappropriately timed (after Gianessi and Williams, 2011 in Reinhardt, 2011). Past crop-weed competition studies have recognised that weeds can harm crop growth and productivity by competing for light, moisture, nutrients, space, as well as by hampering harvesting operations, and reducing the quality of the harvested crop (Hager *et al.,* 1998). This has resulted in the determination of critical weeding periods and weed thresholds that have enabled Agriculturists to come up with ways of minimising the effects of weed competition. Justification of the use of technologies like herbicides and realisation of the need for integrated weed management (IWM) techniques have been key milestones in minimising the effects of weed competition on crops (Bastiaans & Kropff, 2003).

Farmers are aware that weeds reduce crop yields and although several weed control methods are available, often they do not always know the best methods. More information needs to be gathered on the efficacy of various weed control techniques and weed management systems for different soils and cropping systems (Zimdahl, 1999). The most problematic weed species also need to be singled out and their effects on maize yield quantified, before a carefully planned and integrated management system can be developed to efficiently and economically control weeds from planting to harvest (Hager *et al.,* 1998).

When making weed management decisions, it is important to bear in mind that the critical period for controlling weeds varies widely, depending upon weed species and densities, environmental conditions and cultural practices. Many research studies have addressed this issue and helped to establish some of the thresholds and guidelines currently available. Establishing consistent thresholds or numbers of weeds that cause a specific yield reduction has been difficult to derive across many locations, years and weather patterns. Furthermore, as tillage, planting and weed management practices have changed over the years, the former guidelines regarding crop/weed competition should perhaps be revisited, in some instances modified, as new findings are reported (Hager *et al.,* 1998). Therefore a need exists to have a study that focuses specifically on the North West province conditions in order to generate relevant information to its unique environment.

Most emerging farmers are getting grain yields of around 1 t ha^{-1} which is less than 50% of 3 t ha^{-1} that commercial farmers obtain. This is partly owing to limited success in weed control, probably as a result of over-simplification in tackling the problem. Amongst emerging farmers there is a general lack of awareness of several aspects of weed interference, specifically the time at which weed control should be applied (Gianessi & Williams, 2011). There could also be too much emphasis or reliance on particular weed control tactics (especially synthetic herbicides) as the 'solution' to any weed problem in any environment whilst integrating different tactics (for example preventative, cultural, mechanical and chemical methods) appears not to be receiving proper attention when weed management is being planned and implemented. Weed control decisions taken by farmers appear often to be based on incomplete information (Zimdahl, 1999). There is therefore a need to appraise the suitability of a range of weed control techniques available to farmers, always considering variation in soils and cropping systems. A cost benefit analysis of the available weed control methods needs to be conducted, in order to keep maize farming sustainable and economically viable for emerging farmers.

The hypotheses of the study were:-

- Different weed control methods affect maize yields differently
- Weeding costs vary among different weeding methods

The specific objectives of the study were:-

- To determine the effect of different weed control methods on maize yields of emerging farmers at two localities in the North West province.
- To identify the most competitive or problematic weed species at two localities in the North West province.
- To compare the economic benefit of different weed control methods at the two localities.

CHAPTER 1
LITERATURE REVIEW

1.1 Maize production status in South Africa

South Africa has a total surface area of 122 million hectares (Department of Agriculture Forestry Fisheries (DAFF), 2013). The average area under maize production was 4.5 million ha between 1970 and 1995. It has, however, dropped to an average of 3.3 million ha from 1996 to date. During the 2013/14 growing season 3.9 million ha of arable land was under production with different field crops, of which maize (both white and yellow) occupied 2.7 million ha. Thus maize occupied 67% of the total land under field crop production. The North West province contributed 25% (665 000 ha) of the total area under maize production, coming second after the Free State province with 44% (1.2 million ha) (Crop Estimates Committee, 2014). This trend was the same even in 2013 when 740 000 ha were under maize in the North West province out of 2.8 million ha nationally. Even in the years preceding the 2012/13 growing season, maize was the most popular field crop under production occupying the largest surface area nationally.

The North West province, although placed second after the Free State province in terms of hectares devoted to maize production, was third in terms of grain yield attained, after the Free State and the Mpumalanga provinces. In 2014, a total of 14.4 million tonnes of field crops were forecasted and of these 12.4 million tonnes (86%) was maize. Maize production in the North West province would thus contribute approximately 2.2 million tonnes (18%), coming third after the Free State and the Mpumalanga provinces with 5.3 million tonnes (43%) and 2.7 million tonnes (21%), respectively (Crop Estimates Committee, 2014). In 2013 (2012/13 season) 13.3 million tonnes of field crops produce were harvested, with 11.7 million tonnes (88%) being maize grain. The largest producers were the Free State, Mpumalanga and the North West provinces with 4.8 million tonnes (41%), 3 million (26%) and 1.6 tonnes (13%) in that respective order (Crop Estimates Committee, 2014).

The government is currently busy with land reform programmes in which land ownership is being transferred to previously disadvantaged (mainly black) South

Africans. It is estimated that about 5.7 million hectares of land have been transferred to about 4.2 million previously disadvantaged South Africans since 1995, through land restitution and redistribution programmes (Cronje, 2012). Problems associated with these programmes have included uncertainty about the future of agriculture and reduced productivity owing to the replacement of experienced commercial farmers with emerging farmers. Production levels of new entrants have also been affected by a lack of resource endowment and know-how (Cronje, 2012).

Areas put under maize have shrunk by about 27% since 1970. Between 1970 and 1995 the area under maize production averaged about 4.5 million hectares, however, this has been reduced to about 3.3 million since 1995 (DAFF, 2013). This reduction might be attributed partly to emerging farmers that receive large tracts of land from government sponsored land reform programmes. Productive lands as a result are left lying fallow or idle for considerable lengths of time. The land area under field crop production has significantly decreased except for a few crops like sunflower, soybeans and sugar cane, where areas have tremendously increased. However, despite the reduction in areas devoted to crops, especially maize, productivity has actually increased by about 17% from 1995 (DAFF, 2013). The increased productivity may be a result of improved technology being introduced.

The agricultural sector contributed on average 5.9% to the Gross Domestic Product (GDP) between 1970 and 1994. This contribution reduced to an average of 3.3% between 1995 and 2012, a period when agrarian reforms were implemented (DAFF, 2013). Agriculture, forestry, hunting and the fishing industry in 2012 contributed 2.6% of the annual gross domestic product which was about R 1.6 billion. Field crops comprised 28% of the contribution of Agriculture to the gross domestic product, of which 15% was contributed by maize. That is to say, of the total field crop contribution, maize alone made up 52% (DAFF, 2013). These statistics clearly emphasise the importance of maize production in South Africa and thus why this study is of such importance.

1.2 Duration of weed competition

Crop-weed competition is an indirect form of competition in which shared resources mediate the interaction of the competing species. Competition studies have led to the minimisation of weed effects on crops through the determination of critical periods for weed competition (CPWC). The critical period has been defined as "the period of time between that period after seeding when weed competition does not reduce yield" and the time after which weed presence does reduce yield (Zimdahl, 1999). Knezevic *et al*. (2002) defined CPWC as "a window in the crop growth cycle in which weeds must be controlled to prevent unacceptable yield losses". Hall *et al.* (1992) described this stage for maize as the period between the 3 and 14-leaf stage.

Van Acker *et al*. (1993) in Rajcan and Swanton (2001) have described the critical period of maize as ranging from 1 to 8 weeks after crop emergence (WACE), because they have defined the CPWC using the number of weeks after crop emergence approach rather than the crop growth stages approach. They therefore defined CPWC as "a number of weeks after crop emergence during which the crop must be weed-free in order to prevent yield losses greater than 5%". The CPWC is illustrated in Figure 1.1.

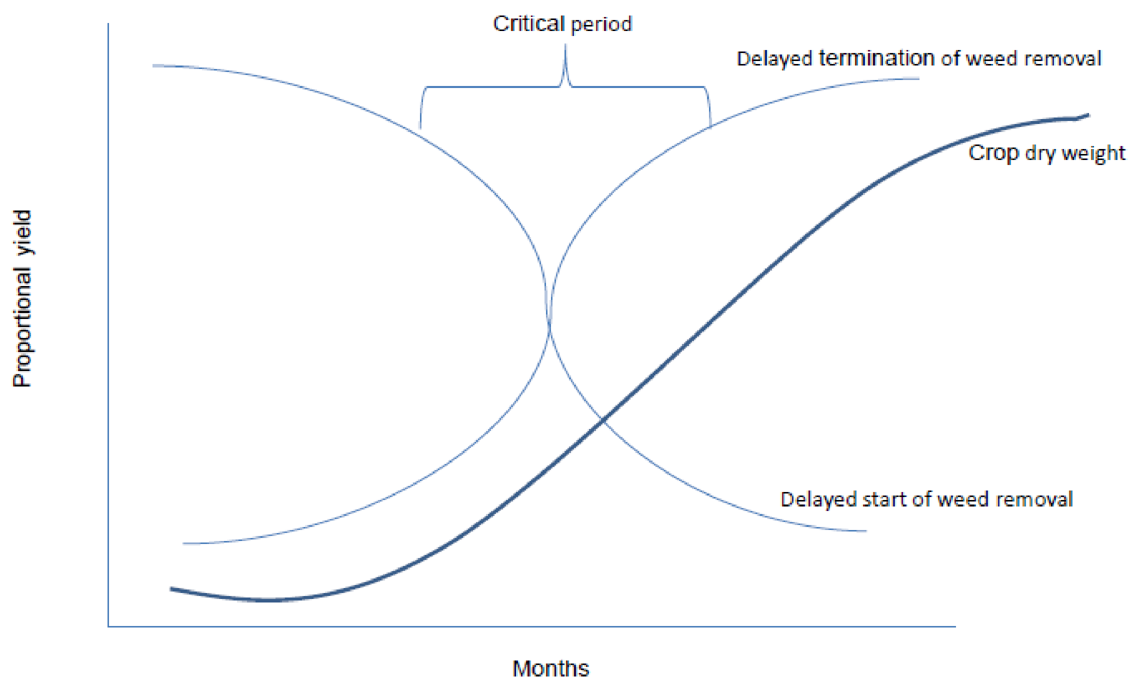

Figure 1.1 Critical period of weed competition (Zimdahl, 1999)

Figure 1.1, indicates that the longer weed control is delayed the greater the loss in proportional yield. Further, the longer the time taken before weed control is terminated the better, as proportional yield increases. The period of time when proportional yield is at the maximum before delayed weeding starts reducing yield and after delayed termination of weed removal no longer adds any benefit to proportional yield is indicated as the critical period for weeding. Critical periods have been determined for many crops.

The critical period has been hailed by many as an important tool in the sustainable Integrated Weed Management (IWM) approach. Bastiaans & Kropff (2003) noted that the duration of competition studies were mainly focused on safe-guarding crop production by minimising weed effects. Scientists wanted to develop better ways of predicting yield losses before they actually occurred so as to justify control methods employed. These descriptive weed-crop competition studies have enabled Agriculturists to come up with ways of minimising weed competition effects (Hager *et al.,* 1998).

The approach to the critical period has been twofold: - the critical duration of weed competition and the critical weed free period.

1.2.1 Critical duration of weed competition

These studies focused mainly on the competitive effects of weeds that emerge together with the crop and are removed, after being allowed to co-exist with the crop for a certain period of time. The crop was kept weed-free until it was physiologically mature (Zimdahl, 1999). These classical approaches evaluated crop yield losses owing to weed competitiveness, for the period between the time of weed emergence and the time of weed removal (Sattin & Berti, 1996). It was concluded that weed control was unnecessary in the first few weeks after both crop and weed emergence (Zimdahl, 1988). This is supported by Liebman *et al*. (2001) who reported that at emergence most field crops have a greater leaf area and larger root systems than weeds. Initially, this gives crops a greater absolute growth rate with a better competitive ability for the first few weeks before the weeds turn the situation around.

1.2.2 Critical weed-free period (CWFP)

The CWFP means that the crop was kept free of weeds from emergence until a certain period, after which weeds were not tolerated up to the end of the season

(Zimdahl, 1999). This period was important in determining when weed control efforts should be terminated, as the weeds would no longer be having any effect on crop yield. The studies have also been useful in timing planting of cover crops.

Limitations to the use of CWFP are that it is crop-specific, is influenced by the climate and location; and weed-species specific (Rajcan & Swanton, 2001). This has resulted in different critical periods of weed control, being experimentally established for different field crops (Stagnari & Pisante, 2010) as shown in Table 1.1. These studies have been pivotal in timing and enhancing efficiency in weed management techniques like post emergence herbicide applications (Ahmadvand *et al*., 2009).

Table 1.1 Crops with an apparent critical period for weed competition (after Zimdahl, 2004 in Hasanuzzaman, 2009)

Crop	**Weed-free weeks required**	**Weeks of competition tolerated**
Maize	3-5	3-6
Rice	4-6	4-9
Soya bean	2-4 after planting	4-8 after planting
Potato	4-6	4-9

Stagnari & Pisante (2010) reported that the CPWC varied owing to a number of factors including weed density, time of weed emergence, weed species composition, light intensity, crop species and variety, crop density and planting pattern, soil temperature and moisture, soil fertility and crop sowing time.

Weed density seems to be one of the main determining factors as it can delay, hasten or eliminate CPWC (Stagnari & Pisante, 2010). Relative time of emergence of weeds has also been found to be an important factor dictating the setting of CPWC.

Weed germination patterns have resulted in the numerical superiority that weeds exhibit over crops (Hasanuzzaman, 2009), as cohorts of seedlings emerge over an extended period of time after initial emergence with crops (Vleeshouwers, 1997).

The increase in weed population over time, increases weed competition by diverting available resources from crops to weeds.

Early in the planting season weed emergence rate is slow, but as the season progresses the emergence rate increases until late into the season when it reaches a maximum point (Figure 1.2). The longer weed control is delayed, the more weeds emerge, increasing weed density, weed competition pressure and prolonged crop-weed competition duration, thus causing greater damage to crops.

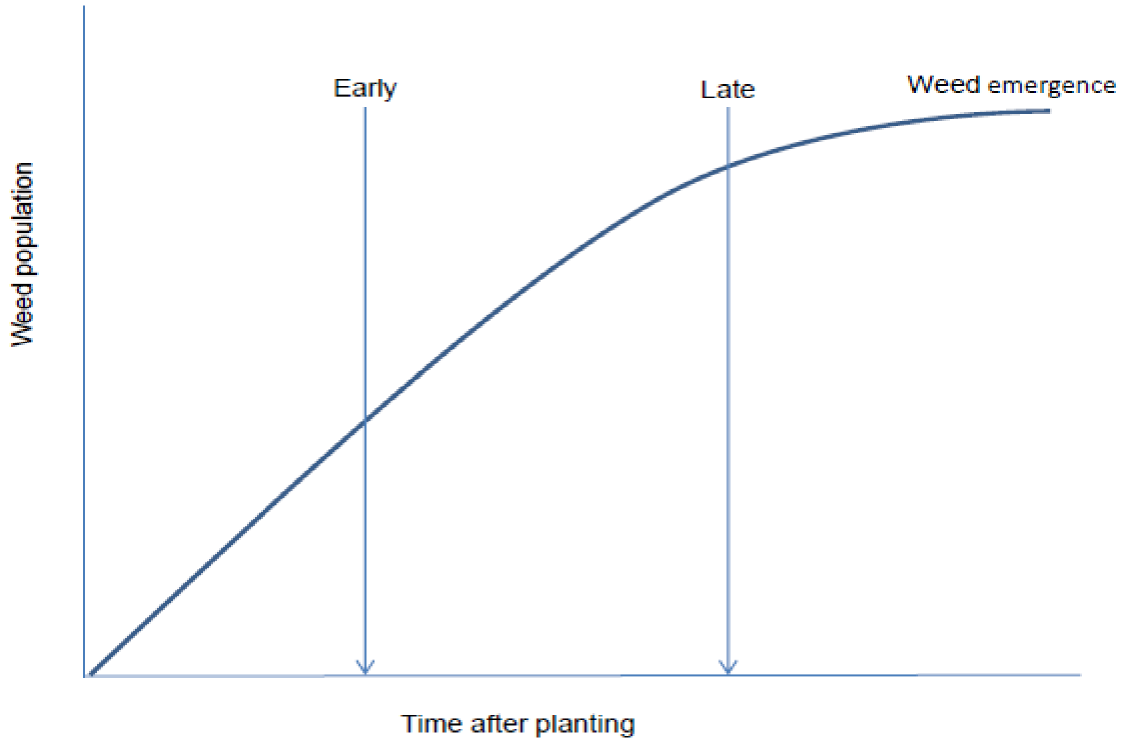

Figure 1.2 Hypothetical pattern of weed emergence as a function of time after crop planting (Sattin & Berti, 1996)

The CPWC is much shorter in high weed density situations. Where there are medium to low densities, it may be delayed. Stagnari & Pisante (2010) reported that, CPWC is non-existant at very low weed densities. The relative emergence time of weeds and crops is another important factor determining CPWC. It can be significantly prolonged by relatively small delays in weed emergence. The CPWC of maize was increased from the V_4 to V_7 stage by delaying weed emergence by seven days (Hartzler, 2003). Differences in the timing of crop management operations in relation to the periodicity of weed emergence can affect weed density (Hasanuzzaman, 2009).

1.3 Maize-weed resource competition

Crop-weed competition represents some form of exploitation competition, with the effects of weeds on crop growth and production being the result of resource capture by weeds. Weeds that share resources available to crops effectively reduce growth and production (Bastiaans & Kropff, 2003). Soil moisture, nutrients and light are the major resources for which crops and weeds compete (Hasanuzzaman, 2009).

1.3.1 Soil moisture

Under weedy conditions water availability to crops is limited, hence the development of water stress symptoms earlier than under weed-free conditions. Maize developmental stage, duration and severity of stress and weed species involved are key factors in determining the effects of water stress on maize and all other crops in general. Water stress interferes with maize growth by affecting dry matter accumulation, thus restricting plant height and reducing the rate of leaf appearance (Stewart *et al.,* 1975, Lorens *et al.*, 1987). If competition duration is restricted to the vegetative phases of plant growth, yield will not necessarily be reduced by water stress due to weed competition. This is not the case when competition is prolonged to reproductive growth phases. Water stress for short periods in maize causes reversible physiological changes like stomata closures. Prolonged water stress, in contrast, causes permanent damage to the photosynthetic apparatus, retarding growth and reducing yield (Nissanka *et al.*, 1997).

Under weedy conditions, plants may develop water stress signs earlier than those under weed-free conditions, yet a comparison of water content in soil profiles did not show any differences (Young *et al.*, 1984; Tollenaar *et al*., 1997). This suggests that during vegetative growth, maize plants may not show signs of water stress as the crop responds to competition by portioning more accumulated dry matter to shoots than roots. This results in maize grown under weedy conditions having less developed roots than those under weed-free conditions, due to the upset of the root/shoot ratio of dry matter distribution. Poor root development results in a reduced ability to absorb water even though it may have been available during the reproductive stage. It can therefore be concluded that the longer the weed competition the greater the effects of moisture stress owing to weed competition (Rajcan & Swanton, 2001).

1.3.2 Nutrients

The type and amount of nutrients available defines competition between maize and weeds. The availability of nitrogen (N) can be decreased if weeds are present for longer periods. The length of the period available for nitrogen uptake during the grain filling period dictates the quantity of maize yields (Rajcan & Swanton, 2001). Thus the magnitude of yield loss was found to be dependent on the amount of nitrogen in the soil. Tollenaar *et al*. (1997) reported that when nitrogen was in abundant supply, yield loss owing to weed competition was 14%, compared to 47% obtained under low nitrogen levels. Poor crop root development means less nutrient uptake ability, impacting negatively on the grain yield (Evans *et al*., 2003).

1.3.3 Light

Light quantity and quality are important for crop growth and development but can be influenced by crop-weed competition. Reduction in the leaf area index (LAI) is the main determining factor for yield losses due to competition for light. Reduction in LAI under weedy conditions results from both less leaf area, coupled with accelerated leaf senescence during crop maturity. Weed competition for light is detrimental if it is prolonged until silking, when it has been reported to reduce LAI of maize by up to 15%, affecting the number of kernels being set per plant (Tollenaar *et al*., 1997). Weed competition up to the grain filling stage has been reported to cause premature leaf senescence.

Competition for light, especially for photosynthetic active radiation (PAR) is important in changing crop morphology. Rajcan & Swanton (2001) argued that the different light composition in shaded weedy conditions and open (weed-free) conditions dictate morphological changes in both crop and weed. Crops can detect the balance between the far-red (FR) and red (R) light in natural radiation using phytochromes. If the FR/R ratio is high as in weedy conditions, crop morphological changes known as shade avoidance syndrome kick in as a competitive strategy for light. Rajcan & Swanton (2001) have described shade avoidance characteristics as developing thin leaves, elongated internodes, heavier stems, lower leaf to stem and lower root to shoot dry mass ratios. If these shade avoidance characteristics are allowed to persist until the reproductive stage, grain yield losses will be inevitable. These characteristics entail less plant dry matter accumulation, poor root development resulting in a reduced ability to absorb water and nutrients as well as a shortened nitrogen uptake period as a result of reduced LAI and accelerated leaf senescence. This therefore ultimately reduces the harvesting index by reducing kernel mass and eventually grain yield.

1.4 Weed competition duration effects

According to Reinhardt (2011) the duration of weed competition is closely linked to the extent of crop yield losses. Sattin & Berti (1996) have found that there is a sigmoidal relationship between the weed competitive effects on crop and the competition duration. Weed competition, if allowed unchecked, can reduce crop yield to a mere fraction of the true potential (Laider, 1985), reduce harvesting efficiency and release thousands of seeds, adding on to the soil-weed seed bank, thereby compounding future weed problems (Hartzler, 2003). Competitive effects of all weed infestation types have been experimentally found to be strongly dependent on the time of weed removal, as well as the relative time of crop-weed emergence.

Evans *et al*. (2003) have observed that prolonging weed competition delayed time to 50% silking and maturity in maize as a result of reduced rates of leaf appearance, thus affecting the relative maximum leaf area. Evans *et al*. (2003) also found that with longer weed interference duration, the maximum biomass and leaf area are decreased. Reduced plant dry matter, however, does not impact on the harvest index or grain yield in the early stages. Prolonged weed competition has, however, been proved to cause a rapid loss of plant dry matter as the plants become incapacitated to accumulate dry matter from the 17th leaf-tip stage to maturity. Rajcan & Swanton (2001) stated that the ability of plants to absorb nutrients and water, as well as to photosynthesise is reduced by weed light interception, resulting in the reduction of photosynthetically active radiation that causes the plant to develop shade avoidance characteristics. This eventually results in loss of yield parameters such as the kernel number and mass and ultimately grain yield (Cerrudo *et al*., 2012).

Growth and reproduction in maize are affected by the duration of weed competition and time of weed removal. It was found that maize height was proportional to the length of the period that weed competition existed. The final maize height was reduced by 12-18% by prolonged weed competition duration. Weed biomass has, however, been found to increase with the decrease in duration with the weed-free period and vice versa (Yirefu *et al*., 2012).

As the competition duration is prolonged, the maize maximum height is progressively reduced until a certain minimum point. Reduction in maximum height means less crop dry mass accumulation, which means reduced development that may eventually result in severely reduced yields (Figure 1.3) (Evans *et al*., 2003).

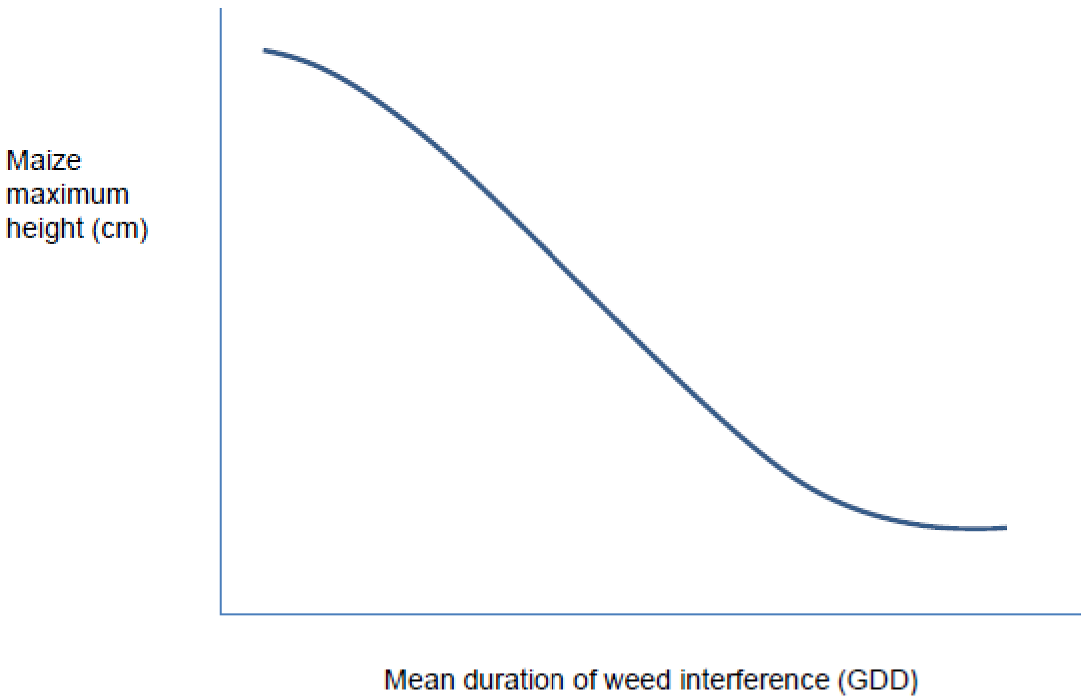

Figure 1.3 Maize maximum height as a function of the mean, duration of weed interference (Evans *et al*., 2003)

Although crops have lower relative growth rates compared to weeds, at emergence of both crop and weeds, crops have a better competitive advantage over weeds. At the initial stages (first few weeks) of competition crops have a higher absolute growth rate because they have a greater leaf area and larger root system than their small seeded weed competitors (Liebman *et al.*, 2001). This crop competitive advantage is, however, overturned after the first few weeks from emergence if crop-weed competition is prolonged, as weeds start manipulating the below-ground competition to their advantage depriving crops of the much needed growth nutrients. Eventually weeds increase the absolute growth rate as well as relative growth rate at the expense of crop growth rate, thus tipping the competition to their advantage. This could, however, be prevented if competition is not prolonged up until weeds start out maneuvering crops in their competitive ability (Liebman *et al.*, 2001).

Effects of weed competition on maize are similar to those that have been observed on other crops. Stagnari & Pisante (2010) have found that prolonging the weed competition period severely reduces LAI and yield components and have reported yield losses of up to 65% in French beans and 83% yield loss in sugar cane was reported by Yirefu *et al*. (2012) who attributed this loss to reduced tillering.

Farmers are currently using a number of weed control methods that are at their disposal including hand weeding, tractor cultivation and chemical weed control either individually or in combinations. Although various categories of farmers are indiscriminately using weed control methods that are feasible and acceptable to them, the economics of using those methods at the expense of others in terms of return per rand invested for each weed control method has not yet been conclusively dealt with under the North West farming conditions. Consequently, the current study also considered costs implications of each method against the benefits in terms of maize yields derived from using such methods.

This study therefore involved the evaluation of several weed control methods currently at the disposal of emerging farmers, for their efficacy and applicability on typical weed spectra in the North West province, as well as comparing the cost-benefit of these different weed control methods.

CHAPTER 2

METHODOLOGY

2.1 Study site description

An on-farm study was carried out at two sites in the Dr. Kenneth Kaunda district of the North West province of South Africa during 2011/12 and 2013/14 summer seasons. The study sites Mogopa and Tigane are situated 25 km North of Ventersdorp and 20 km North-west of Klerksdorp respectively. These study sites are indicated in figure 2.1 with yellow markers.

Figure 2.1 Experimental sites, Mogopa and Tigane with yellow markers (Google earth, 2013)

The geographical coordinates of the study sites are 26° 06'00.00"S, 26° 49'00.00"E and 26°42'45.75" S, 26° 24'48.55" E for Mogopa and Tigane respectively. The average annual rainfall for Mogopa is 648 mm and 600 mm for Tigane. The average maximum and minimum temperatures are around 30°C and 16°C respectively in summer (South Africa Rain Atlas, 2011)

2.2 Experimental design and treatments

The field experiments were laid out in a split-plot design in randomised complete blocks with three replicates. Maize cultivars were allocated to main plots and weed control methods to sub-plots. The gross plot size was 6 rows of each cultivar on 14 m x 7 m and the net plot size was 4 rows of each cultivar on 9.2 m x 5 m. The maize cultivars planted that were recommended for the study area from Monsanto Seed Company were;

a. DKC 78-45BR a stacked gene hybrid with stalk borer (B) and herbicides (Roundup – R) resistance genes
b. CRN 3505 a normal conventional hybrid

Weed control methods were;

1. No weeding
2. Clean field no weeds allowed (hand weeding or chemical)
3. Hand weeding at 3 and 8 weeks after crop emergence (WACE).
4. Pre-emergence herbicides.
5. Mechanical weeding at 3 and 8 WACE.
6. Mechanical weeding at 6 WACE.
7. Pre-emergence herbicides + Mechanical weeding at 6 WACE.
8. Pre-emergence + Post-emergence herbicides.

Mechanical weeding was carried out using a tractor-drawn cultivator

2.3 Soil sampling and analysis

Soil samples were collected from the top 0.30 m using a soil auger from five positions at each site before planting in November. The five samples collected from each site were mixed to obtain a one composite sample which was sent for analysis at North West University Eco-Analytica laboratory. A nutrient status analysis was performed to determine fertilizer types and application rates to be used. The soil analysis checked on the levels of all major and minor soil nutrients (Potassium (K), Phosphorus (P), Sodium (Na), Calcium (Ca) and Magnesium (Mg)).

2.4 Maize establishment and field operations

A rain gauge was installed at each site before the rain season. Temperature data was collected from the local weather station. Land preparation was carried out using a disc plough (conventional tillage) after which the fields were disked to make a fine seed bed. A two in one mechanical planter was used to apply fertilizer and plant seed at the same time. During the 2011/12 season, planting was carried out on the 14th and 15th of December 2011 at Mogopa and Tigane respectively. In the 2013/14 season, planting was carried out on the 11th and 14th of December 2013. The inter- and intra-row spacing was 2.30 m and 0.20 m respectively targeting a plant population of 20 000 ha^{-1} which is the standard maize population recommended for rain-fed production in the North-West Province. Maize was planted after receiving 25 mm of raining which is the normal farmer practice under rain-fed conditions in the North West Province. Basal and top dressing fertilizer application rates (Table 2.1) were calculated based on a target yield of 3 t ha^{-1} under rain-fed conditions.

Table 2.1 Fertilizer application rates for the two sites

Site	**Fertilizer type**	**Application rate** (kg ha^{-1})
Mogopa	N:P:K – basal application 3:2:1 (34)	180
	Top dressing Urea (46% N)	70
Tigane	N:P:K – basal application 3:2:0 (32)	150
	Top dressing Urea (46% N)	70

Herbicides were sprayed using a 15 L knapsack sprayer. The spray volume was 100 L ha^{-1} of water. The application rates for the herbicides used for the two cultivars at both sites are indicated in Table 2.2.

Table 2.2 Herbicides and application rates used with the two maize cultivars at Mogopa and Tigane

Cultivar	Time of application	Herbicide Trade name	Herbicide application rate (L ha^{-1})	Herbicide active ingredients	g a.i. ha^{-1}
Stacked gene	Pre-emergence	Camix	1.5	Mesotrione	125
				S-metalachlor	625.1
DKC 78-45BR	Post-emergence	Powermax roundup	3.5	Glyphosate	1 890
		Acetochlor	0.75	Acetochlor	675
Conventional	Pre-emergence	Bullet	2.25	Acetochlor	562.5
				Atrazine	506.3
CRN 3505				Terbuthylazine	506.3
		Buffalo	0.3	Acetochlor	252
	Post-emergence	Cheetah	2.9	Atrazine	841
				Terbuthylazine	841
		Cantron	0.26	Mesotrione	124.8

During the 2011/12 season harvesting was carried out by hand on the 27th and 30th of June 2012 at Mogopa and Tigane respectively. Subsequently harvesting was done on the 28th of June and the 5th of July 2014 at Mogopa and Tigane respectively during the 2013/2014 season. The maize grain yield was determined from a net plot. Maize crop was left to dry naturally in the fields to 13.5% moisture content before harvesting. No pests and diseases were encountered during the two seasons.

2.5 Weed assessments

Weed species were counted from a 1 m^2 quadrat which was randomly thrown three times in every plot at three and eight WACE. The weed species from each quadrat were cut above ground at eight WACE and dried at 60^{o}C in an oven for 5 days before dry mass was measured. Weed sampling was done just before weeding began. During the 2013/14 season the weeds in the inter- and intra-row spaces were counted by species before obtaining the dry mass at three and eight WACE. The weeds were oven dried at 60^{o}C for 5 days before dry mass was measured. Ranking of weeds in terms of their abundance was performed using relative density which was given as a percentage calculated by:-

$$\text{Relative density \%} = \frac{\text{Mean number of individual weed species in quadrats X 100}}{\text{Mean total number of individuals of all weed species in quadrats}}$$

(From Yakubu *et al.*, 2006)

2.6 Statistical analysis

The weed counts, dry mass, plant height, crop stand, grain yield and yield parameters data were subjected to an analysis of variance (ANOVA) appropriate for split plot design using statistical analysis software (SAS) version 3.0. Tukey's studentised range (HSD) test was used to rank the means. Least significant difference (LSD) was used to separate means where treatments were significantly different at 5% probability level.

2.7 Cost-benefit analysis

A cost-benefit analysis was performed using procedures outlined in an Economics manual (CIMMYT, 1988). The analysis was done in stepwise fashion: Firstly the partial budgeting, followed by dominance analysis and lastly marginal analysis. The calculations were performed on a hectare basis.

2.7.1 Partial budgeting

Partial budgeting was carried out by recording grain yield obtained from every treatment, which was then multiplied by the current market grain prices to obtain the gross field benefits for each treatment. Costs that differ across the treatments or the costs that vary were then considered whilst costs that are similar across treatments were ignored. The costs that are associated with each treatment were calculated using the costs of purchasing, transporting to the farm and application of those particular inputs. Prevailing market prices during the relevant seasons were used. The total costs that vary were then subtracted from the gross field benefits to provide net field benefits for each treatment.

2.7.2 Dominance analysis

Dominance analysis was performed after partial budgeting. The dominance analysis was performed by ranking the treatments in order of increasing costs that vary, showing total costs that vary and net benefits. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is described as dominated. A treatment that was found to be dominated was then eliminated for further consideration on the marginal analysis.

2.7.3 Marginal analysis

A marginal analysis was performed on all methods that were not dominated. The treatments were arranged in order of increasing costs that vary and net benefits. The benefits of changing from a treatment with lesser costs that varies and net benefits to one with higher costs and benefits were expressed as a marginal rate of return that was given as a percentage and was calculated by:-

$$\text{Marginal rate of return} = \frac{\text{marginal net benefits (the change in net benefits)} \times 100}{\text{Marginal costs (the change in costs)}}$$

The marginal rate of return represents a return on investment. The calculation was done from the least costly treatment to the most costly to identify the treatment with the highest returns. However, the acceptability of the best weed control treatment to farmers in the recommendation was considered before a decision could be made.

CHAPTER 3

RESULTS

3.1 Study sites soil and weather conditions

The soil analysis results have shown that the soil nutrient status at the two sites was below the required amounts to meet the targeted yield of 3 t ha^{-1} (Table 3.1).

Table 3.1 Soil analysis results for the two sites before planting

SITE	**NUTRIENT STATUS**						
	Ca	**Mg**	**K**	**Na**	**P**	**pH(KCl)**	**EC**
			(mg/kg)				**(mS/m)**
Mogopa	123.0	14.5	67.0	24.0	6.2	5.05	28
Tigane	277.5	54.5	89.5	24.0	49.3	6.48	12
Optimum amounts	281 - 330	56 - 75	81-110	150	23 - 28	4.81 - 5	350

The soil at Mogopa had a lower nutrient status hence higher fertilizer application rates were used than at Tigane where the soil was richer in nutrients. The Sodium (Na) and electrical conductivity (EC) levels were lower than the danger points, making the soils at both sites suitable for maize production without any remedial efforts.

It should be noted that during season 2 (2013/14), the average annual rainfall received was much less than the normal average annual rainfall for the two areas (Table 3.2). A severe mid-season dry spell was experienced from about five until nine WACE. This was so severe that some maize plants wilted to the permanent wilting point. This resulted in the death of those plants, thus reducing the stand by up to 50% (Figure 3.1).

Table 3.2 Rainfall and temperature data for Mogopa and Tigane

Season	**Year**	**month**	**Temperature (^oC)**		**Monthly total rainfall** (mm)	
			Maximum	Minimum	Mogopa	Tigane
Season 1	2011	November	32	14	50	41
2011/12	2011	December	28	15	115	120
	2012	January	32	16	108	113
	2012	February	30	15	230	222
	2012	March	27	13	116	103
	2012	April	26	6	3	4
	2012	May	26	3	0	2
Season total rainfall					622	605
Season 2	2013	November	31	13	41	37
2013/14	2013	December	30	15	113	110
	2014	January	32	16	27	20
	2014	February	31	15	40	47
	2014	March	30	12	96	87
	2014	April	26	7	3	4
	2014	May	26	4	0	0
Season total rainfall					320	305

a. b.

Figure 3.1 Maize plant's condition five weeks after emergence at a. Mogopa, and b. Tigane

3.2 SEASON 1 - 2011/2012

3.2.1 Weed spectrum at Mogopa and Tigane

A total of nine weed species were identified as the most competitive in maize during the 2011/12 season at the two sites. Five of these nine weed species were common at both sites with two specific different weed species found at each site (Table 3.3).

Table 3.3 Most common weeds in maize at Mogopa and Tigane in season 1

WEED NAME		SITE	
Common name	**Scientific name**	**Mogopa**	**Tigane**
Common couch	*Cynodon dactylon* (L)	X	X
Yellow nutsedge	*Cyperus esculentus* (L)	X	X
Large thorn apple	*Datura ferox* (L)	X	X
Pretty lady	*Cleome rubella* (Burch)	X	X
Goose or Rapoko grass	*Eleusine coracana* (L)	X	X
Khakiweed	*Tagetes minuta* (L)	X	-
Sweet buffalo grass	*Panicum schinzii* (Hack.)	X	-
Devil's thorn	*Tribulus terrestris* (L)	-	X
Dwarf marigold	*Schkuhria pinnata* (Lam)	-	X

X : Weed present   - : Weed absent

T. minuta and *P. schinzii* were prevalent at Mogopa but were absent at Tigane. *T. terrestris* and *S. pinnata* were additional problematic weeds noted at Tigane but were absent in Mogopa.

Generally, other than keeping a clean field throughout the season, hand weeding managed to suppress the weeds better than the rest of the weed control methods. At three WACE there was no significant difference. However, at eight WACE the clean field, pre-emergence herbicides + mechanical weeding at six WACE and pre- + post-emergence herbicides methods resulted in a significant reduction in weeds as compared to the no weeding method at Mogopa (Table A1, Annexure A). At Tigane, the application of pre-emergence herbicides and hand weeding managed to significantly reduce weeds as compared to the untreated control (Table A4, Annexure A). Though not significantly different from each other, the conventional cultivar experienced lower weed pressure as compared to the stacked gene cultivar at both sites (Tables A2 and A3, Annexure A).

3.2.1a Mogopa weed competition

Significant differences were only noted for weed density and weed dry mass eight WACE. Weed density at three WACE did not show any significant differences.

The clean field, pre-emergence herbicides + mechanical weeding at six WACE and pre- + post-emergence herbicides methods significantly lowered weed densities when compared to the no weeding method. The rest of the methods did not show any significant differences at 5% probability level (Figure 3.2).

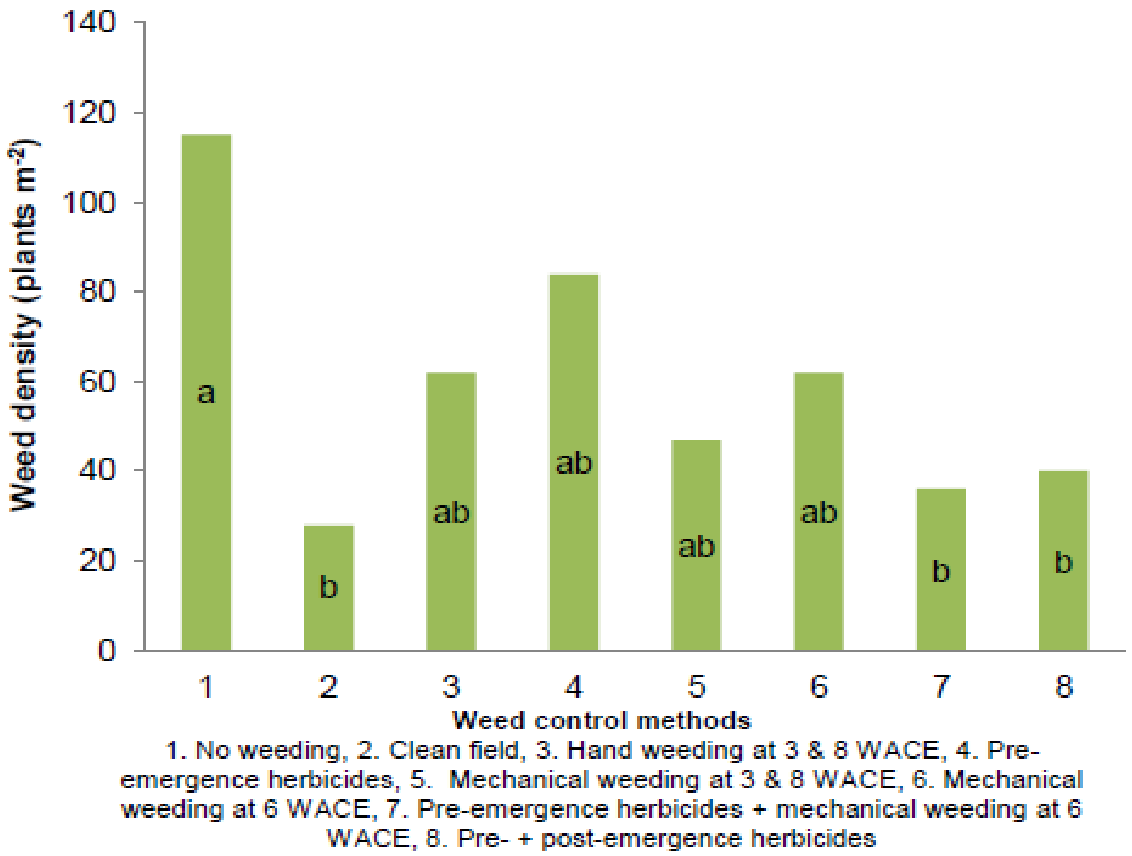

Figure 3.2 Weed density (plants m^{-2}) in maize cultivars eight WACE at Mogopa in season 1. (Letters on each bar represent significant differences ($p \leq 0.05$))

Only the clean field and hand weeding methods significantly suppressed weed dry mass accumulation, as compared to the no weeding method at eight WACE; the rest showed no significant differences at p≤0.05 (Figure 3.3). Generally, other than clean field and hand weeding methods, the rest of the methods did not achieve a meaningful reduction of weed dry mass accumulation.

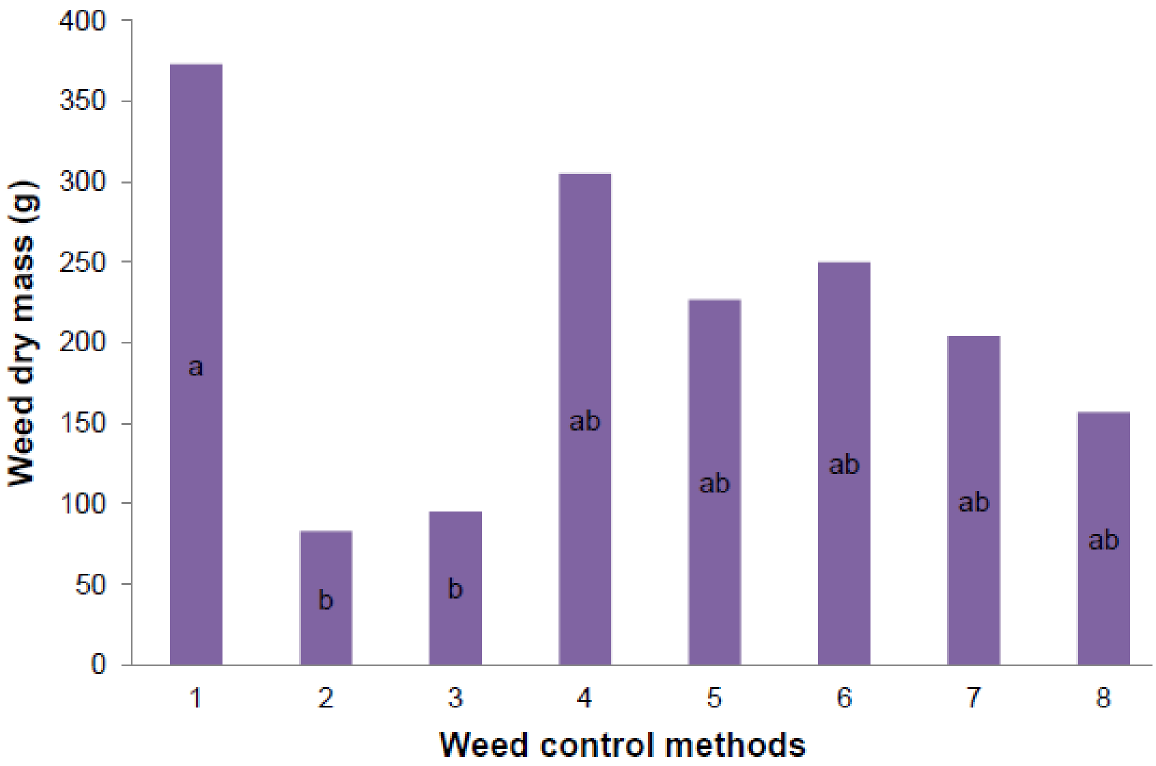

Figure 3.3 Total weed dry mass (g) in maize cultivars eight WACE at Mogopa in season 1. (Letters on each bar represent significant differences (p≤0.05))

3.2.1b Tigane weed competition

Weed density at three WACE and weed dry mass at eight WACE were the only weed parameters that showed significant differences. Weed density was highest (120 plants m^{-2}) where weeds were not controlled as expected (Figure 3.4).

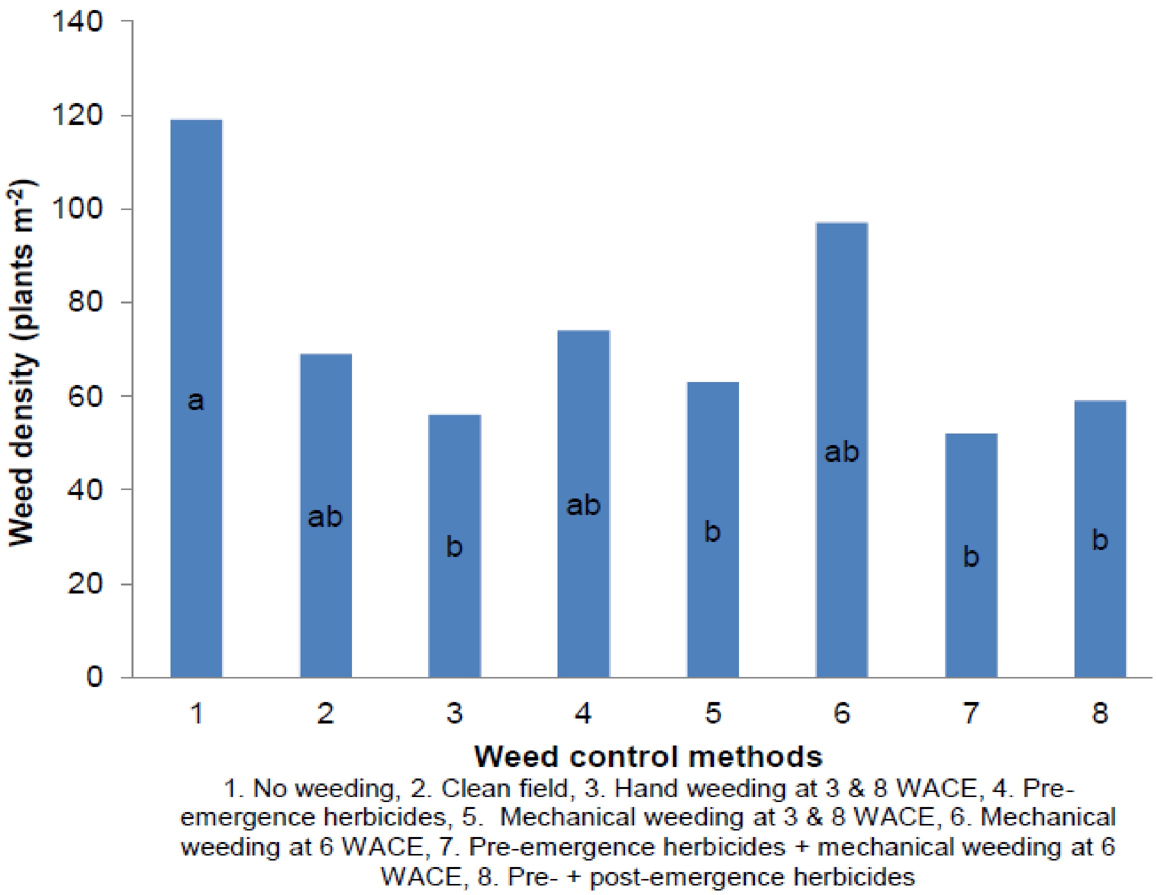

Figure 3.4 Weeds density (plants m^{-2}) in maize cultivars three WACE at Tigane in season 1. (Letters on each bar represent significant differences ($p \leq 0.05$))

Hand weeding, other than keeping a clean field, has proved to be about 74% more efficient than the no-weeding method, in reducing weed dry mass accumulation for both cultivars. Neither pre-emergence herbicides only, nor mechanical cultivation at six WACE could control weed dry mass accumulation satisfactorily, when used separately in both cultivars. However, though not significantly different, combining the two methods proved effective in the stacked gene cultivar, whilst it was less effective in the conventional cultivar (Figure 3.5).

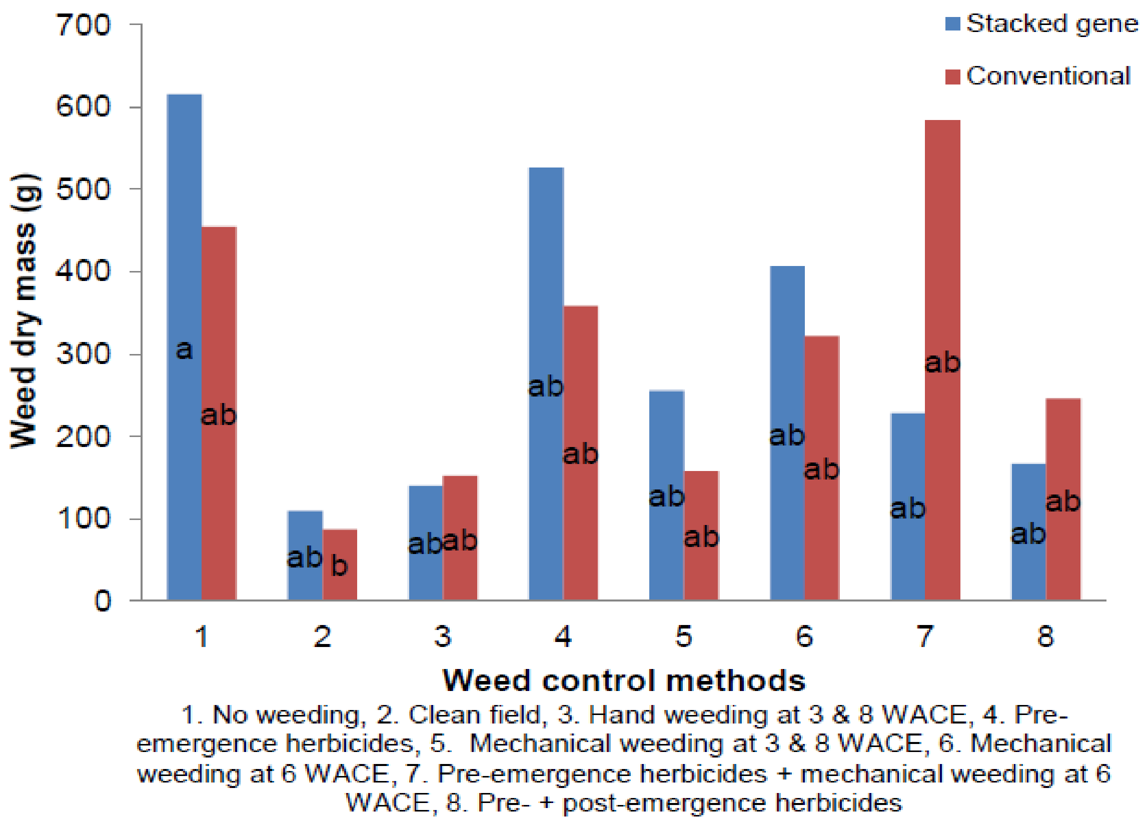

Figure 3.5 Weed dry mass (g) in two maize cultivars eight WACE at Tigane in season 1. (Letters on each bar represent significant differences (p≤0.05))

3.2.2 Maize growth and development

At Mogopa only plant height at harvest showed some significant differences (Table 3.4) whilst at Tigane significant differences were only noted on days to 50% tasseling and plant population at both three WACE and at harvest.

Table 3.4 Average maize plant height (cm) at harvest at Mogopa in season 1

Weed control method	Average plant height (cm)	
No weeding	115.2	b
Clean field	190	a
Hand weeding at 3 & 8 WACE	187.2	a
Pre-emergence herbicides only	169.8	ab
Mechanical weeding at 3 & 8 WACE	200.5	a
Mechanical weeding at 6 WACE	150.2	ab
Pre-emergence herbicides + mechanical weeding at 6 WACE	195.7	a
Pre- + post-emergence herbicides	183.5	a
LSD	**58.7**	

NB. Different letters represent significant differences ($p \leq 0.05$)

It can be seen from Table 3.4 that the maize plant height during season 1 in Mogopa was lowest where no weeding was practised. The highest plant heights were achieved after mechanical weeding at 3 and 8 WACE.

3.2.3 Maize grain yield and yield parameters

3.2.3a Mogopa

Hand weeding twice in a season and use of pre- + post-emergence herbicides resulted in the highest average 100 kernel mass. Although these were not significantly different from other control methods, they were however, significantly greater than the no-weeding method (Figure 3.6).

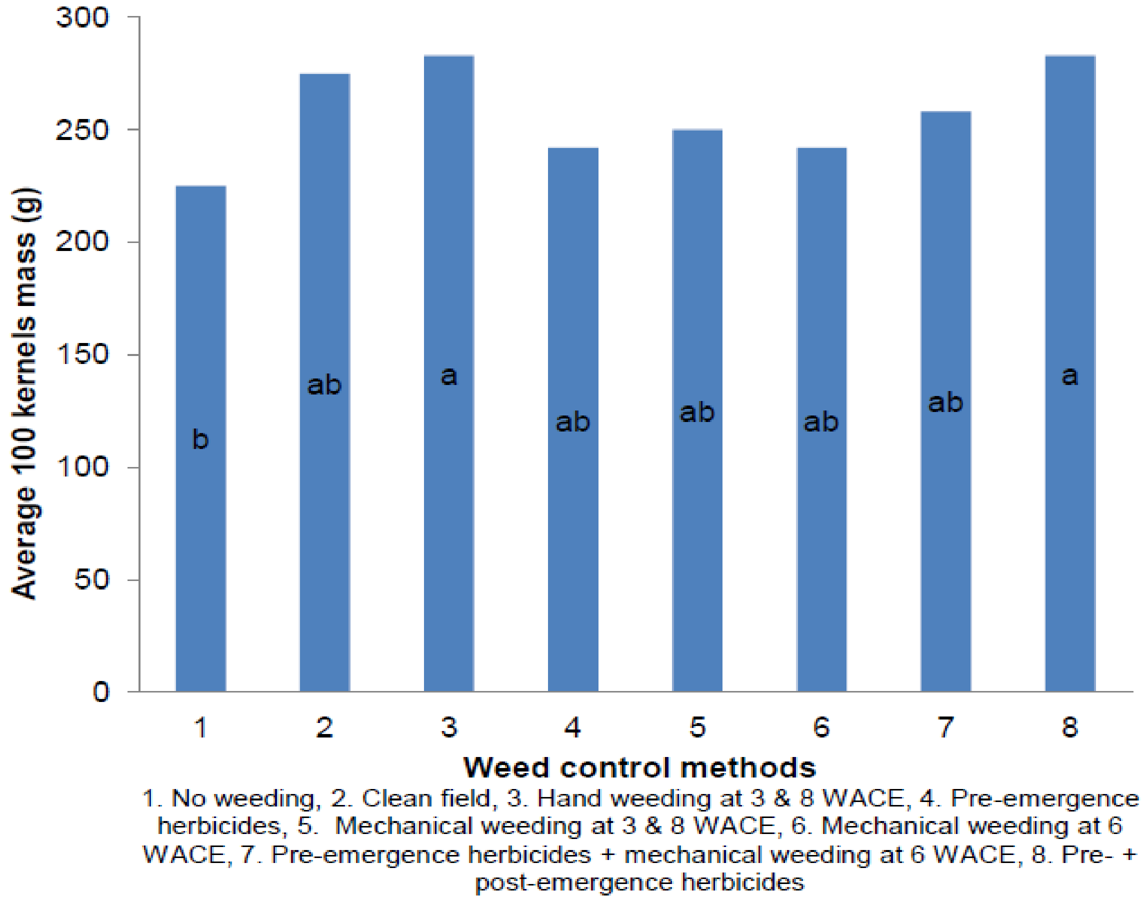

Figure 3.6 Average mass (g) of 100 maize kernels of two cultivars at Mogopa in season 1. (Letters on each bar represent significant differences (p≤0.05))

Methods that produced the highest 100 kernel mass, subsequently produced the highest grain yields (Table A1). The use of pre- + post-emergence herbicides in the stacked gene cultivar was the best method, giving yields that were about 65% significantly higher than the worst method of not weeding. In the conventional cultivar, the best method was the clean field method that produced a significantly higher yield when compared to the no weeding method. Using the pre-emergence herbicides + mechanical weeding at six WACE method, rather than the no weeding method, increased grain yield by only 13% in the stacked gene cultivar. However, when used in the conventional cultivar it resulted in a 132% grain yield increase. Although hand weeding twice per season in both cultivars resulted among the top yielding methods, it produced grain yields that were not significantly different from the rest of the methods (Figure 3.7).

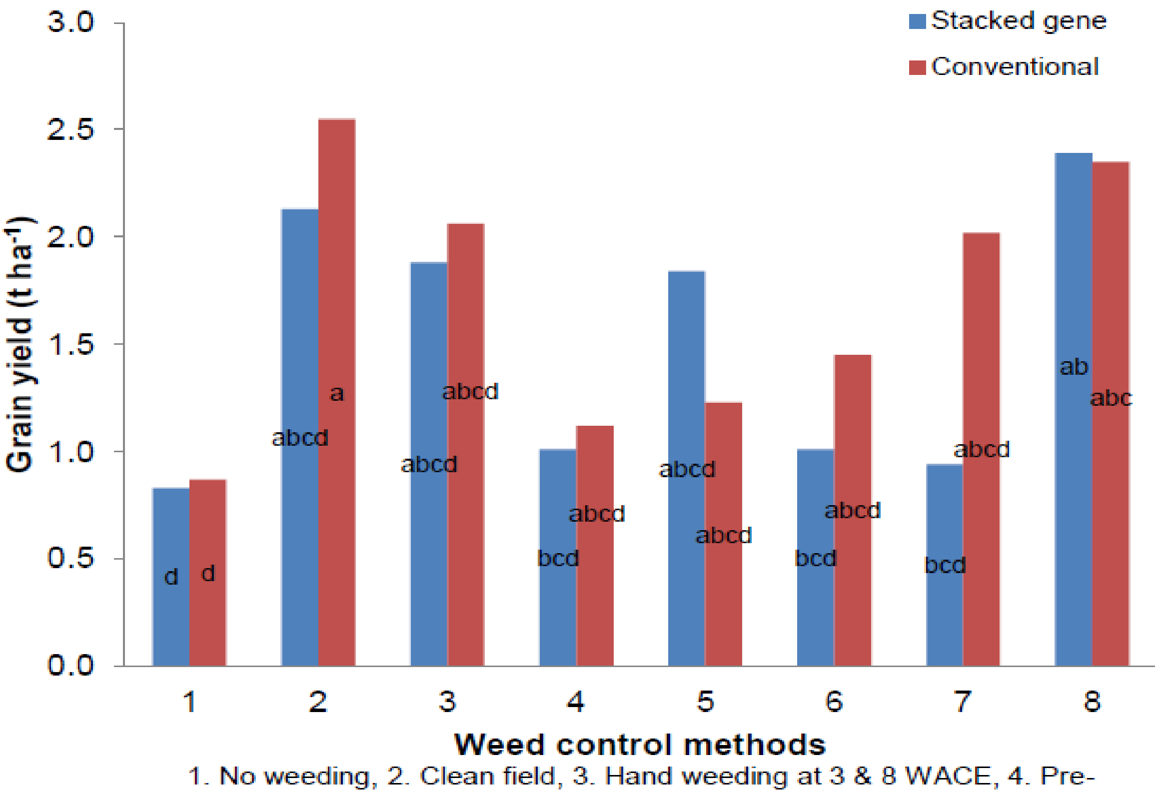

Figure 3.7 Maize grain yield of two cultivars subjected to eight weed control methods at Mogopa in season 1. (Letters on each bar represent significant differences ($p \leq 0.05$))

3.2.3b Tigane

Significant differences were only noted on the average maize ear mass. Maize grain yield and 100 maize kernels did not show any significant differences at 5% significance level (Table A4).

As was expected, the clean field and the no weeding methods produced the highest and the lowest average ear mass respectively. The clean field method had a significantly higher average ear mass than the no weeding and the mechanical weeding at six WACE methods. Whilst all other weed control efforts produced almost similar average masses, the mechanical weeding only method produced the lowest average ear mass, although not significantly different from the rest (Figure 3.8).

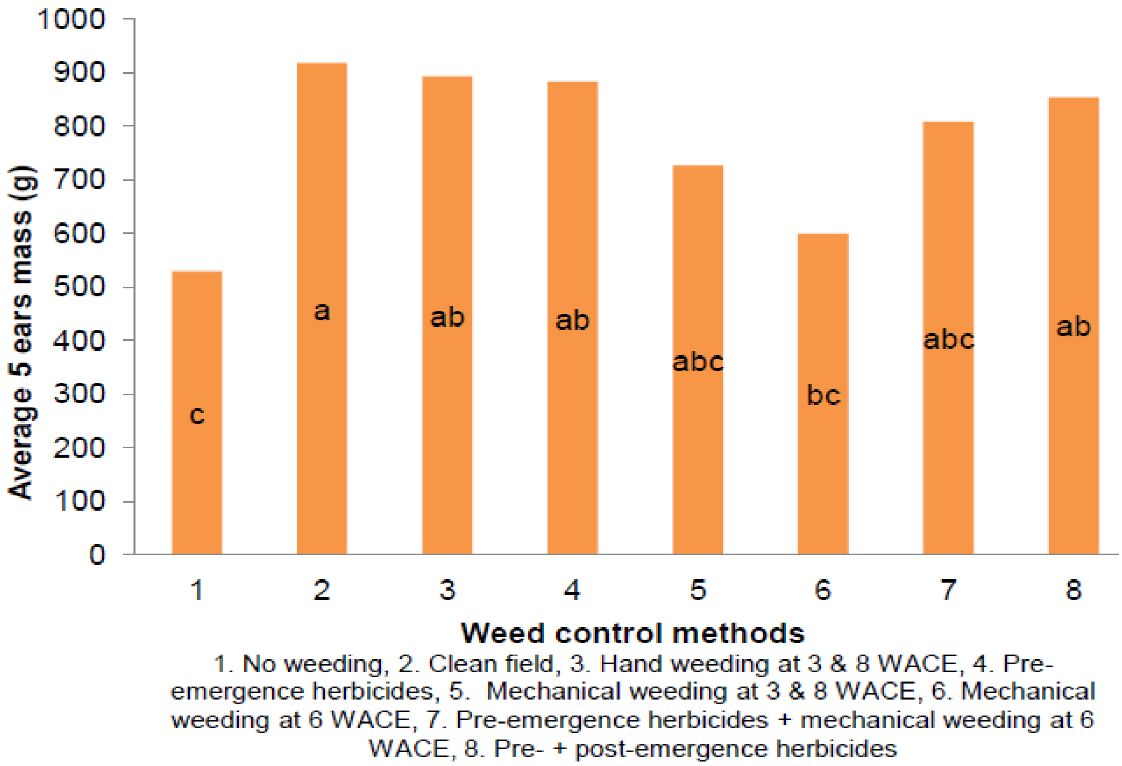

Figure 3.8 Average mass (g) of five maize ears at Tigane in season 1. (Letters on each bar represent significant differences ($p \leq 0.05$))

3.2.4 Cost-benefit analysis

3.2.4.1 Partial budgeting

At Mogopa pre- + post-emergence herbicides had the highest gross field benefit which was 63% higher than the lowest gross benefit obtained where no weeding was carried out in the stacked gene cultivar. The clean field method produced the highest gross benefit in the conventional cultivar whilst no weeding had the lowest gross benefits (Figure 3.9a). In the stacked gene cultivar the clean field method had the highest variable costs (R 2 174 ha^{-1}) whilst use of pre- + post-emergence herbicides was the most expensive in the conventional cultivar. Mechanical weeding once at six WACE had the lowest variable costs irrespective of the cultivar (Figure 3.9b). In the stacked gene cultivar the pre- + post-emergence herbicides and the pre-emergence herbicides + mechanical weeding at six WACE produced the highest (R 3 814 ha^{-1}) and the lowest (R 666 ha^{-1}) net benefit respectively. In the conventional cultivar, keeping a clean field throughout the season had the highest net benefit which was 75% more than the lowest method of using pre-emergence herbicides only (Figure 3.9c).

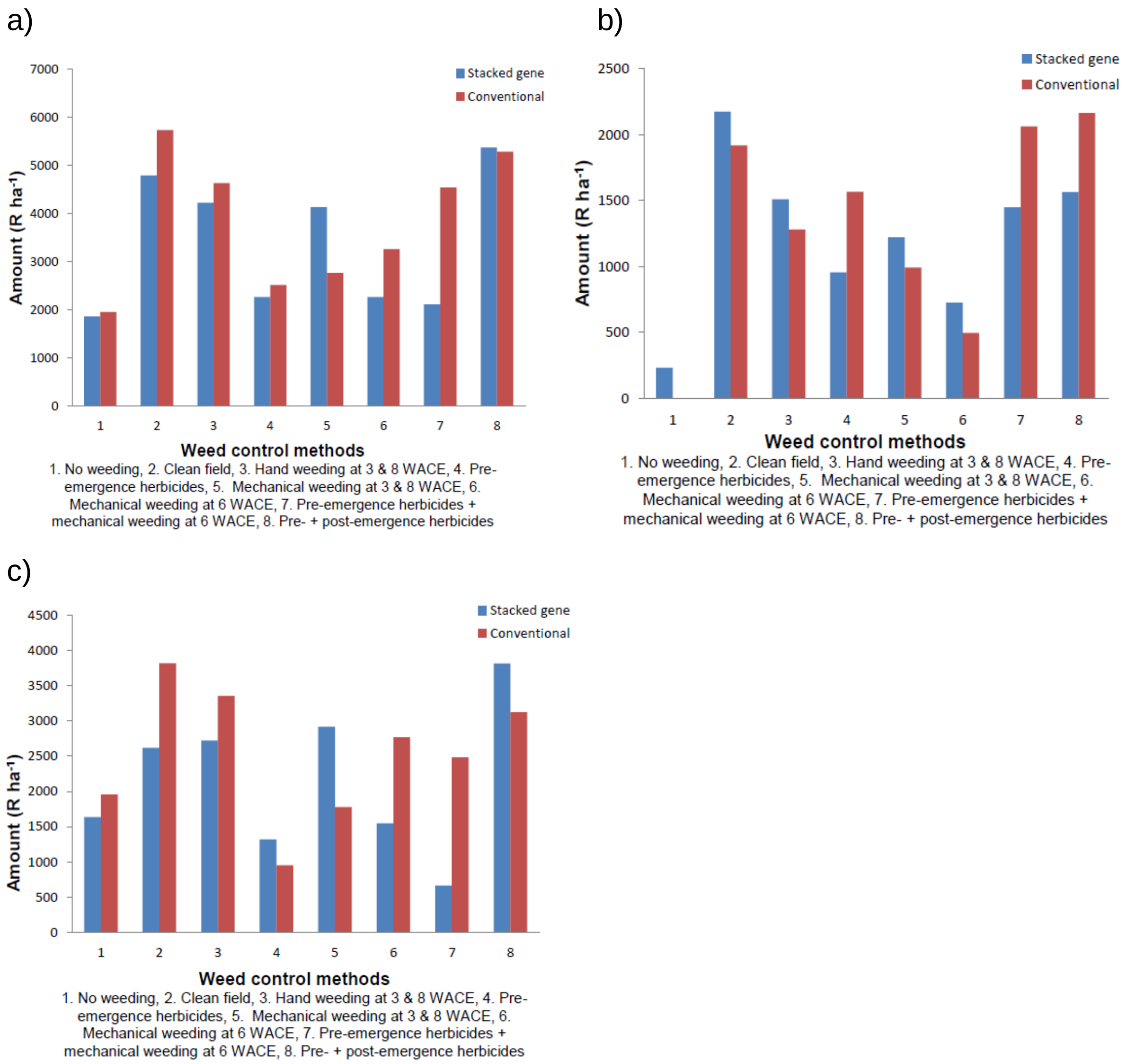

Figure 3.9 a) Gross field benefit, b) costs that vary, and c) net benefit of two maize cultivars subjected to different weed control methods at Mogopa in season 1

At Tigane, the highest gross field benefit of R 5 379 ha^{-1} and R 4 320 ha^{-1} in the stacked gene and conventional cultivars respectively was obtained where pre-emergence herbicides + mechanical weeding at six WACE method was used. The lowest gross benefit was obtained with the use of hand weeding at three and eight WACE and no weeding methods for the stacked gene and the conventional cultivars respectively (Figure 3.10 a). Single tractor cultivation operation at six WACE was the cheapest weeding method costing only R 495 ha^{-1} irrespective of cultivar. However, an extra cost of R 230 ha^{-1} for seed was added on the stacked gene cultivar as it was more expensive than the conventional maize cultivar seed. This brought the total variable costs to R 725 ha^{-1}. The clean field method in the stacked gene cultivar resulted in the highest total costs that vary (R 2 174 ha^{-1}) whilst the pre- + post-emergence herbicides method in the conventional was the most expensive method (R 2 164 ha^{-1}) (Figure 3.10b).

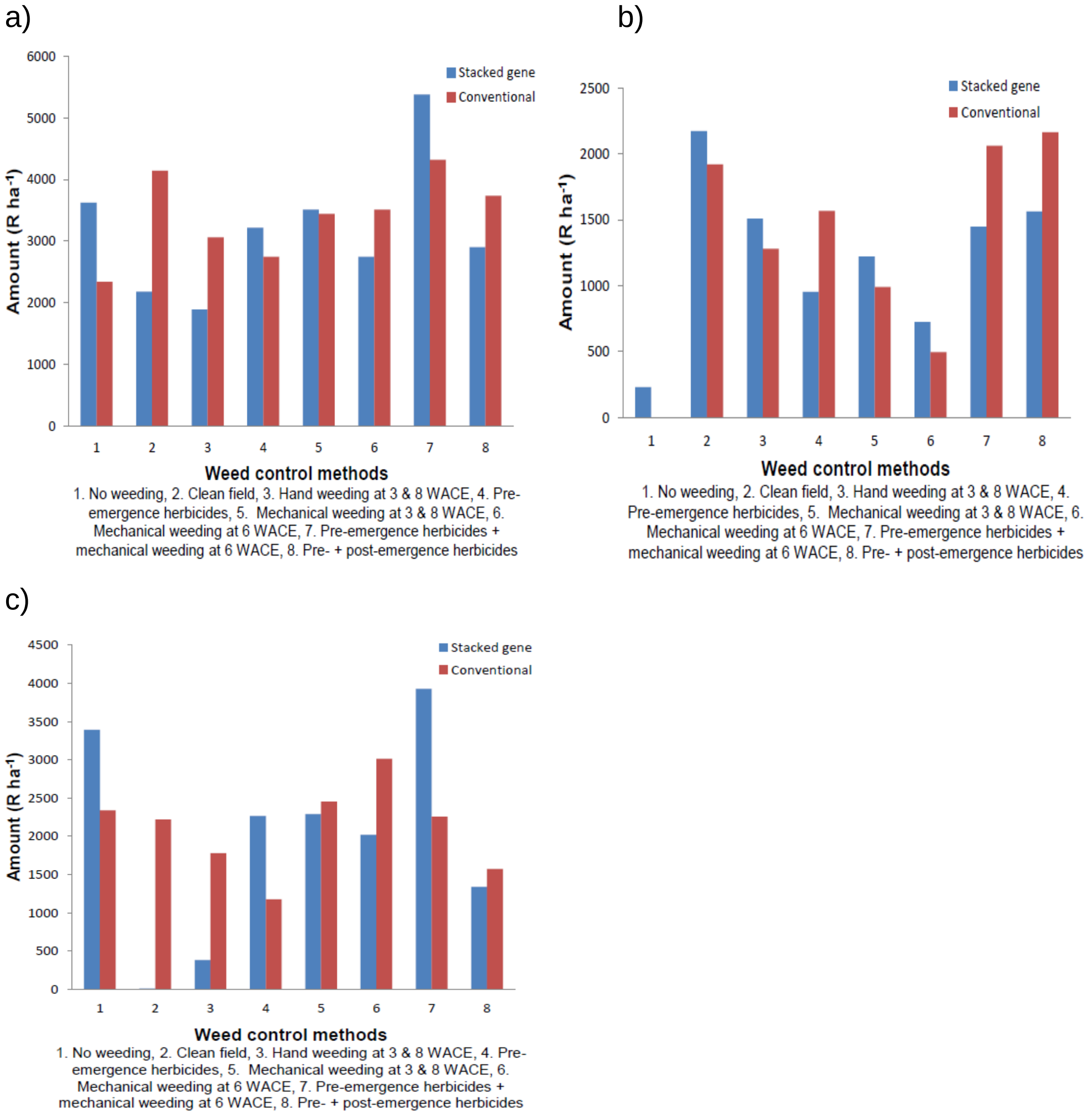

Figure 3.10 a) Gross benefits, b) costs that vary, and c) net benefits of two maize cultivars subjected to different weed control methods at Tigane in season 1

At Tigane, in the stacked gene cultivar, pre-emergence herbicides combined with mechanical weeding at six WACE had the highest net field benefit which was 99.8% better than the clean field which gave the least benefit (9 ha^{-1}) (Figure 3.10c). In the conventional cultivar mechanical weeding at six WACE was 61% better than using pre-emergence herbicides only, the least beneficial method.

3.2.4.2 Dominance analysis

A number of weeding methods that were tested produced seemingly good grain yield results, but after a dominance analysis was performed only a few were found to have a positive change to return on investment. At Mogopa, in the stacked gene cultivar only mechanical weeding twice and pre- and post-emergence herbicides methods were not dominated. The rest of the methods were found to be dominated by the no weeding method hence they were disqualified for further consideration. Mechanical weeding at six WACE, hand weeding twice and clean field were the only methods found not to be dominated by the no weeding method in the conventional cultivar, hence they were further considered for marginal analysis (Table 3.5).

Table 3.5 Dominance analysis of weed control methods on maize at Mogopa in season 1

Weed Control method	Cultivar	Costs that vary (R ha^{-1})	Net benefits (R ha^{-1})	
No weeding	Stacked gene	230	1 638	
Mechanical weeding @ 6 WACE	Stacked gene	725	1 548	D
Pre-emergence herbicides only	Stacked gene	954	1 319	D
Mechanical weeding @ 3 & 8 WACE	Stacked gene	1 220	2 920	
Pre-emergence herbicides + mechanical weeding @ 6 WACE	Stacked gene	1 449	666	D
Hand weeding @ 3 & 8 WACE	Stacked gene	1 510	2 720	D
Pre- + post- emergence herbicides	Stacked gene	1 564	3 814	
Clean field (no weeds allowed)	Stacked gene	2 174	2 619	D
No weeding	Conventional	0	1 958	
Mechanical weeding @ 6 WACE	Conventional	495	2 768	
Mechanical weeding @ 3 & 8 WACE	Conventional	990	1 778	D
Hand weeding @ 3 & 8 WACE	Conventional	1 280	3 355	
Pre-emergence herbicides only	Conventional	1 568	952	D
Clean field (no weeds allowed)	Conventional	1 920	3 818	
Pre-emergence herbicides + mechanical weeding @ 6 WACE	Conventional	2 063	2 482	D
Pre- + post- emergence herbicides	Conventional	2 164	3 124	D

KEY: D = dominated, weed control methods marked D are dominated by those above them in terms of net benefits hence they were disqualified for further analysis

At Tigane, pre-emergence herbicides combined with mechanical weeding at six WACE and mechanical weeding at six WACE were the only methods not dominated by the no weeding method in the stacked gene and conventional cultivars respectively (Table 3.6). Therefore only those two methods were further considered for marginal analysis.

Table 3.6 Dominance analysis of weed control methods on maize at Tigane in season 1

Weed Control method	Cultivar	Costs that vary (R ha^{-1})	Net benefits (R ha^{-1})
No weeding	Stacked gene	230	3 393
Mechanical weeding @ 6 WACE	Stacked gene	725	2 020 D
Pre-emergence herbicides only	Stacked gene	954	2 264 D
Mechanical weeding @ 3 & 8 WACE	Stacked gene	1 220	2 290 D
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Stacked gene	1 449	3 930
Hand weeding @ 3 & 8 WACE	Stacked gene	1 510	380 D
Pre- + post- emergence herbicides	Stacked gene	1 564	1 339 D
Clean field (no weeds allowed)	Stacked gene	2 174	9 D
No weeding	Conventional	0	2 340
Mechanical weeding @ 6 WACE	Conventional	495	3 015
Mechanical weeding @ 3 & 8 WACE	Conventional	990	2 453 D
Hand weeding @ 3 & 8 WACE	Conventional	1 280	1 780 D
Pre-emergence herbicides only	Conventional	1 568	1 177 D
Clean field (no weeds allowed)	Conventional	1 920	2 220 D
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Conventional	2 063	2 257 D
Pre- + post- emergence herbicides	Conventional	2 164	1 571 D

KEY: D = dominated, weed control methods marked D are dominated by those above them in terms of net benefits hence they were disqualified for further analysis

3.2.4.3 Marginal analysis

At Mogopa (Table 3.7), changing from no weeding to mechanical weeding twice in a season should give farmers a return/gain of R 1.29 for every R 1 invested. However, the best weed control method for the stacked gene cultivar would be the use of both pre- and post-emergence herbicides as farmers can expect a return of R 2.60 for every R 1 invested. A return of R 1.64 for every R 1 invested could be expected if mechanical weeding at six WACE is used to control weeds in a conventional maize variety. Changing weed control methods further from mechanical weeding at six WACE to hand weeding at three and eight WACE and then to clean fields method resulted in reduced returns of R 0.75 and R 0.72 respectively.

Table 3.7 Marginal analysis of weed control methods on maize at Mogopa in season1

Weed control method	**Cultivar**	**Costs that vary** (R ha^{-1})	**Marginal costs** (R ha^{-1})	**Net Benefits** (R ha^{-1})	**Marginal net benefits** (R ha^{-1})	**Marginal rate of return**
No weeding	Stacked gene	230		1 638		
			990		1 282	129%
Mechanical weeding @ 3 & 8 WACE	Stacked gene	1220		2 920		
Pre- + post-emergence herbicides	Stacked gene	1 564	344	3 814	894	260%
No weeding	Conventional	0		1 958		
			495		810	164%
Mechanical weeding @ 6 WACE	Conventional	495		2 768		
Hand weeding @ 3 & 8 WACE	Conventional	1 280	785	3 355	587	75%
		1 920	640	3 818	463	72%
Clean field (no weeds allowed)	Conventional					

At Tigane (Table 3.8), controlling weeds in the stacked gene cultivar using a pre-emergence herbicide application, combined with mechanical weeding at six WACE rather than not weeding, should give a return of R 0.44 for every R 1 invested. However, if conventional maize cultivars are planted, rather than not weeding, but carrying out a mechanical weeding once at six WACE, a return of R 1.36 for every R 1 invested could be expected.

Table 3.8 Marginal analysis of weed control methods on maize at Tigane in season 1

Weed control method	**Cultivar**	**Costs that vary** (R ha^{-1})	**Marginal costs** (R ha^{-1})	**Net Benefits** (R ha^{-1})	**Marginal net benefits** (R ha^{-1})	**Marginal rate of return**
No weeding	Stacked gene	230	1 219	3 393	537	44%
Pre-mergence herbicides + mechanical weeding @ 6 WACE	Stacked gene	1449		3 930		
No weeding	Conventional	0	495	2 340	675	136%
Mechanical weeding @ 6 WACE	Conventional	495		3 015		

3.3 SEASON 2 – 2013/2014

3.3.1a Weed spectrum at Mogopa and Tigane

The field trial blocks were changed within the farms during this season owing to farmers' changing plans and problems experienced in the previous seasons. This resulted in the weed list changing slightly as some of the weeds were unevenly distributed across the arable lands of site farms.

A total of 11 weed species (Table 3.9) were identified as being troublesome during the 2013/14 season in the Dr. Kenneth Kaunda district of the North West province. These weeds directly impacted on grain yields obtained. Four weed species, *C. dactylon*, *C. esculentus*, *S. pinnata* and *D. ferox,* were found to be common at both sites. However, there seemed to be evidence of new weed species invasions at the two sites. In terms of relative density, the most competitive weeds at Mogopa were *C. dactylon, C. esculentus, C. lanatus* and *P. schinzii* whilst at Tigane, they were *C. esculentus, C. dactylon* and *D. ferox.*

Table 3.9 Most common weeds in maize at Mogopa and Tigane in season 2

WEED NAME		**Relative density %**	
Common name	**Scientific name**	**Mogopa**	**Tigane**
Common couch	*Cynodon dactylon* (L)	38	21
Yellow nutsedge	*Cyperus esculentus* (L)	23	32
Large thorn apple	*Datura ferox*(L)	1	32
Dwarf marigold	*Schkuhria pinnata* (Lam.)	1	3
Wild watermelon	*Citrullus lanatus* (Thunb)	16	-
Sweet buffalo grass	*Panicum schinzii* (Hack.)	12	-
Goose or Rapoko grass	*Eleusine coracana* (L)	7	-
Pretty lady	*Cleome rubella* (Burch)	2	-
Green goosefoot	*Chenopodium carinatum* (R. Br.)	-	7
Purslane	*Portulaca oleracea* (L)	-	3
Devil's thorn	*Tribulus terrestris* (L)	-	2

- : Weed absent

3.3.1b Efficacy of herbicides in controlling weeds

The herbicides that were used in the two cultivars had varied efficiencies in controlling the prevailing weeds at the two sites. The herbicides used in the stacked gene cultivar controlled weeds better than those used in the conventional cultivar (Table 3.10). The herbicides managed total control of *E. coracana* and *C. rubella* at Mogopa.

Table 3.10 Weed control efficiency of herbicides used in a stacked gene and a conventional maize cultivar at Mogopa and Tigane in season 2

Weed name	**Weed relative density %**			
	Stacked gene cultivar		**Conventional cultivar**	
	Pre-emergence herbicides	Post-emergence herbicides	Pre-emergence herbicides	Post-emergence herbicides
Mogopa				
Cynodon dactylon	33	16	36	38
Cyperus esculentus	11	16	13	12
Datura ferox	0	0	0	0
Schkuhria pinnata	0	0	0	0
Citrullus lanatus	9	0	11	13
Panicum schinzii	18	2	11	11
Eleusine coracana	0	0	0	0
Cleome rubella	0	0	0	0
Tigane				
Cynodon dactylon	31	7	13	2
Cyperus esculentus	20	2	23	26
Datura ferox	18	2	36	9
Schkuhria pinnata	1	0	1	0
Chenopodium carinatum	0	2	4	4
Portulaca oleracea	2	0	2	0
Tribulus terrestris	1	0	2	0

3.3.1.1 Intra-row weeds density

3.3.1.1a Mogopa

In the first three WACE, significant differences in the intra-row weed density were only noted for *C. esculentus*. However, at nine WACE no significant differences were noted on the density of any of the weeds present.

The density of *C. esculentus* was significantly higher in the intra-row spaces of the stacked gene cultivar than those of the conventional cultivar at three WACE. The suppression of *C. esculentus* density was 50% more effective in the conventional cultivar when compared to the stacked gene cultivar (Table 3.11).

Table 3.11 *Cyperus esculentus* mean density in the intra-row spaces of two maize cultivars three WACE at Mogopa in season 2

Cultivar	**Mean density** (plants m^{-2})
Stacked gene	4.417 a
Conventional	2.167 b
LSD	**2.036**

NB. Different letters represent significant differences (p≤0.05)

Although only significantly different from mechanical weeding at six WACE method, the clean field, pre-emergence herbicides and pre-+post-emergence herbicides methods were effective in suppressing the germination of *C. esculentus.* These methods therefore eliminated early competition from this weed at three WACE (Figure 3.11).

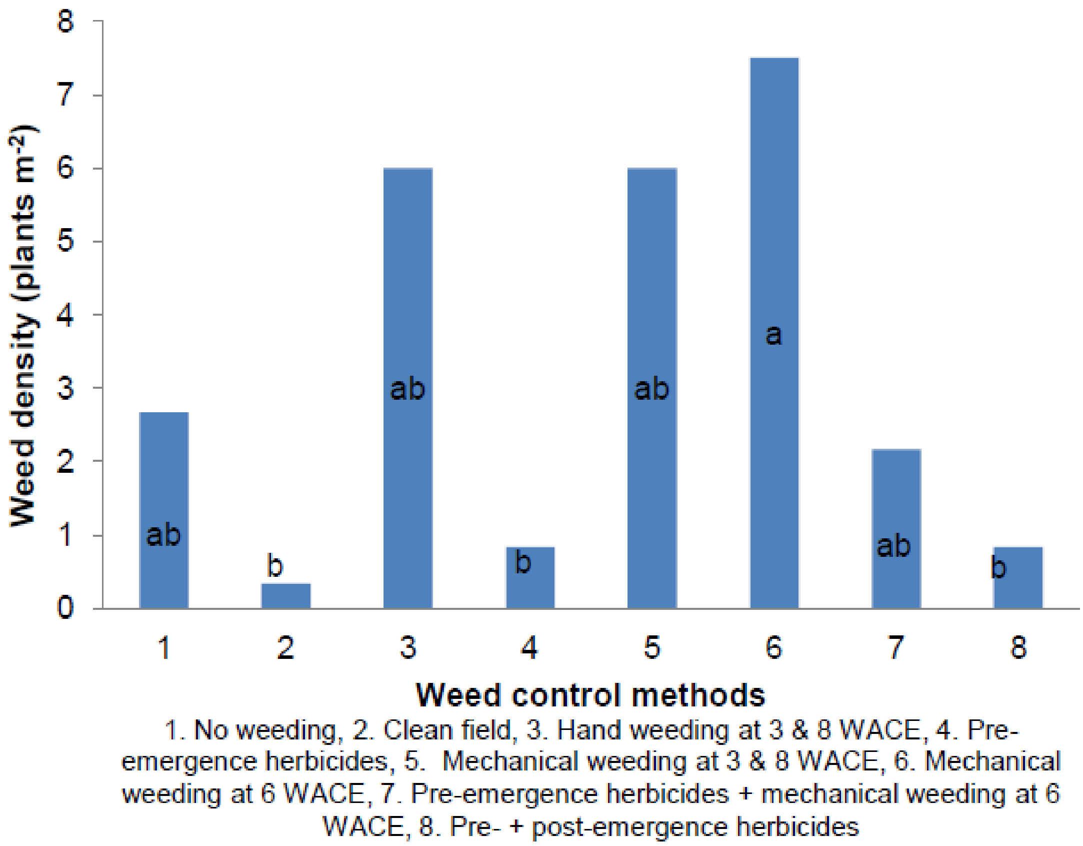

Figure 3.11 *Cyperus esculentus* intra-row mean density in maize cultivars three WACE at Mogopa in season 2. Letters on each bar represent significant differences ($p \leq 0.05$)

3.3.1.1b Tigane

Three WACE significant differences in terms of the intra-row density were only noted for *C. dactylon, C. esculentus* and *P. oleracea.* The rest of the weeds present at that period did not show any significant differences. Only *D. ferox* intra-row densities were significantly different at nine WACE.

At three WACE, the control of *C. dactylon* density was significantly better in the conventional cultivar (3 plants m^{-2}) than in the stacked gene cultivar (4 plants m^{-2}) across all weeding methods (Table 3.12).

Table 3.12 *Cynodon dactylon* mean density in the intra-row spaces of two maize cultivars three WACE at Tigane in season 2

Cultivar	**Mean density** (plants m^{-2})	
Stacked gene	4.042	a
Conventional	3.208	b
LSD	**0.646**	

NB. Different letters represent significant differences (p≤0.05)

Pre-emergence herbicides used in the stacked gene cultivar proved to be more effective in controlling *C. esculentus* than those used in the conventional cultivar (Figure 3.12). The pre- + post-emergence herbicides method was 93% more efficient in controlling this weed density in the stacked gene cultivar (0.7 plants m^{-2}) than in the conventional cultivar (11 plants m^{-2}). The chemical control of this weed was generally more effective than mechanical and hand weeding methods in the stacked gene cultivar. Furthermore regardless of the weed control method, *C. esculentus* density was generally lower in the stacked gene cultivar than in the conventional cultivar.

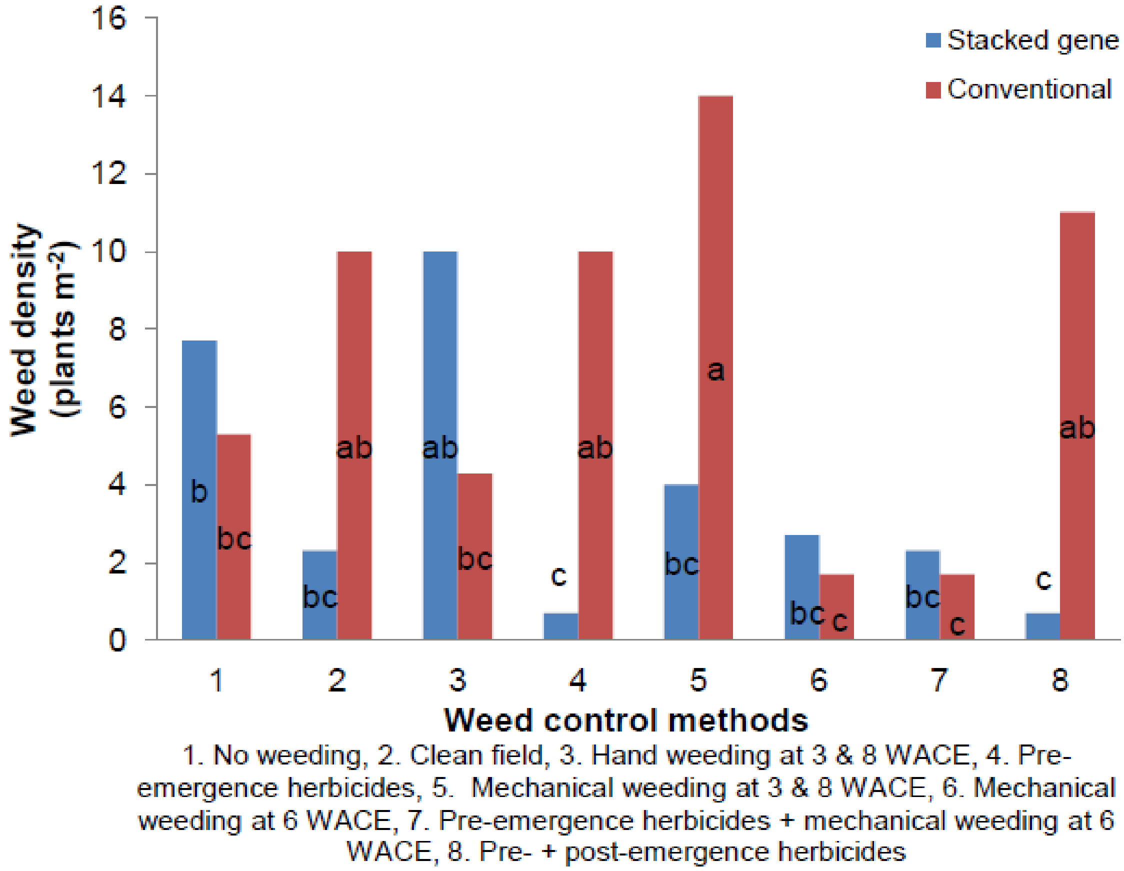

Figure 3.12 *Cyperus esculentus* intra-row density in two maize cultivars three WACE at Tigane in season 2. (Letters on each bar represent significant differences ($p \leq 0.05$))

Clean field and pre-emergence herbicides + mechanical weeding at six WACE were the best methods to significantly suppress *D. ferox* density in the intra-row spaces (Table 3.13). At nine WACE, mechanical weeding at six WACE method had a significantly higher mean weed density than the clean field, hand weeding, pre-emergence herbicides + mechanical weeding at six WACE and pre- + post-emergence herbicides methods.

Table 3.13 *Datura ferox* density in the intra-row spaces of maize nine WACE at Tigane in season 2

Weed control method	Mean density (plants m^{-2})	
No weeding	2.333	bc
Clean field	0.667	c
Hand weeding at 3 & 8 WACE	1.833	c
Pre-emergence herbicides only	3.333	abc
Mechanical weeding at 3 & 8 WACE	5.333	ab
Mechanical weeding at 6 WACE	5.667	a
Pre-emergence herbicides + mechanical weeding at 6 WACE	0.833	c
Pre- + post-emergence herbicides	1.500	c
LSD	**5.0256**	

NB. Different letters represent significant differences (p≤0.05)

3.3.1.2. Intra-row weed dry mass

3.3.1.2a Mogopa

In terms of dry mass, significant differences were noted only for *E. coracana* at nine WACE, while the rest of the weeds did not differ significantly (p≤0.05).

Weed control methods where pre-emergence herbicides were used significantly controlled *E. coracana* when compared to the no weeding method in the stacked gene cultivar. Less effective control was observed where mechanical and hand weeding methods were used in both cultivars (Figure 3.13). Mechanical weeding at six WACE had a higher weed dry mass than the no weeding method used in the conventional cultivar.

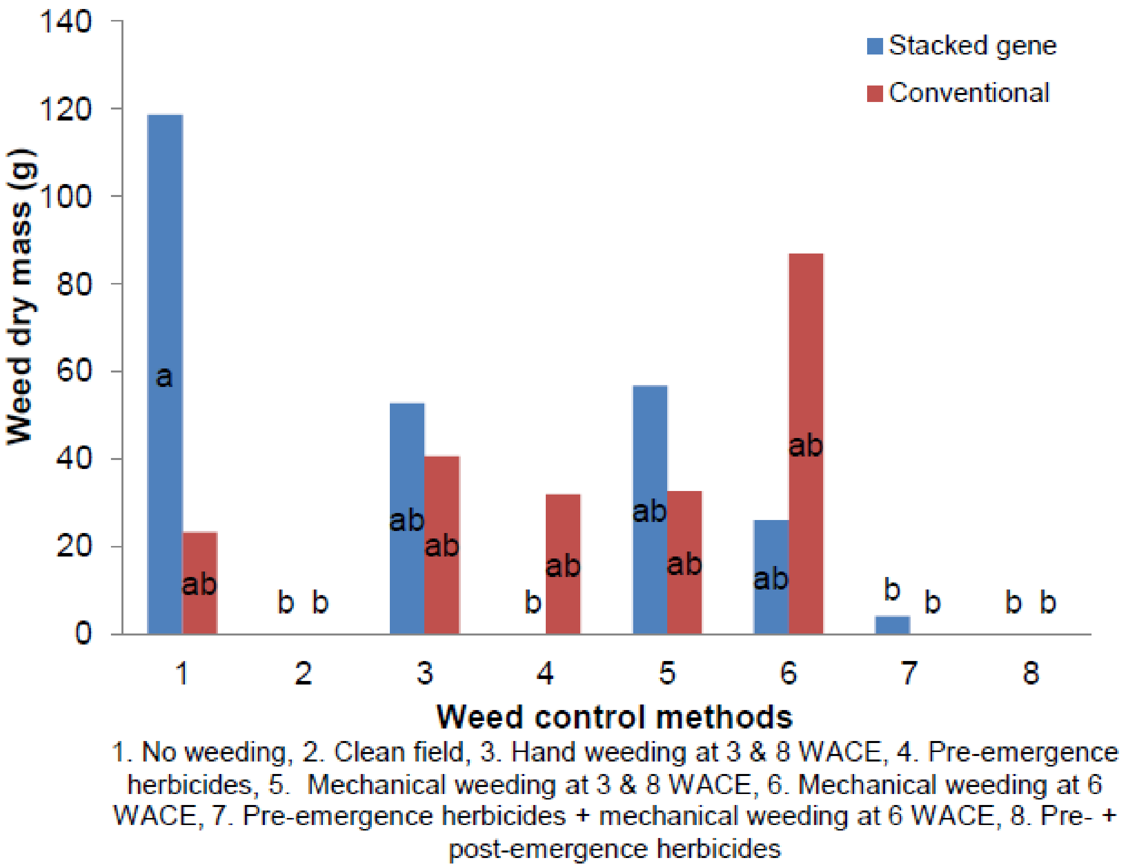

Figure 3.13 *Eleusine coracana* intra-row dry mass in two maize cultivars nine WACE at Mogopa in season 2. (Letters on each bar represent significant differences (p≤0.05))

3.3.1.2b Tigane

Significant differences for intra-row weed dry mass were noted only on *D. ferox, C. esculentus* and *S. pinnata* whilst the rest of the weeds present did not significantly differ at three WACE (Table B9). At nine WACE significant differences were noted only for *C. dactylon* and *D. ferox* at p≤0.05 (Table B10).

D. ferox biomass was significantly reduced (0.9 g m^{-2}) by application of pre-emergence herbicides only which was 94% greater than the least effective method of hand weeding (15.7 g m^{-2}) at three WACE (Figure 3.14). However, at nine WACE, other than the clean field method, application of both pre- + post-emergence herbicides was the best method that significantly suppressed dry mass accumulation (9.97 g m^{-2}) of *D. ferox.* This method was almost 86% more efficient than the worst method of mechanical weeding at three and eight WACE (72.23 g m^{-2}) (Table 3.14).

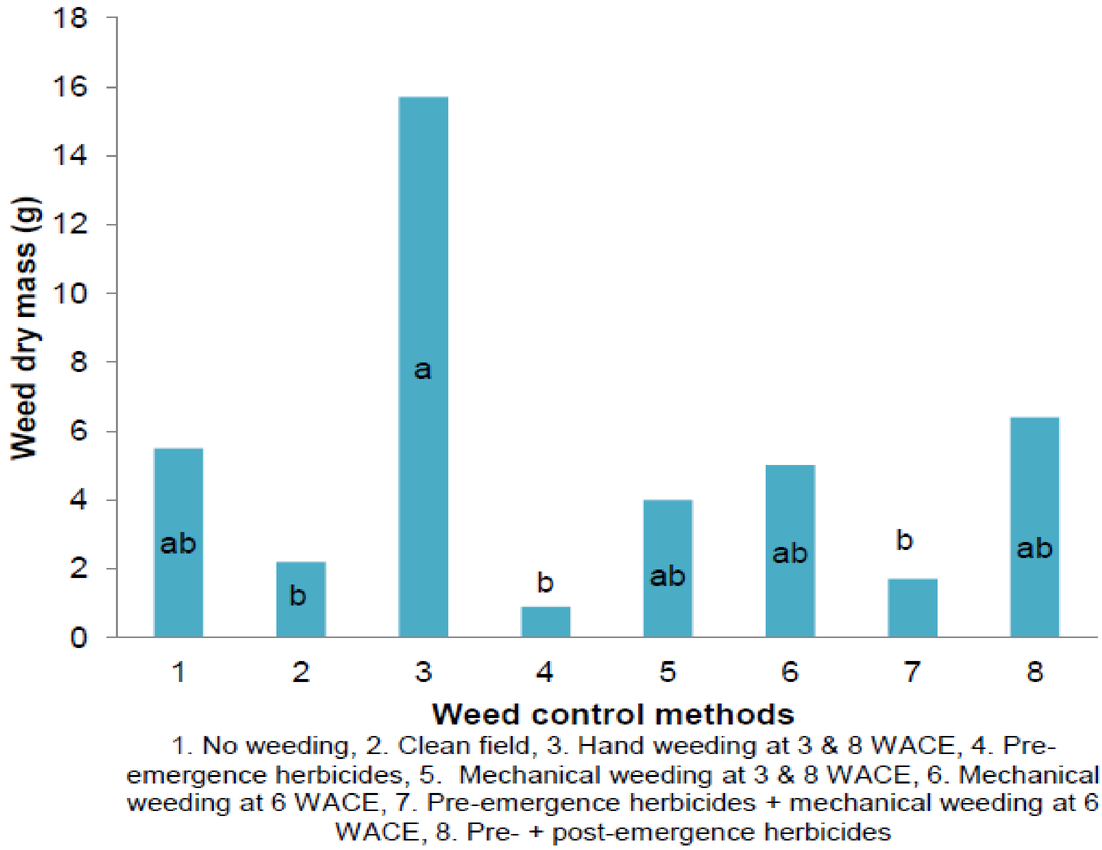

Figure 3.14 *Datura ferox* intra-row dry mass (g) in maize cultivars three WACE at Tigane in season 2. (Letters on each bar represent significant differences (p≤0.05))

Table 3.14 *Datura ferox* intra-row dry mass accumulation in maize nine WACE at Tigane in season 2

Weed control method	**Dry mass** (g m^{-2})
No weeding	12.15 bc
Clean field	1.93 c
Hand weeding at 3 & 8 WACE	9.22 bc
Pre-emergence herbicides only	54.10 ab
Mechanical weeding at 3 & 8 WACE	72.23 a
Mechanical weeding at 6 WACE	66.48 a
Pre-emergence herbicides + mechanical weeding at 6 WACE	12.90 bc
Pre- + post-emergence herbicides	9.97 bc
LSD	**46.95**

NB. Different letters represent significant differences (p≤0.05)

Dry mass accumulation suppression of *C. esculentus* was much greater where pre-emergence herbicides were used in the stacked gene cultivar when compared to the conventional cultivar. Mechanical weeding at three and eight WACE method was the worst in controlling this weed in both cultivars. The method showed significant differences when compared to hand weeding, mechanical weeding at six WACE and pre-emergence herbicides + mechanical weeding at six WACE methods in the conventional cultivar but not in the stacked gene cultivar (Figure 3.15). Generally suppression of dry mass accumulation was better in the stacked gene cultivar than the conventional cultivar.

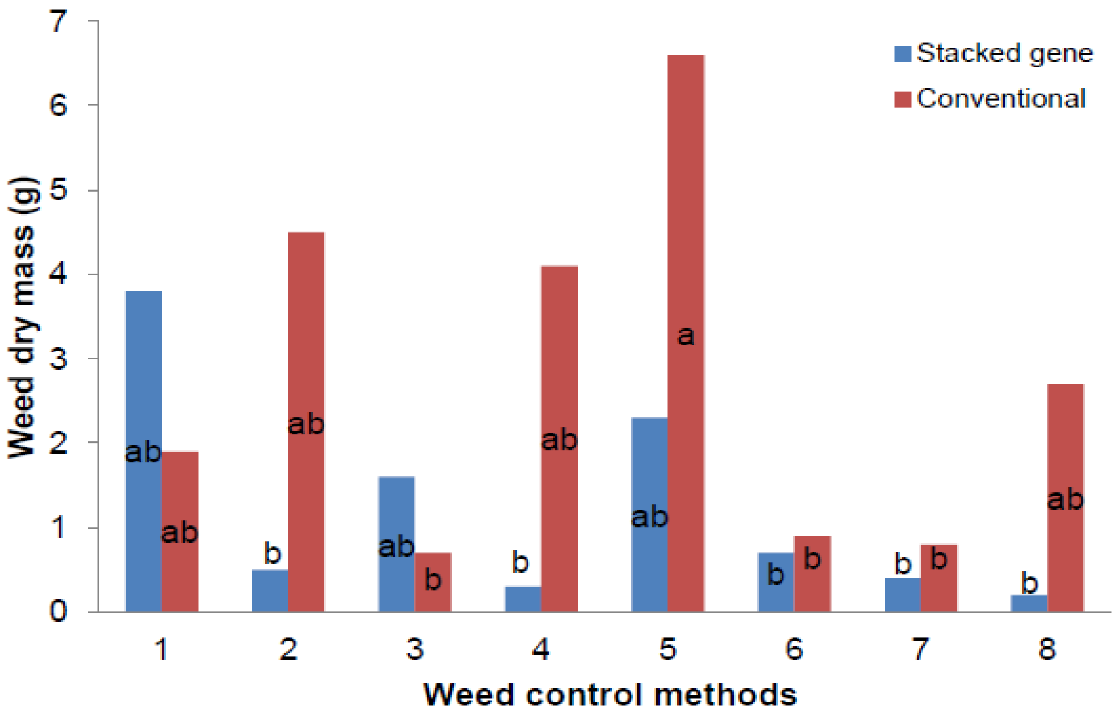

Figure 3.15 *Cyperus esculentus* intra-row dry mass in two maize cultivars three WACE at Tigane in season 2. (Letters on each bar represent significant differences ($p \leq 0.05$))

Intra-row *S. pinnata* dry mass accumulation control was significantly better (73%) in the stacked gene cultivar than in the conventional cultivar (Figure 3.16).

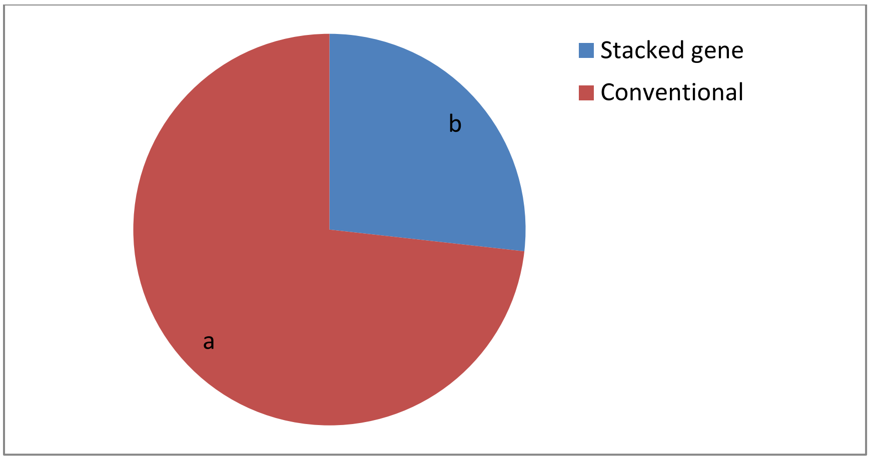

Figure 3.16 *Schkuhria pinnata* intra-row mean dry mass in two maize cultivars three WACE at Tigane in season 2. (Letters represent significant differences (p≤0.05))

3.3.1.3. Inter-row weed density

3.3.1.3a Mogopa

Significant differences were noted only for *C. rubella* on the inter-row weed density whilst the rest of the weeds did not show any significant differences at nine WACE.

C. rubella inter-row density was significantly kept under check where the conventional cultivar was planted as compared to where the stacked gene cultivar was planted. The stacked gene cultivar had 41% more weeds than the conventional cultivar (Table 3.15).

Table 3.15 *Cleome rubella* inter-row mean density in two maize cultivars nine WACE at Mogopa in season 2

Cultivar	**Mean density** (plants m^{-2})	
Stacked gene	1.63	a
Conventional	0.96	b
LSD	**0.65**	

NB. Different letters represent significant differences (p≤0.05)

3.3.1.3b Tigane

Nine WACE *D. ferox* and *P. oleracea* were the only weeds with some significant differences in their density that occupied the inter-row spaces.

Mechanical weeding at six WACE significantly failed to control *D. ferox* density when compared to clean field, hand weeding, pre-emergence herbicides + mechanical weeding at six WACE and pre- + post-emergence herbicides methods (Figure 3.17). Although not significantly different from the rest of the methods, use of pre-emergence herbicides only was not effective in controlling this weed.

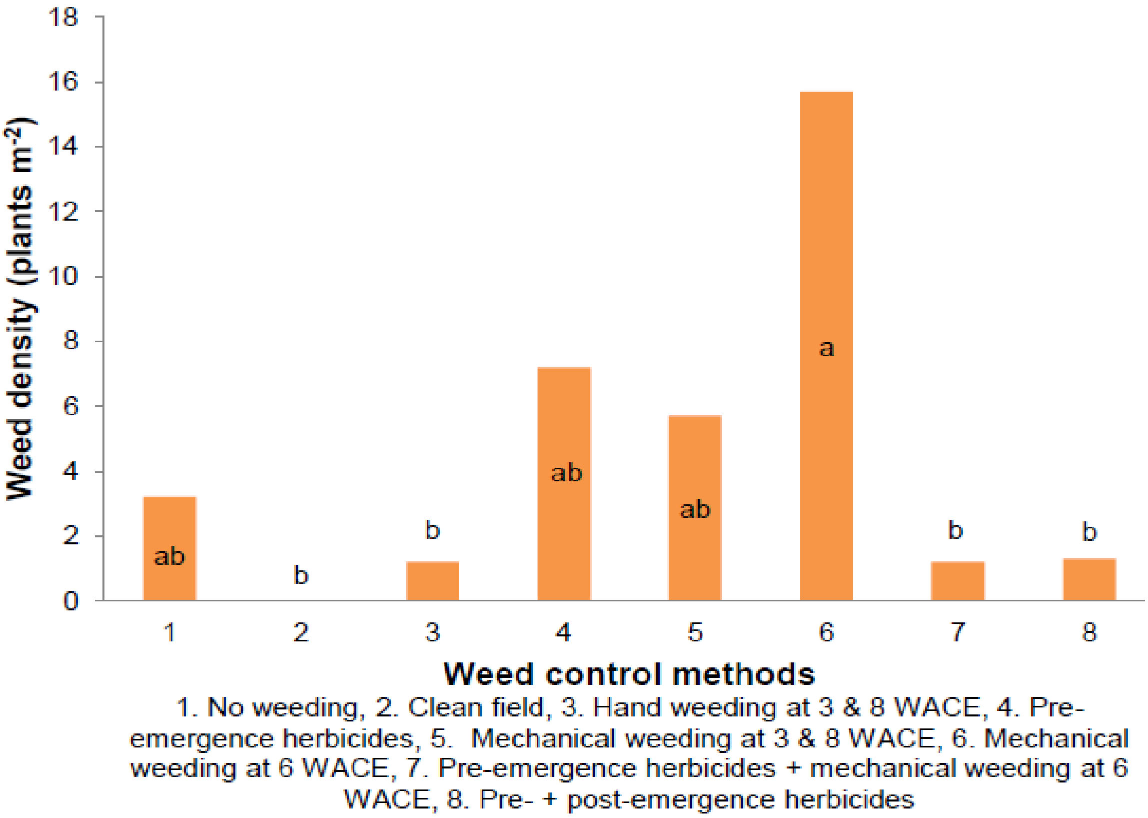

Figure 3.17 *Datura ferox* inter-row density in maize cultivars nine WACE at Tigane in season 2. (Letters on each bar represent significant differences ($p \leq 0.05$))

Most weeding methods generally managed to control *P. oleracea* satisfactorily. No weeding had significantly higher density of this weed, when compared to clean field, pre-emergence herbicides and pre-+post-emergence herbicides methods. Though not significantly different from the rest, delaying weeding for six WACE and then applying mechanical weeding once, was the least effective method for controlling *P. oleracea* density in the inter-row spaces (Figure 3.18).

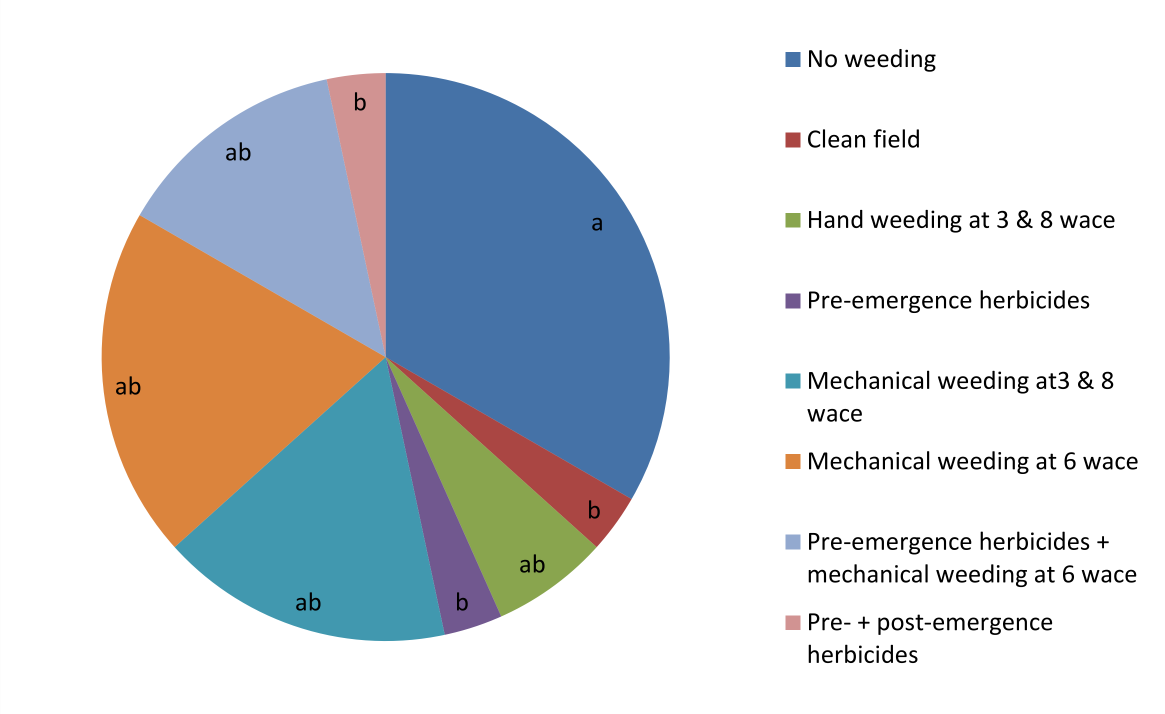

Figure 3.18 *Portulaca oleracea* inter-row density in maize nine WACE at Tigane in season 2. (Different letters represent significant differences ($p \leq 0.05$))

3.3.1.4. Inter-row weed dry mass

3.3.1.4a Mogopa

In the first three WACE *C. dactylon* and *C. lanatus* inter-row dry masses exhibited interactive and main effects significant differences respectively; the other two weeds present did not show any differences. At nine WACE, *C. esculentus* and *C. rubella* inter-row dry masses significantly differ whilst no significant differences were noted on *C. dactylon, C. lanatus, P. schinzii, E. coracana, S. pinnata* and *D. ferox.*

The no weeding method, at three WACE, had the highest *C. dactylon* dry matter in the conventional maize cultivar (45.5 gm^{-2}), which was 76% higher than the one in the stacked gene maize cultivar (10.7 gm^{-2}). In the conventional cultivar, significant differences were only observed where no weeding method was compared to clean field and pre- + post- emergence herbicides. However, in the stacked gene cultivar the dry mass of this weed did not significantly differ across all methods (Figure 3.19).

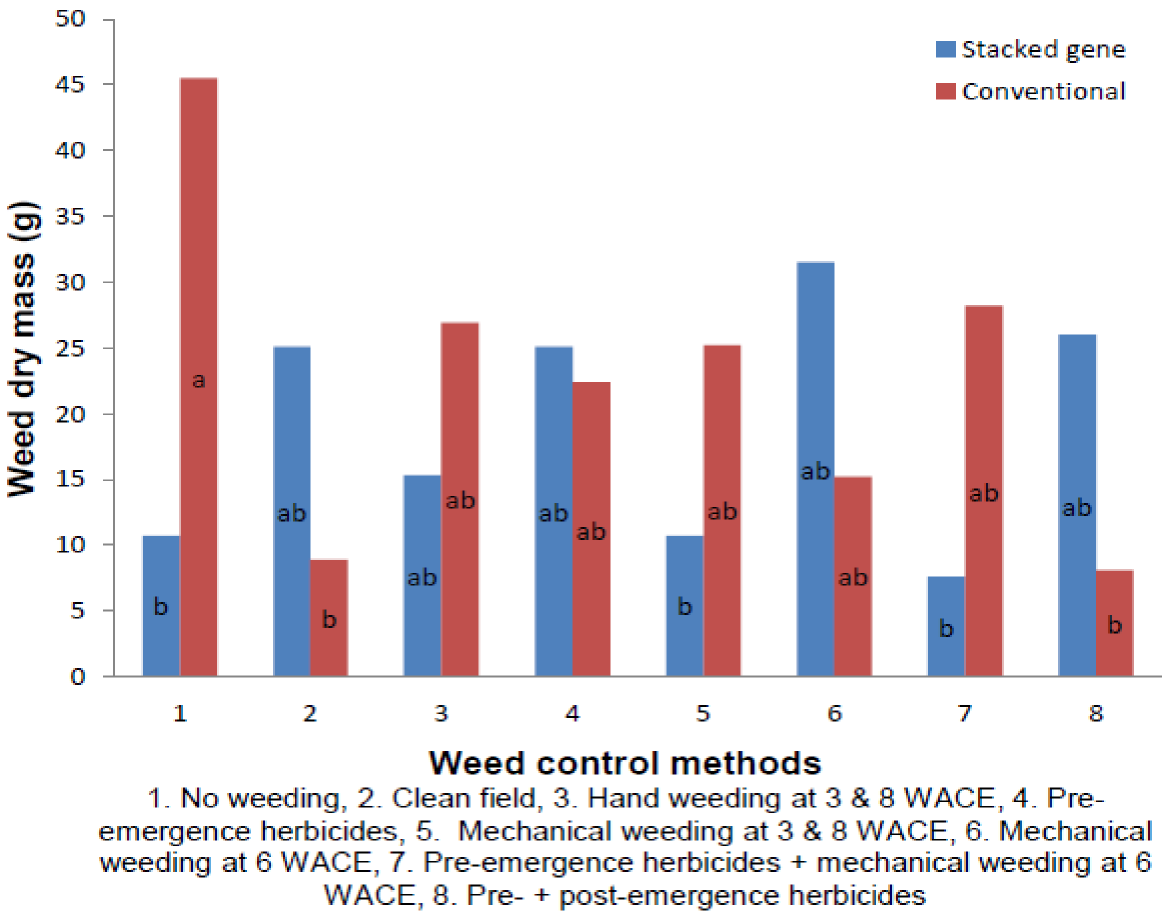

Figure 3.19 Inter-row dry mass of *Cynodon dactylon* in two maize cultivars three WACE at Mogopa in season 2. (Letters on each bar represent significant differences (p≤0.05))

Citrullus lanatus was 50% better controlled in the stacked gene cultivar when compared to the conventional cultivar (Table 3.16).

Table 3.16 *Citrullus lanatus* inter-row dry mass in two maize cultivars three WACE at Mogopa in season 2

Cultivar	**Dry mass** (g m^{-2})
Stacked gene	1.04 b
Conventional	2.11 a
LSD	0.48

NB. Different letters represent significant differences (p≤0.05)

Cyperus esculantus dry mass was significantly higher, where hand weeding was used, than where no weeding, clean field and pre-emergence herbicides only methods were used (Figure 3.20). The performance of hand weeding, mechanical weeding once and twice in a season, pre-emergence + mechanical weeding once and pre- + post-emergence herbicides methods were almost similar.

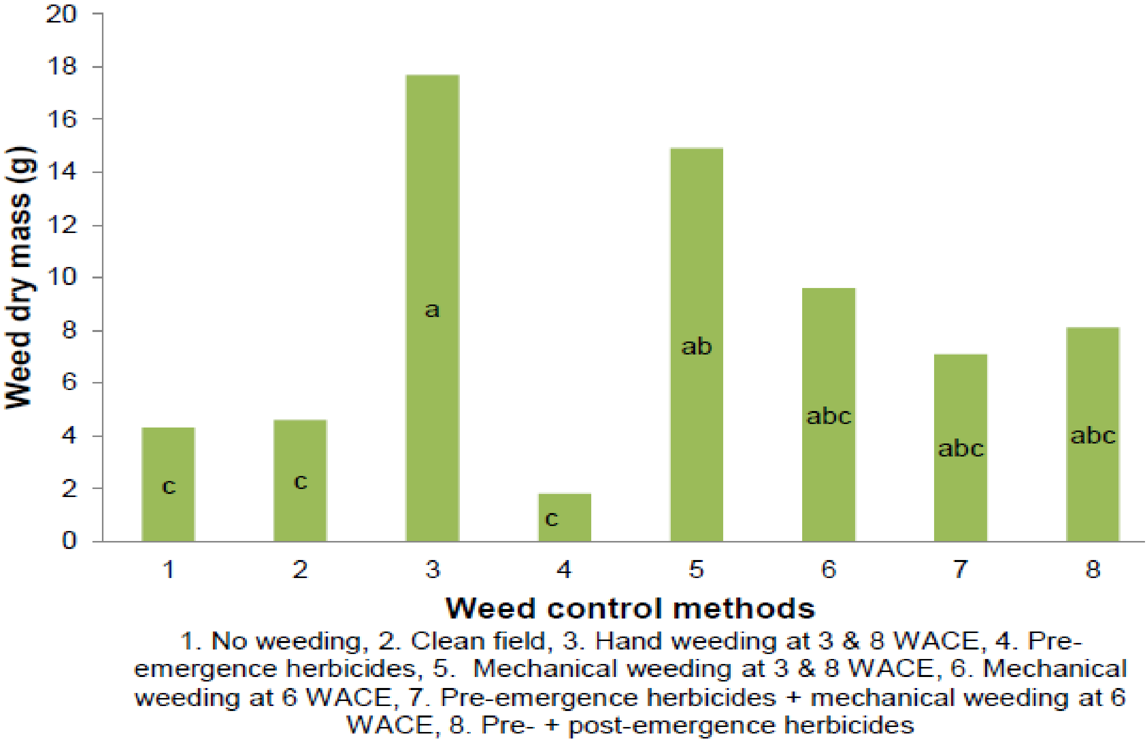

Figure 3.20 Inter-row dry mass of *Cyperus esculentus* in maize cultivars nine WACE at Mogopa in season 2. (Letters on each bar represent significant differences ($p \leq 0.05$))

3.3.1.4b Tigane

Three WACE inter-row dry masses for only *S. pinnata* and *T. terrestris* showed some significant differences. At nine WACE, significant differences were noted for only *D. ferox;* the rest of the weeds did not show any significant differences at the 5% significance level.

Use of pre-emergence herbicides proved to be an effective method in suppressing dry mass accumulation of *S. pinnata* in the inter-row spaces. Waiting until the third week of crop growth before weed control is carried out resulted in significant dry mass accumulation (Table 3.17).

Table 3.17 Inter-row dry mass of *Schkuhria pinnata* in maize three WACE at Tigane in season 2

Weed control method	**Dry mass** (g m^{-2})	
No weeding	0.35	ab
Clean field	0.27	b
Hand weeding at 3 & 8 WACE	0.47	ab
Pre-emergence herbicides only	0.17	b
Mechanical weeding at 3 & 8 WACE	1.15	a
Mechanical weeding at 6 WACE	0.37	ab
Pre-emergence herbicides + mechanical weeding at 6 WACE	0.17	b
Pre- + post-emergence herbicides	0	b
LSD	**0.87**	

NB. Different letters represent significant differences (p≤0.05)

T. terrestris dry mass was significantly higher (91%) in the conventional cultivar when compared to the stacked gene cultivar (9%) (Figure 3.21)

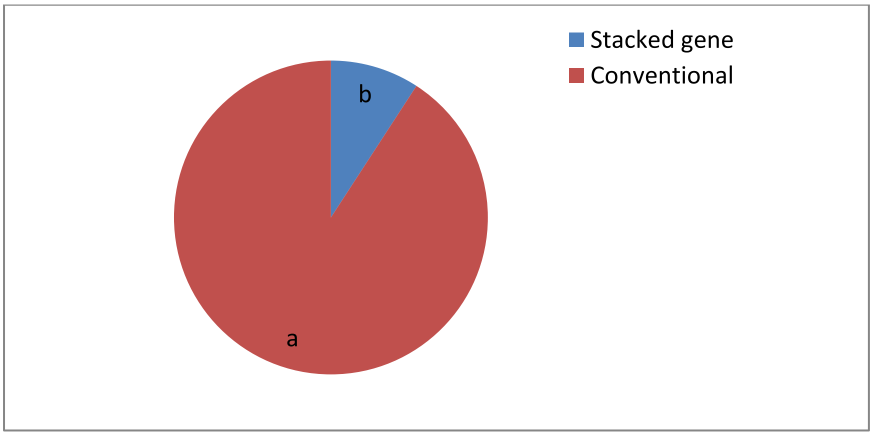

Figure 3.21 *Tribulus terrestris* inter-row dry mass three WACE at Tigane in season 2. (Different letters represent significant differences (p≤0.05))

Mechanical weeding at six WACE method had significantly higher *D. ferox* dry mass in the inter-row spaces, when compared to the clean field and pre- + post-emergence herbicides methods at nine WACE. The application of post-emergence herbicides resulted in significant differences in controlling dry mass accumulation of this weed (Figure 3.22).

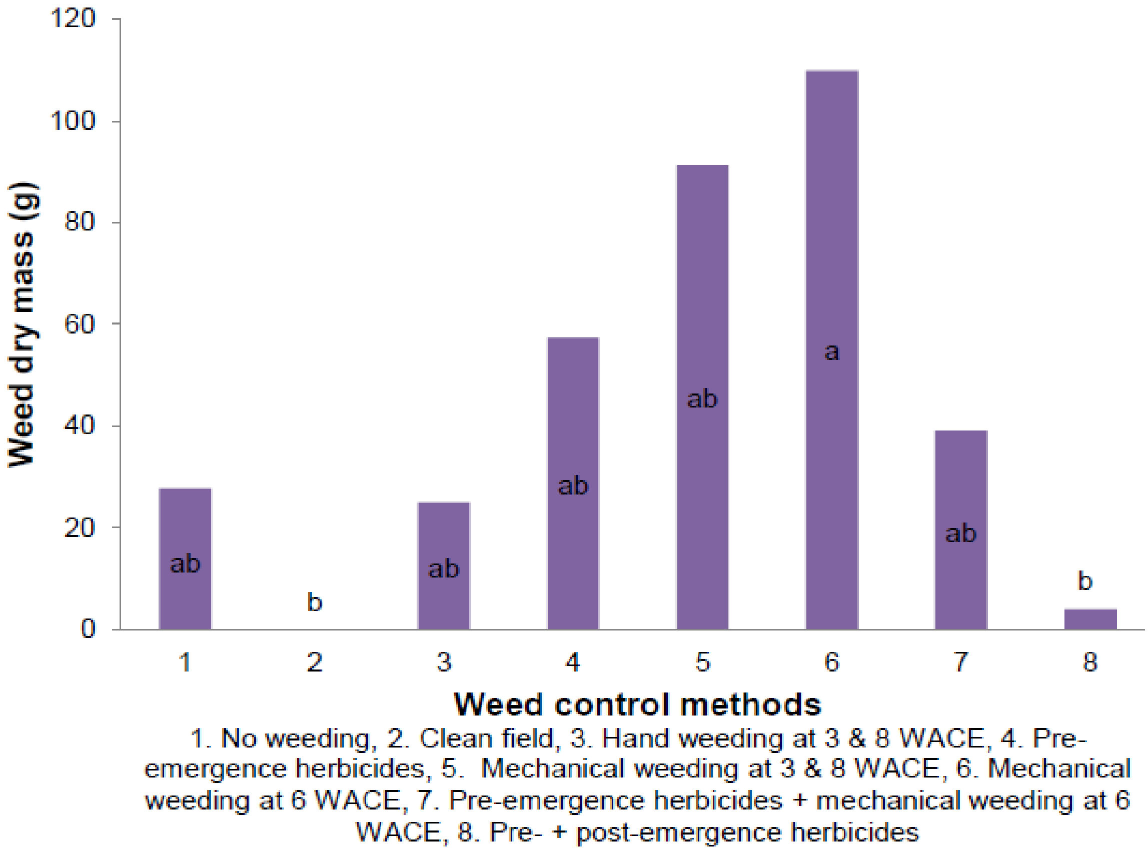

Figure 3.22 *Datura ferox* inter-row dry mass in maize cultivars nine WACE at Tigane in season 2. (Letters on each bar represent significant differences ($p \leq 0.05$))

3.3.2 Maize growth and development

In Mogopa significant differences were only noted on plant population at two WACE whilst plant height at two WACE, plant population and height at harvest did not show any significant differences. In Tigane none of these parameters showed any significant differences at $p \leq 5\%$.

Two WACE maize plant population at Mogopa, was significantly higher in the conventional variety than in the stacked gene cultivar (Table 3.18).

Table 3.18 Maize plant population two WACE at Mogopa in season 2

Cultivar	Plant population (ha^{-1})
Stacked gene	6 834 b
Conventional	10 302 a
LSD	**3 243.6**

NB. Different letters represent significant differences ($p \leq 0.05$)

3.3.3 Maize grain yield and yield parameters

3.3.3a. Mogopa

Significant interaction effects between cultivar and weeding methods were observed on maize grain yield. Only main effects were observed on five ears mass and no significant differences were recorded on 100 kernels mass.

The average mass of five ears was significantly higher in the stacked gene cultivar than the conventional cultivar (Table 3.19).

Table 3.19 Average mass of five maize ears of two cultivars at Mogopa in season 2

Cultivar	Average mass (g)
Stacked gene	0.53 a
Conventional	0.44 b
LSD	**0.06**

NB. Different letters represent significant difference ($p \leq 0.05$)

The clean field method had significantly higher average five ear mass than the no weeding and mechanical weeding at six WACE methods. The rest of the methods were not significantly different from each other (Table 3.20).

Table 3.20 Average mass of five maize ears of two cultivars subjected to eight weeding control methods at Mogopa in season 2

Weed control method	Average mass (g)	
No weeding	0.36	b
Clean field	0.71	a
Hand weeding at 3 & 8 WACE	0.56	ab
Pre-emergence herbicides only	0.39	ab
Mechanical weeding at 3 & 8 WACE	0.53	ab
Mechanical weeding at 6 WACE	0.32	b
Pre-emergence herbicides + mechanical weeding at 6 WACE	0.53	ab
Pre- + post-emergence herbicides	0.47	ab
LSD	**0.3156**	

NB. Different letters represent significant difference ($p \leq 0.05$)

The clean field and the pre- + post-emergence herbicides methods were outstanding in the stacked gene. This cultivar produced grain yields that were significantly higher (at least 53%) than the conventional cultivar where the two methods were used. Mechanical weeding at six WACE method produced the least yield in both varieties; however, the lowest yield for the stacked gene cultivar was 55% higher than the lowest yield of the conventional cultivar. Generally, the stacked gene cultivar had higher yields than the conventional cultivar across all weed control methods. Grain yields from other weeding methods that were relatively weedy were not significantly different from one another (Figure 3.23).

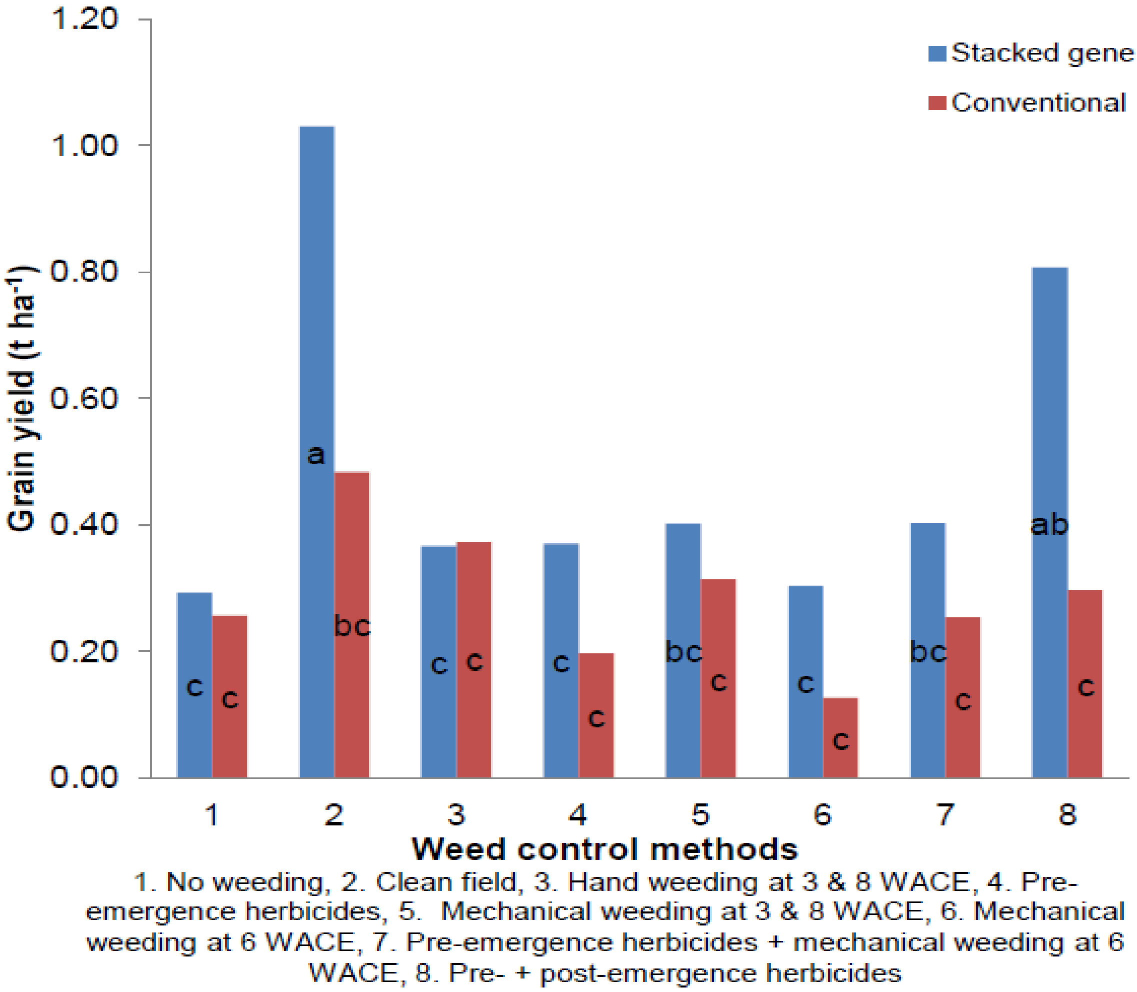

Figure 3.23 Maize grain yield of two cultivars subjected to different weed control methods at Mogopa in season 2. (Letters on each bar represent significant differences (p≤0.05))

3.3.3b Tigane

Significant differences were noted for grain yield, the average mass of five ears and the average mass of 100 kernels. Only the main effects of both factors were detected whilst interaction effects could not be detected.

The average mass of five ears of the stacked gene cultivar (0.55 g) was significantly higher than that of the conventional cultivar (0.44 g). The clean field method had a significantly higher average ear mass than the pre-emergence herbicides only as well as the mechanical weeding methods. Mechanical weeding at six WACE had the least ear mass (Table 3.21).

Table 3.21 Average mass of five maize ears at Tigane in season 2

Weed control method	Average mass (g)
No weeding	0.50 ab
Clean field	0.75 a
Hand weeding at 3 & 8 WACE	0.64 ab
Pre-emergence herbicides only	0.39 b
Mechanical weeding at 3 & 8 WACE	0.36 b
Mechanical weeding at 6 WACE	0.32 b
Pre-emergence herbicides + mechanical weeding at 6 WACE	0.42 ab
Pre- + post-emergence herbicides	0.58 ab
LSD	**0.35**

NB. Different letters represent significant differences ($p \leq 0.05$)

The stacked gene cultivar produced a significantly higher 100 kernels average mass of 29.3 g compared to 27.3 g obtained in the conventional cultivar. The clean field method had a significantly higher 100 kernels average mass when compared to no weeding, pre-emergence herbicides only, mechanical weeding at six WACE and pre-emergence herbicides + mechanical weeding at six WACE methods (Table 3.22).

Table 3.22 Mass of 100 maize kernels at Tigane in season 2

Weed control method	Mass (g)	
No weeding	26.9	b
Clean field	34.3	a
Hand weeding at 3 & 8 WACE	28.8	ab
Pre-emergence herbicides only	26.3	b
Mechanical weeding at 3 & 8 WACE	28.9	ab
Mechanical weeding at 6 WACE	24.9	b
Pre-emergence herbicides + mechanical weeding at 6 WACE	26.1	b
Pre- + post-emergence herbicides	30.2	ab
LSD	**6.86**	

NB. Different letters represent significant differences (p≤0.05)

The clean field method produced the highest yield that was significantly higher than the rest of the methods except for the hand weeding method at three and eight WACE. Mechanical weeding produced the lowest grain yield that was 78% and 76% lower than the highest and the second highest yielding methods respectively (Figure 3.24).

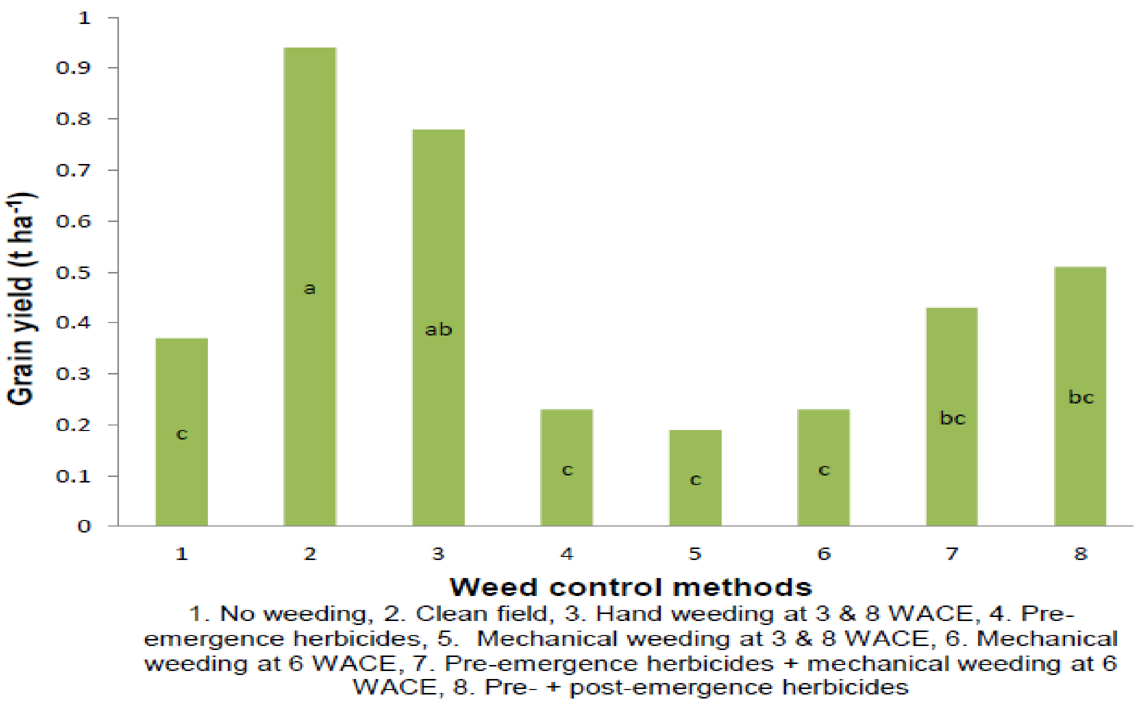

Figure 3.24 Grain yield of maize cultivars subjected to different weed control methods at Tigane in season 2. (Letters on each bar represent significant differences (p≤0.05))

3.3.4 Cost-benefit analysis

3.3.4.1 Partial budgeting

Partial budgeting indicated that, at Mogopa, keeping a clean field produces the highest yields, resulting in the highest gross field benefit whilst no weeding method produced the least yields and gross benefit in both the stacked gene and the conventional cultivar (Figure 3.25 a). The clean field method, however, had the highest total variable costs (Figure 3.25 b).

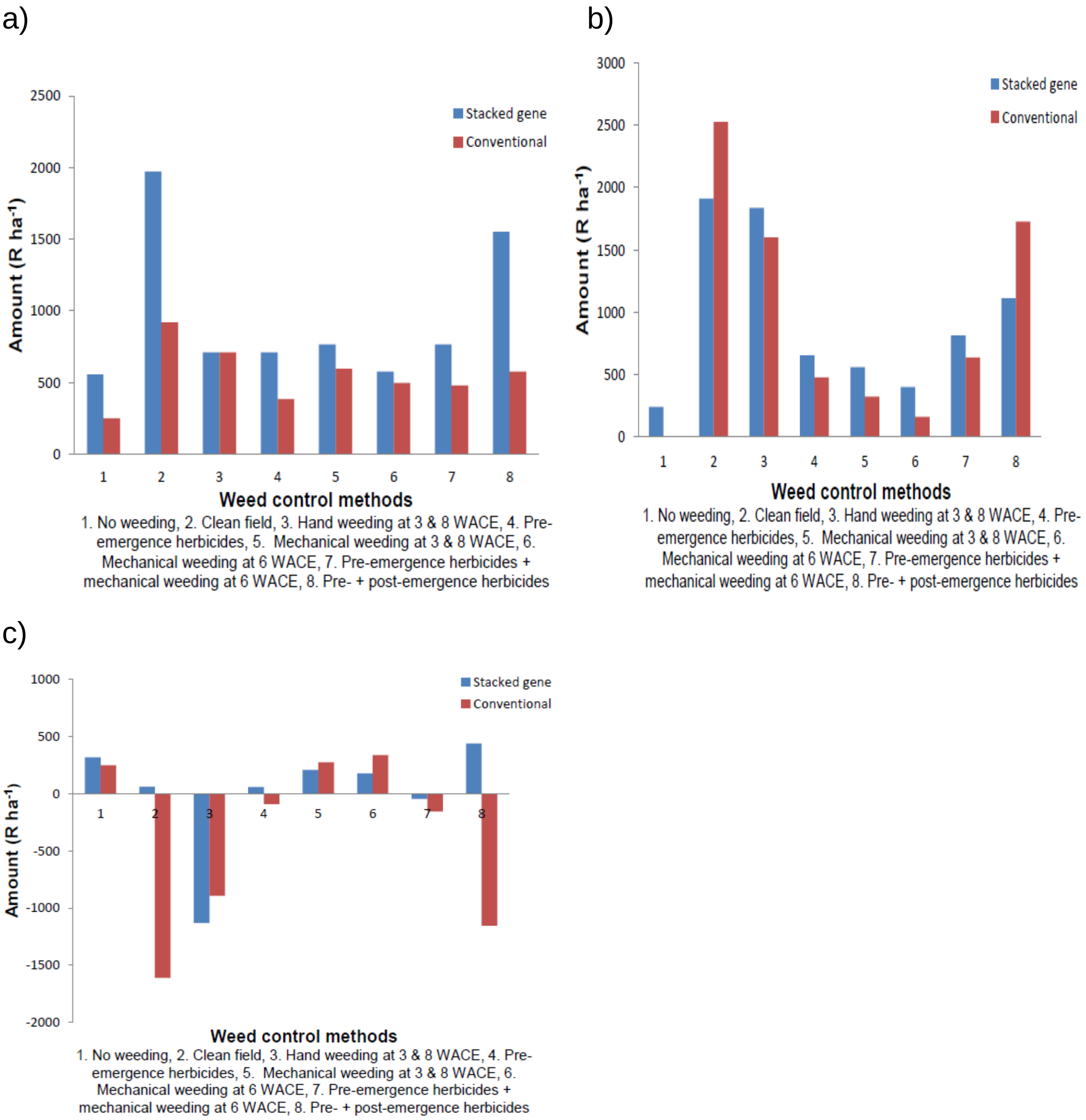

Figure 3.25 a) Gross benefits, b) costs that vary, and c) net benefits of two maize cultivars subjected to different weed control methods at Mogopa in season 2

In the stacked gene cultivar the highest net benefit (R 440 ha^{-1}) was obtained where pre-+post-emergence herbicides were used whilst lowest (-R 1 129 ha^{-1}) was found where hand weeding was used twice per season. In the conventional cultivar, the highest net benefit (R 338 ha^{-1}) was obtained where mechanical weeding at six WACE was used whilst the least (-R 1 609 ha^{-1}) was obtained where a clean field was maintained (Figure 3.25 c).

Partial budgeting at Tigane has shown that the clean field method and hand weeding twice at three and eight WACE method produced the highest gross benefit for the stacked gene and conventional cultivars respectively. The least gross benefit per ha was obtained where mechanical weeding was carried out at three and eight WACE for both cultivars (Figure 3.26 a). Keeping a clean field was the most costly method for both stacked gene and conventional cultivars at R 2 148 ha^{-1} and R 2 528 ha^{-1} respectively (Figure 3.26 b).

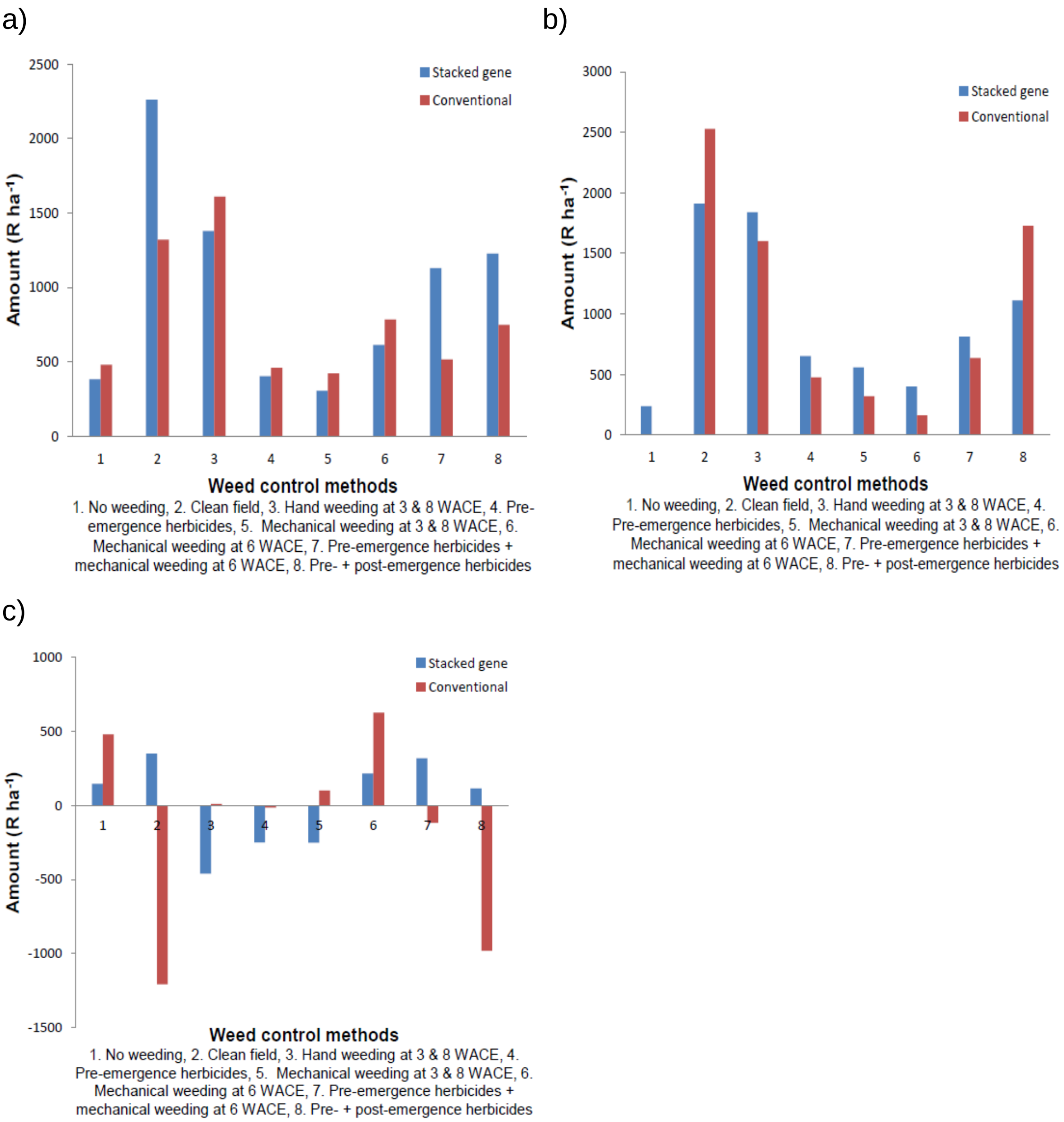

Figure 3.26 a) Gross benefits, b) costs that vary, and c) net benefits of two maize cultivars subjected to different weed control methods at Tigane in season 2

The clean field method produced the highest net benefit (R 349 ha^{-1}) for the stacked gene cultivar whilst in the conventional cultivar the highest net benefit (R 625 ha^{-1}) was obtained where mechanical weeding was carried out at six WACE. Keeping a clean field produced the least net benefit (-R 1 207 ha^{-1}) in the conventional cultivar and in the stacked gene hand weeding performed twice in the season produced the least net benefit (-R 459 ha^{-1}) (Figure 3.26 c).

3.3.4.2 Dominance analysis

At Mogopa, no weeding and pre- + post-emergence herbicides methods in the stacked gene cultivar and no weeding and mechanical weeding at six WACE methods in the conventional cultivar qualified for further consideration in the marginal analysis (Table 3.23).

Table 3.23 Dominance analysis of weed control methods on maize at Mogopa in season 2

Weed Control method	Cultivar	Costs that vary (R ha^{-1})	Net benefits (R ha^{-1})
No weeding	Stacked gene	238	317
Mechanical weeding @ 6 WACE	Stacked gene	398	177 D
Mechanical weeding @ 3 & 8 WACE	Stacked gene	558	208 D
Pre-emergence herbicides only	Stacked gene	652	57 D
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Stacked gene	812	-46 D
Pre- + post- emergence herbicides	Stacked gene	1111	440
Hand weeding @ 3 & 8 WACE	Stacked gene	1838	-1129 D
Clean field (no weeds allowed)	Stacked gene	1911	61 D
No weeding	Conventional	0	249
Mechanical weeding @ 6 WACE	Conventional	160	338
Mechanical weeding @ 3 & 8 WACE	Conventional	320	274 D
Pre-emergence herbicides only	Conventional	475	-92 D
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Conventional	635	-156 D
Mechanical weeding @ 3 & 8 WACE	Conventional	1600	274 D
Pre- + post- emergence herbicides	Conventional	1728	- 1153 D
Clean field (no weeds allowed)	Conventional	2528	-1609 D

KEY: D = dominated, weed control methods marked D are dominated by those above them in terms of net benefits hence they were disqualified for further analysis

At Tigane, no weeding, mechanical weeding at six WACE and pre-emergence herbicides + mechanical weeding at six WACE were the only viable methods found necessary to further consider for marginal analysis in the stacked gene cultivar. In the conventional cultivar only no weeding and mechanical weeding at six WACE qualified for further consideration. The rest of the methods were dominated by the no weeding method, hence they were disqualified from marginal analysis (Table 3.24).

Table 3.24 Dominance analysis of weed control methods on maize at Tigane in season 2

Weed Control method	Cultivar	Costs that vary (R ha^{-1})	Net benefits (R ha^{-1})
No weeding	Stacked gene	238	145
Mechanical weeding @ 6 WACE	Stacked gene	398	215
Mechanical weeding @ 3 & 8 WACE	Stacked gene	558	-252 D
Pre-emergence herbicides only	Stacked gene	652	-250 D
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Stacked gene	812	318
Pre- + post- emergence herbicides	Stacked gene	1111	115 D
Hand weeding @ 3 & 8 WACE	Stacked gene	1838	-459 D
Clean field (no weeds allowed)	Stacked gene	1911	349
No weeding	Conventional	0	479
Mechanical weeding @ 6 WACE	Conventional	160	625
Mechanical weeding @ 3 & 8 WACE	Conventional	320	101 D
Pre-emergence herbicides only	Conventional	475	-15 D
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Conventional	635	-118 D
Hand weeding @ 3 & 8 WACE	Conventional	1600	9 D
Pre- + post- emergence herbicides	Conventional	1728	-981 D
Clean field (no weeds allowed)	Conventional	2528	-1207 D

KEY: D = dominated, weed control methods marked D are dominated by those above them in terms of net benefits hence they were disqualified for further analysis

3.3.4.3 Marginal analysis

The marginal analysis revealed that in a difficult year like the 2013/14 season, farmers at Mogopa may expect to gain R 0.14 for every R 1 invested by changing from their preferred method of no weeding to the use of pre- + post-emergence herbicides in the stacked gene cultivar. In the conventional cultivar, farmers can expect a gain of R 0.56 for every R 1 invested by changing from no weeding to the use of mechanical weeding at six WACE (Table 3.25).

Table 3.25 Marginal analysis of weed control methods on maize at Mogopa in season 2

Weed control method	**Cultivar**	**Costs that vary** (R ha^{-1})	**Marginal costs** (R ha^{-1})	**Net Benefits** (R ha^{-1})	**Marginal net benefits** (R ha^{-1})	**Marginal rate of return**
No weeding	Stacked gene	238		317		
			873		123	14%
Pre- + post-emergence herbicides	Stacked gene	1111		440		
No weeding	Conventional	0		249		
			160		89	56%
Mechanical weeding @ 6 WACE	Conventional	160		338		

At Tigane, if a stacked gene cultivar is planted, then farmers can expect a gain of R 0.44 per R 1 invested by changing from no weeding to mechanical weeding at six WACE. However, changing from the no weeding method to mechanical weeding at six WACE will give farmers a gain of R 0.91 per R 1 invested if conventional cultivar is planted (Table 3.26).

Table 3.26 Marginal analysis of weed control methods on maize at Tigane in season 2

Weed control method	**Cultivar**	**Costs that vary** (R ha^{-1})	**Marginal costs** (R ha^{-1})	**Net Benefits** (R ha^{-1})	**Marginal net benefits** (R ha^{-1})	**Marginal rate of return**
No weeding	Stacked gene	238		145		
			160		70	44%
Mechanical weeding @ 6 WACE	Stacked gene	398		215		
			414		103	25%
Pre-emergence herbicides + Mechanical weeding @ 6 WACE	Stacked gene	812		318		
			1099		31	3%
Clean field	Stacked gene	1911		349		
No weeding	Conventional	0		479		
			160		146	91%
Mechanical weeding @ 6 WACE	Conventional	160		625		

CHAPTER 4

DISCUSSION

The most competitive weeds at Tigane were *C. dactylon, C. esculentus* and *D. ferox* whilst at Mogopa it was *C. dactylon, P. schinzii, C. esculentus* and *C. lanatus.* These weeds were present in large numbers and occurred very uniformly across the fields. Their presence made a vast difference in terms of crop performance, particularly where they were not controlled properly.

Herbicides used in combination with the stacked gene cultivar were more effective than those used with the conventional cultivar for controlling the most common weeds in the North West province (Figure 4.1).

Figure 4.1 Weed control efficiency of post-emergence herbicides in the maize stacked gene and conventional cultivars

Early weed control, like the application of pre-emergence herbicides, has been shown to be a very effective method in controlling some of the most competitive weeds like *C. esculentus.* At three WACE, *C. esculentus* was totally absent where pre-emergence herbicides were used, but was present and accumulated significant dry masses where weed control was delayed until three WACE. Weed pressure was not effectively reduced with the use of mechanical weed control methods throughout the season. This finding agrees with reports, which suggest that weed germination patterns result in the numerical superiority that weeds exhibit over crops

(Hasanuzzaman, 2009). Cohorts of weed seedlings emerged over an extended period of time from the time of initial emergence with crops (Vleeshouwers, 1997).

The conventional cultivar showed better establishment compared to the stacked gene cultivar which may be attributed to better germination abilities. However, this did not translate into better early crop growth and development as the two cultivars plant heights were not significantly different at three WACE. The stacked gene cultivar proved to be environmentally hardy as adverse conditions only reduced plant population by about 50% compared to about 60% observed in the conventional cultivar.

Weed competition, as already reported, has proved to negatively interfere with maize growth. As has been reported by Cerrudo *et al*. (2012) that continued weed competition results in a loss of yield parameters of kernel numbers and kernel mass, as well as grain yield. Ear and seed kernel mass were significantly lower where weeding was never done, resulting in the lowest grain yields being obtained. Yirefu *at al.* (2012) found that the final maize height was reduced by 12-18% by prolonging the duration of weed competition. This was also shown in the present study by the significantly lower maize heights observed at harvest where weed density was high especially where weeding was not carried out. This observation also concurs with the findings of Evans *et al.* (2003) and Rajcan and Swanton (2001) who reported that weed competition interfered with crop growth. This interference reduces biomass accumulation, resulting in poor crop development which eventually leads to poor yields. Crop losses of 55-90% in maize under unweeded conditions have been reported by Ishaya *et al.* (2008).

A report by Yirefu *et al*. (2012) indicated that, weed biomass increased with the decrease in the duration of the weed-free period and *vice versa,* which was supported by the findings of the present study. The significant suppression of weed dry mass (83 g m^{-2}) accumulation was achieved where concerted efforts were made to control weeds throughout the season, whilst not weeding allowed a significantly higher weed dry mass accumulation of 373 g m^{-2}.

A mid-season dry spell was experienced from three WACE to nine WACE. The drought in the second season impacted on grain yield, reducing it to a maximum of only 1 t ha^{-1} instead of the average 3 t ha^{-1} that is normally obtained when rainfall was sufficient and evenly distributed. Although rainfall improved towards the end of the growing season, grain yield did not increase significantly. This observation agrees with earlier research findings by Nissanka *et al.* (1997). They reported that, moisture stress causes damage to the photosynthetic apparatus, thereby reducing whole plant photosynthesis. Even though moisture stress occurred in the vegetative growth stages of the maize, it may result in reduced yields because of poorly developed root systems owing to the upset of the root/shoot ratio of dry matter accumulation (Rajcan and Swanton, 2001). Poor root development results in a reduced ability to absorb water even though it may be available during the reproductive stage of maize.

Generally, the stacked gene cultivar yielded better than the conventional cultivar, a trait that may be linked to improved hardiness to local environmental conditions; thus it probably has better inherent abilities to survive severe conditions. In a drier season, the environmental hardiness of the stacked gene cultivar to produce better yields than the conventional cultivar, was exhibited when weeds were effectively controlled. However, these inherent abilities to produce better yields can be rendered ineffective by weed competition. Weed competition seemed to cancel out the superiority of the stacked gene cultivar over the conventional cultivar in a season when rainfall distribution is severely erratic. The stacked gene cultivar managed to obtain yields that were more than 50% higher than that of the conventional cultivar where post-emergence herbicides were used and where weed control was effective. In the case of all the other methods that could not significantly suppress weed competition, their associated maize yields were also not significantly different.

Gouse *et al.* (2005) reported that a few years' data in South Africa about transgenic maize produced stable yields in scant rainfall seasons. These findings agree with a report by IFPRI (2009), in that researchers generally agree that transgenic plants increase yields even under difficult conditions. Pretty *et al.* (2011), reported that the use of new and improved technologies combined with changes to agronomic practices has increased crop yields by a factor of 2.13 on 12.8 million ha that they have reviewed. In the case of all the other methods that could not significantly suppress weed competition, their associated maize yields were also not significantly different.

The best weed control methods that produce the highest yields are not necessarily the most economic methods that provide the highest value for money invested in terms of net benefit or return on investment. This is because variable costs are not the same across different weed control methods. Hence the highest net benefits were not necessarily obtained from methods with the highest gross benefits. Post-emergence herbicide combinations used in the conventional variety in order to achieve meaningful results are costly. They may result in negative net returns if a farmer obtains grain yields of less than 1 t ha^{-1}, owing to other factors such as erratic rainfall. Keeping a clean field throughout the season is the best method to obtain higher yields, but not necessarily the best when economic factors are considered. It is so costly that in a season with below average rainfall like the 2013/14 season, it produced the worst negative net benefits in the conventional maize cultivars. Thus, it actually results in serious losses that may leave farmers bankrupt. The study has demonstrated that the use of herbicides could be much more expensive in the case of a conventional cultivar than for a stacked gene cultivar.

Hand weeding is also an effective weed management method in terms of preserving grain yield, but the method does not make any economic sense as it also produces negative net returns if grain yields are low. Mechanical weeding in terms of grain yields could not be seriously considered, but it was actually a promising method in terms of economic returns especially in a season characterized by low and erratic rainfall. The yields from mechanical weeding were not significantly different from the clean field method. This agrees with earlier findings of the critical duration of weed competition studies. The study concluded that weed control was unnecessary in the first few weeks after emergence of both crop and weed (Zimdahl, 1988). Liebman *et al*. (2001) reported that most field crops at emergence have a greater leaf area and larger root system than weeds, which give them greater initial absolute growth rates; hence a better competitive ability that lasts the first few weeks before the weeds turn the situation around.

No weeding as a practice that certain farmers are following proved to be better than some weed control methods in terms of net benefits because it has zero weeding costs. This has actually led to most methods being eliminated for further consideration by farmers as they only result in extra costs without extra benefits. Although the results of this study apparently vindicated the no weeding method on an economical basis, it should be noted that this is a highly risky practice, which logically and scientifically cannot be supported. There is an overwhelming body of literature proving that this method can lead to total crop failure under certain conditions like high weed pressure and severe drought. Mavudzi *et al.* (2001) reported that 21% of farmers abandon 20% of their crop each year in Zimbabwe owing to weed infestation. Benson (1982) reported an increased yield loss of 62% caused by applying fertilizer to weedy maize plots in a trial conducted in South Africa.

Informal surveys and observations made on the farmers falling in the targeted group of this study have revealed that, these farmers will only adopt new technologies if it produces sound financial gains for them. Acceptable gain should be at least 100% (R 1 per R 1 invested) for them to consider shifting to these new technologies. A 50% gain may be acceptable if the new technology or shift in their normal way of doing things only require a minor adjustment to their usual methods. However, major adjustments that require them to acquire new implements like boom sprayers for spraying herbicides and purchasing expensive transgenic seed rather than the cheap conventional cultivars seed require lucrative gains of more than 150% for them to adopt it. Benson (1982) suggested an improvement of several major infrastructure systems for the successful introduction of herbicides. This included the ability of the extension system to support emerging farmers to understand and adopt new technologies.

Controlling weeds using mechanical weeding at three and eight WACE, rather than not weeding in the first season, produced 130% return. However, changing to the sole use of herbicides in the stacked gene cultivar resulted in a higher return on investment of 260%. These findings were supported by Gouse *et al.* (2006), who reported increased profits in maize production since the inception of transgenic maize production in South Africa in 1998. In the case of the conventional variety, changing weed control methods from the no weeding to mechanical weeding once at six weeks, will provide farmers with a return of 164%. Although this method did not necessarily produce the highest net benefits, it had the highest marginal net benefits because the methods with the highest net benefits came with exorbitant variable costs.

In a drier year, if farmers at a place like Mogopa, put in weed control efforts, a profit of only R 0.14 (14%) could be realised for every R 1 invested if the stacked gene cultivars are used, whilst a gain of R 0.56 could be expected when the conventional varieties are planted. At Tigane, for every R 1 invested a profit of R 0.44 for the stacked gene cultivar and R 0.91 for the conventional cultivar was shown. This however, was in stark contrast to what was obtained in the first season when rainfall distribution was closer to the long-term average. Profit per R 1 invested was as high as R 2.60 and R 1.64 in the stacked gene and the conventional cultivars respectively. It is therefore less likely that emerging farmers will consider the latest maize weed control technologies in a year when erratic rainfall is forecast, because of unacceptably low economic gains for their efforts.

The 14% gain obtained in a drier season from the stacked gene cultivar that requires major shifts in the way emerging farmers are farming, falls far below the minimum expectation of 100% gain for farmers to consider it seriously. The conventional cultivar on the other hand requires that farmers use mechanical weeding at least once a season for them to gain a minimum of R 0.56 per every R 1 invested. This is a slight adjustment to the farmers' usual way of farming. Although some of them will have to buy cultivators, this seems to be more acceptable to them. A gain of R 0.56 per R 1 invested (56%) covers the farmers' expectation of at least 50% where they need to make minor changes in their farming practices.

Net benefits obtained from the conventional cultivar in the present study may be far higher than those that may accrue under conditions prevailing in a season that might have high weed and pest infestations. High insect pressure might result in farmers spending more money on pesticides purchases and pesticide applications, hence increasing costs that vary and effectively reduce net benefits for conventional cultivars. These kinds of efforts might not be necessary for a transgenic cultivar as it is bred to resist pests like stalk borer, thus effectively saving on pesticides. Chikoye *et al.* (2007), in Gianessi and Williams (2011), reported cost reductions of up to 50%, whilst Kibata *et al.* (2002) reported an increase in net benefits of 46% in maize through the use of new technologies.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Different weed control methods affect maize productivity with effective weed control resulting in higher grain yields whilst poor weed control results in severely reduced yields. Timing of weed control is very critical if profitable maize grain yields are to be attained. The leading competitive weeds at Tigane were *Cynodon dactylon, Cyperus esculentus* and *Datura ferox* whilst at Mogopa it was *Cynodon dactylon, Panicum schinzii, Cyperus esculentus* and *Citrullus lanatus.* The different weed control options available to farmers come at varying costs and care needs to be taken when choosing effective methods to reduce and even eliminate weed interference with the crop. Farmers should not only focus on obtaining high yields as this might come at high costs that can be avoided.

The best methods for suppressing weed pressure, although they may promise impressive crops yields, are not necessarily the best methods when it comes to returns on investment for farmers. Although keeping fields free of weeds for the whole season is ideal, because it offers the best opportunity for attaining maximum grain yield, the yield might not justify the high costs that come with it. Exorbitantly high costs actually result in serious losses that may drive farmers to bankruptcy if low yields are obtained owing to other factors like drought, which can decimate a crop irrespective of weed interference or not.

Use of tractor-driven mechanical weeding at least once in a season at six WACE seems to be promising, from both a practical and economic viewpoint for emerging farmers resettling on commercial farms, especially when conventional varieties are being planted. If herbicides are to be used to control weeds, then serious consideration must be given to planting a stacked gene cultivar rather than a conventional cultivar. Herbicides used in combination with the stacked gene cultivar were more effective and are cheaper per unit area than those used with the conventional cultivar for controlling the most common weeds. Hand weeding under commercial production does not look promising as sufficient labour is not readily available, takes long to complete and is too expensive.

The use of modern technologies such as the stacked gene cultivars like the one used in this study, can be a good drought mitigating tool because climate change impacts greatly on agricultural productivity. The stacked gene cultivar outperformed the conventional cultivar by at least 50% where weed control was effective, thus proving to be more tolerant to growth-limiting environmental conditions. In a drier year, weed control options need to be carefully weighed as these extra efforts may not bring about any meaningful change to maize productivity that can justify the returns. However, herbicides used in combination with the stacked gene cultivar can be cautiously recommended, although the economic returns thereof still need to be investigated further since this study produced unacceptably low returns on investment.

Use of modern technologies such as the stacked gene cultivars and use of herbicides however, still need to be continuously evaluated under the current crop production environment and cropping patterns of the emerging farmers. Integrated weed management methods need to be prioritised ahead of singular methods if weeds are to be managed efficiently, in order to achieve profitable maize production for the enhancement and development of especially emerging farmers resettling on commercial farms. Weeds need to be 'managed' rather than just 'controlled'.

The present study needs to be intensified, covering a wider geographical extent, to cater for variation that can be expected as a result of differences in climate, soil type and weed spectra. Hopefully this study can serve as a springboard for further investigations of this nature.

SUMMARY

Maize is an important crop for day-to-day livelihoods of most people in Africa. It dominates production of all field crops in Southern Africa. In South Africa, maize occupies approximately 67% of the total area committed to field crop production and contributes about 86% of the total production. Maize production is, however, under threat owing to a number of challenges; one of them being excessive weed competition. Weed competition is a major factor, reducing maize grain yields and farmers' income to a mere fraction of the true potential. This problem is serious, especially among emerging farmers that are resettled on commercial farms through the government land redistribution programmes. The government to date has transferred 5.7 million hectares of land to about 4.2 million emerging farmers. These farmers are typically resource poor and they lack the necessary skills to farm efficiently and profitably.

Many research studies have addressed the crop-weed competition issue and have helped to establish some of the thresholds and guidelines currently available. Establishing consistent thresholds or numbers of weeds that cause a specific yield reduction has been difficult to derive across many locations, years, and weather patterns. Furthermore, as tillage, planting and weed management practices have changed over the years, the former guidelines regarding crop/weed competition perhaps should be revisited; in some instances modified, as new findings are reported.

Most emerging farmers are obtaining grain yields of around 1 t ha^{-1} which is less than 50% of 3 t ha^{-1} that commercial farmers obtain. This is partly owing to limited success in weed control, probably as a result of a general lack of awareness of several aspects of weed interference. These farmers are aware that weeds reduce crop yields and although several weed control methods are available to them, often they either do not know the best method(s), or do not have the knowledge or financial means to apply them. The most problematic weed species also need to be singled out and their effects on maize yield quantified, before a carefully planned and integrated management system can be developed to efficiently and economically

control weeds from planting to harvest. Such studies have not yet been conducted to any meaningful extent under South African conditions.

There is, therefore, a need to appraise the suitability of a range of weed control techniques available to farmers, always considering variation in soils and cropping systems. Against this background an economic benefit analysis of the available weed control methods need to be carried out in order to justify the use of these methods so as to keep farming sustainable and economically viable.

Split-plot randomised block design was used with one stacked gene and one conventional maize cultivar planted in strips across eight weed control methods that included: hand weeding, mechanical, chemical (herbicides) and a combination of these methods. Weed species were counted and crop heights were recorded during different intervals of crop growth. Weed dry biomass was also determined. Grain yield and the yield components of ear mass and 100 kernels mass were recorded. A cost-benefit analysis of these weed control methods was carried out in the context of total production costs.

The current study has revealed that chemical weed control is more efficient and profitable when the stacked gene cultivars are used; a gain of R 2.60 for every R 1 invested can be expected. Using chemical weed control with the conventional cultivars may result in serious losses especially if rainfall is low and erratic. The best returns to investment of R 1.64 for every R 1 invested can, however, be realised if mechanical weeding methods are used when the conventional cultivars are planted.

Controlling weeds can result in 73% higher maize grain yields than no weeding if rainfall is sufficient and evenly distributed throughout the growing season. In a season with below average rainfall, the stacked gene cultivar has performed about 63% better than the conventional cultivar when weed control was efficiently performed. However, failure to control weeds efficiently results in the inherent ability of the stacked gene cultivar being rendered inefficient, resulting in the two cultivars producing more or less in the same manner. Integrated weed management methods need to be prioritised ahead of singular methods if weeds are to be managed efficiently, leaving maize production profitable for enhancement and development of especially emerging farmers resettling on commercial farms.

The present study needs to be intensified, covering a wider geographical extent, to cater for variation that can be expected as a result of differences in climate, soil type and weed spectra. Hopefully this study can serve as a springboard for more investigations of this nature.

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ANNEXURE A

TABLES OF RESULTS AND COST-BENEFIT ANALYSIS

Table A1 Effects of different weed control methods on weed growth and maize cultivar development, yield parameters and grain yield at Mogopa in season 1

Weed Control methods	Weed density at 3 WACE (plants m^{-2})	Weed density at 8 WACE (plants m^{-2})	Weed dry mass at 8 WACE (g)	Days to 50% tasseling	Plant population at harvest	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
1. No weeding	80	115 a	373 a	57	105	115 b	556	225 b	0.8 b
2. Clean field	71	28 b	83 b	54	112	190 a	654	275 ab	2.3 a
3. Hand weeding @ 3 & 8 WACE	74	62 ab	95 b	55	114	187 a	866	283 a	2.0 ab
4. Pre-emergence herbicides	70	84 ab	305 ab	55	94	170 ab	678	242 ab	1.1 b
5. Mechanical @ 3 & 8 WACE	72	47 ab	227 ab	52	109	201 a	702	250 ab	1.5 ab
6. Mechanical weeding @ 6 WACE	88	62 ab	250 ab	57	101	150 ab	633	242 ab	1.2 ab
7. Pre-emergence herbicides + Mechanical weeding @ 6 WACE	91	36 b	204 ab	52	118	196 a	674	258 ab	1.5 ab
8. Pre- + post-emergence herbicides	60	40 b	157 ab	55	113	184 a	798	283 a	2.4 a
LSD	**ns**	**72**	**260**	**ns**	**ns**	**59**	**ns**	**55**	**1.2**

Table A2 Weed growth and maize cultivars development, yield parameters and grain yield response to different weed control methods at Mogopa in season 1

Cultivar	Weed density at 3 WACE (plants m^{-2})	Weed density at 8 WACE (plants m^{-2})	Weed dry mass at 8 WACE (g)	Days to 50% tasseling	Plant population at harvest	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
Conventional	73	55	209	55	114	174	727	256	1.7
Stacked gene	79	63	214	55	103	174	664	258	1.5
LSD	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**Ns**	**ns**

Table A3 Weed growth and maize cultivars development, yield parameters and grain yield response to different weed control methods at Tigane in season 1

Cultivar	Weed density at 3 WACE (plants m^{-2})	Weed density at 8 WACE (plants m^{-2})	Weed dry mass at 8 WACE (g)	Days to 50% tasseling	Plant population at harvest	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
Conventional	72	57	295	55	127 a	173	767	251	1.5
Stacked gene	75	59	306	55	103 b	171	785	247	1.4
LSD	**ns**	**ns**	**ns**	**ns**	**17**	**ns**	**ns**	**Ns**	**ns**

Table A4 Effects of different weed control methods on weed growth and maize cultivar development, yield parameters and grain yield at Tigane in season 1

Weed Control methods	Weed density at 3 WACE (plants m^{-2})	Weed density at 8 WACE (plants m^{-2})	Weed dry mass at 8 WACE (g)	Days to 50% tasseling	Plant population at harvest	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
1. No weeding	119 a	104	536	61 a	103	155	529 c	220	1.3
2. Clean field	69 ab	36	98	51 b	121	183	918 a	270	1.4
3. Hand weeding @ 3 & 8 WACE	56 b	26	146	50 b	120	185	893 ab	278	1.1
4. Pre-emergence herbicides	74 ab	72	443	54 ab	100	169	884 ab	237	1.3
5. Mechanical @ 3 & 8 WACE	63 ab	33	207	57 ab	116	178	727 abc	245	1.5
6. Mechanical weeding @ 6 WACE	97 ab	40	365	61 a	98	138	600 bc	237	1.4
7. Pre-emergence herbicides + Mechanical weeding @ 6 WACE	52 b	55	406	56 ab	139	191	809 abc	253	2.2
8. Pre- + post-emergence herbicides	59 b	96	206	51 b	126	178	855 ab	278	1.5
LSD	**57**	**ns**	**ns**	**9**	**ns**	**ns**	**303**	**ns**	**ns**

Table A5 Effects of different weed control methods on maize cultivar growth, development, yield and yield parameters at Mogopa in season 2

Weed Control methods	Plant population at 3 WACE	Plant population at harvest	Plant height at 3 WACE (cm)	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
1. No weeding	81	38	26	119	0.36 b	26.9	0.28 bc
2. Clean field	98	47	23	140	0.71 a	31.7	0.76 a
3. Hand weeding @ 3 & 8 WACE	90	38	24	141	0.56 ab	29	0.37 bc
4. Pre-emergence herbicides	90	40	26	124	0.39 ab	28.6	0.28 bc
5. Mechanical @ 3 & 8 WACE	86	36	27	133	0.53 ab	30.6	0.36 bc
6. Mechanical weeding @ 6 WACE	88	34	26	119	0.32 b	28.9	0.22 c
7. Pre-emergence herbicides + Mechanical weeding @ 6 WACE	57	28	26	125	0.53 ab	30.1	0.33 bc
8. Pre- + post-emergence herbicides	81	36	25	130	0.47 ab	30.9	0.55 ab
LSD	**ns**	**ns**	**ns**	**ns**	**0.32**	**ns**	**0.31**

Table A6 Two maize cultivars growth, development and yield parameters at Mogopa in season 2

Weed Control methods	Plant population at 3 WACE	Plant population at harvest	Plant height at 3 WACE (cm)	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
Conventional	101 a	44	25	126	0.4 b	29	0.3 b
Stacked gene	67 b	31	25.7	132	0.5 a	30	0.5 a
LSD	**31.8**	**ns**	**ns**	**ns**	**0.06**	**ns**	**0.1**

Table A7 Two maize cultivars growth, development and yield parameters at Tigane in season 2

Weed Control methods	Plant population at 3 WACE	Plant population at harvest	Plant height at 3 WACE (cm)	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
Conventional	94	39	31.4	129	0.4 b	27 b	0.4
Stacked gene	61	26	31.8	150	0.6 a	29 a	0.5
LSD	**ns**	**ns**	**ns**	**ns**	**0.09**	**1.7**	**ns**

Table A8 Effects of different weed control methods on two maize cultivars growth, development, yield and yield parameters at Tigane in season 2

Weed Control methods	Plant population at 3 WACE	Plant population at harvest	Plant height at 3 WACE (cm)	Plant height at harvest (cm)	Average ear mass (g)	100 seed kernels mass (g)	Maize grain yield (t ha^{-1})
1. No weeding	78	27	32.8	136	0.50 ab	26.9 b	0.37 c
2. Clean field	77	32	32.2	149	0.75 a	34.3 a	0.94 a
3. Hand weeding @ 3 & 8 WACE	72	50	30.8	156	0.64 ab	28.8 ab	0.78 ab
4. Pre-emergence herbicides	81	29	30.3	141	0.39 b	26.3 b	0.23 c
5. Mechanical @ 3 & 8 WACE	73	26	31	140	0.36 b	28.9 ab	0.19 c
6. Mechanical weeding @ 6 WACE	80	29	32.2	132	0.32 b	24.9 b	0.23 c
7. Pre-emergence herbicides + Mechanical weeding @ 6 WACE	75	37	30.7	137	0.42 ab	26.1 b	0.43 bc
8. Pre- + post-emergence herbicides	85	31	32.7	127	0.58 ab	30.2 ab	0.51 bc
LSD	**ns**	**ns**	**ns**	**ns**	**0.35**	**6.86**	**0.36**

Table A9 Partial budget for different maize weed control methods at Mogopa in season 1

	Cultivar	WEEDING METHODS							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Average yield (t ha^{-1})	Stacked gene	0.83	2.13	1.88	1.01	1.84	1.01	0.94	2.39
Gross field benefits (R ha^{-1})	Stacked gene	1 868	4 793	4 230	2 273	4 140	2 273	2 115	5 378
Extra cost of seed (R ha^{-1})	Stacked gene	230	230	230	230	230	230	230	230
Cost of herbicides (R ha^{-1})	Stacked gene	0	834	0	354	0	0	354	594
Cost of applying herbicides (R ha^{-1})	Stacked gene	0	1 110	0	370	0	0	370	740
Cost of labour for hand weeding (R ha^{-1})	Stacked gene	0	0	1280	0	0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Stacked gene	0	0	0	0	990	495	495	0
Total costs that vary (R ha^{-1})	Stacked gene	230	2 174	1 510	954	1 220	725	1 449	1 564
Net Benefits (R ha^{-1})	Stacked gene	1 638	2 619	2 720	1 319	2 920	1 548	666	3 814
Average yield (t ha^{-1})	Conventional	0.87	2.55	2.06	1.12	1.23	1.45	2.02	2.35
Gross field benefits (R ha^{-1})	Conventional	1 958	5 738	4 635	2 520	2 768	3 263	4 545	5 288
Cost of herbicides (R ha^{-1})	Conventional	0	0	0	1 198	0	0	1 198	1 424
Cost of applying herbicides (R ha^{-1})	Conventional	0	0	0	370	0	0	370	740
Cost of labour for hand weeding (R ha^{-1})	Conventional	0	1 920	1280		0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Conventional	0	0	0	0	990	495	495	0
Total costs that vary (R ha^{-1})	Conventional	0	1 920	1 280	1 568	990	495	2 063	2 164
Net Benefits (R ha^{-1})	Conventional	1 958	3 818	3 355	952	1 778	2 768	2 482	3124

Table A10 Partial budget for different maize weed control methods at Tigane in season 1

	Cultivar	WEEDING METHODS							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Average yield (t ha^{-1})	Stacked gene	1.61	0.97	0.84	1.43	1.56	1.22	2.39	1.29
Gross field benefits (R ha^{-1})	Stacked gene	3 623	2 183	1 890	3 218	3 510	2 745	5 379	2 903
Extra cost of seed (R ha^{-1})	Stacked gene	230	230	230	230	230	230	230	230
Cost of herbicides (R ha^{-1})	Stacked gene	0	834	0	354	0	0	354	594
Cost of applying herbicides (R ha^{-1})	Stacked gene	0	1 110	0	370	0	0	370	740
Cost of labour for hand weeding (R ha^{-1})	Stacked gene	0	0	1280	0	0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Stacked gene	0	0	0	0	990	495	495	0
Total costs that vary (R ha^{-1})	Stacked gene	230	2 174	1 510	954	1 220	725	1 449	1 564
Net Benefits (R ha^{-1})	Stacked gene	3 393	9	380	2 264	2 290	2 020	3 930	1 339
Average yield (t ha^{-1})	Conventional	1.04	1.84	1.36	1.22	1.53	1.56	1.92	1.66
Gross field benefits (R ha^{-1})	Conventional	2 340	4 140	3 060	2 745	3 443	3 510	4 320	3 735
Cost of herbicides (R ha^{-1})	Conventional	0	0	0	1 198	0	0	1 198	1 424
Cost of applying herbicides (R ha^{-1})	Conventional	0	0	0	370	0	0	370	740
Cost of labour for hand weeding (R ha^{-1})	Conventional	0	1 920	1280		0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Conventional	0	0	0	0	990	495	495	0
Total costs that vary (R ha^{-1})	Conventional	0	1 920	1 280	1 568	990	495	2 063	2 164
Net Benefits (R ha^{-1})	Conventional	2 340	2 220	1 780	1 177	2 453	3 015	2 257	1 571

Table A11 Partial budget for different maize weed control methods at Mogopa in season 2

	Cultivar	WEEDING METHODS							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Average yield (t ha^{-1})	Stacked gene	0.29	1.03	0.37	0.37	0.40	0.30	0.40	0.81
Gross field benefits (R ha^{-1})	Stacked gene	555	1972	709	709	766	575	766	1551
Extra cost of seed (R ha^{-1})	Stacked gene	238	238	238	238	238	238	238	238
Cost of herbicides (R ha^{-1})	Stacked gene	0	633	0	294	0	0	294	633
Cost of applying herbicides (R ha^{-1})	Stacked gene	0	240	0	120	0	0	120	240
Cost of labour for hand weeding (R ha^{-1})	Stacked gene	0	800	1600	0	0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Stacked gene	0	0	0	0	320	160	160	0
Total costs that vary (R ha^{-1})	Stacked gene	238	1911	1838	652	558	398	812	1111
Net Benefits (R ha^{-1})	Stacked gene	317	61	-1129	57	208	177	-46	440
Average yield (t ha^{-1})	Conventional	0.13	0.48	0.37	0.20	0.31	0.26	0.25	0.30
Gross field benefits (R ha^{-1})	Conventional	249	919	709	383	594	498	479	575
Cost of herbicides (R ha^{-1})	Conventional	0	1488	0	355	0	0	355	1488
Cost of applying herbicides (R ha^{-1})	Conventional	0	240	0	120	0	0	120	240
Cost of labour for hand weeding (R ha^{-1})	Conventional	0	800	1600	0	0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Conventional	0	0	0	0	320	160	160	0
Total costs that vary (R ha^{-1})	Conventional	0	2528	1600	475	320	160	635	1728
Net Benefits (R ha^{-1})	Conventional	249	-1609	-891	-92	274	338	-156	-1153

Table A12 Partial budget for different maize weed control methods at Tigane in season 2

	Cultivar	WEEDING METHODS							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Average yield (t ha^{-1})	Stacked gene	0.20	1.18	0.72	0.21	0.16	0.32	0.59	0.64
Gross field benefits (R ha^{-1})	Stacked gene	383	2260	1379	402	306	613	1130	1226
Extra cost of seed (R ha^{-1})	Stacked gene	238	238	238	238	238	238	238	238
Cost of herbicides (R ha^{-1})	Stacked gene	0	633	0	294	0	0	294	633
Cost of applying herbicides (R ha^{-1})	Stacked gene	0	240	0	120	0	0	120	240
Cost of labour for hand weeding (R ha^{-1})	Stacked gene	0	800	1600	0	0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Stacked gene	0	0	0	0	320	160	160	0
Total costs that vary (R ha^{-1})	Stacked gene	238	1911	1838	652	558	398	812	1111
Net Benefits (R ha^{-1})	Stacked gene	145	349	-459	-250	-252	215	318	115
Average yield (t ha^{-1})	Conventional	0.25	0.69	0.84	0.24	0.22	0.41	0.27	0.39
Gross field benefits (R ha^{-1})	Conventional	479	1321	1609	460	421	785	517	747
Cost of herbicides (R ha^{-1})	Conventional	0	1488	0	355	0	0	355	1488
Cost of applying herbicides (R ha^{-1})	Conventional	0	240	0	120	0	0	120	240
Cost of labour for hand weeding (R ha^{-1})	Conventional	0	800	1600	0	0	0	0	0
Cost of mechanical cultivation (R ha^{-1})	Conventional	0	0	0	0	320	160	160	0
Total costs that vary (R ha^{-1})	Conventional	0	2528	1600	475	320	160	635	1728
Net Benefits (R ha^{-1})	Conventional	479	-1207	9	-15	101	625	-118	-981

ANNEXURE B

ABBREVIATED ANOVA TABLES

Table B1. Maize grain yield and yield parameters at Mogopa in season 1

		Yield		5 Ear mass		100 Kernel mass	
Source	**DF**	**F-Value**	**P**	**F-Value**	**P**	**F-Value**	**P**
Cultivar	1	1.36	0.364	4.23	0.176	0.08	0.807
Weeding	7	5.4	0.004	1.39	0.285	3.79	0.016
Cult X Weed	7	3.1	0.034	1.35	0.297	0.86	0.562
C.V %		20.9		17.7		9.7	

Table B2. Weed and maize development at Mogopa in season 1

		Weed density 3 WACE		Weed density 8 WACE		Weed dry mass 8 WACE		Plant height 3 WACE		Plant height at harvest		Plant population 3 WACE		Plant population at harvest	
Source	**DF**	**F-Value**	**P**	**F-Value**	**P**	**F-Value**	**P**	**F-Value**	**P**	**F-Value**	**P**	**F-Value**	**P**	**F-Value**	**P**
Cultivar	1	0.56	0.531	0.85	0.455	0.17	0.720	2.85	0.233	0	0.981	8.76	0.098	14.31	0.063
Weeding	7	0.97	0.488	3.97	0.014	3.66	0.019	0.61	0.736	5.92	0.002	0.66	0.699	0.78	0.618
Cult X Weed	7	0.82	0.588	0.37	0.904	2.49	0.069	0.51	0.811	0.34	0.923	1.06	0.434	0.93	0.515
C.V %		18.5		68.4		28.3		8.3		8.3		11.1		11.7	

Table B3. Maize grain yield and yield parameters at Tigane in season 1

		Yield		5 Ear mass		100 Kernel mass	
Source	DF	F-Value	P	F-Value	P	F-Value	P
Cultivar	1	0.86	0.451	0.3	0.637	0.08	0.808
Weeding	7	1.49	0.249	5.7	0.003	2.49	0.069
Cult X Weed	7	1.12	0.404	0.34	0.919	0.86	0.562
C.V %		39.8		17.9		24.7	

Table B4. Weed and maize development at Tigane in season 1

		Weed density 3 WACE		Weed dry mass 8 WACE		Plant height 3 WACE		Plant height at harvest		Plant population 3 WACE		Plant population at harvest	
Source	DF	F-Value	P	F-Value	P	F-Value	P	F-Value	P	F-Value	P	F-Value	P
Cultivar	1	0.75	0.478	2.32	0.267	2.97	0.227	0.15	0.738	109.78	0.009	35.33	0.027
Weeding	7	4.06	0.012	2.92	0.052	1.13	0.399	1.82	0.162	0.7	0.671	0.98	0.482
Cult X Weed	7	0.49	0.825	3.86	0.015	2.28	0.090	0.95	0.504	0.25	0.963	0.24	0.969
C.V %		35.5		35.4		9.3		7.4		20.8		22.7	

Table B5. Maize grain yield, yield and vegetative growth parameters during season 2 at Mogopa

		Yield		5 Ear mass		100 Kernel mass		Plant population 2 WACE		Plant height 2 WACE		Plant population at harvest		Plant height at harvest	
Source	DF	F-Value	P	F-Value	P	F-Value	P	F-Value	P	F-Value	P	F-Value	P	F-Value	P
Cultivar	1	78.06	0.013	39.08	0.025	2.77	0.238	22.08	0.042	3.96	0.185	8.61	0.099	1.27	0.377
Weeding	7	8.11	0.001	4.03	0.013	0.8	0.602	0.53	0.796	0.72	0.658	0.85	0.566	1.17	0.377
Cult X weed	7	3.91	0.014	0.52	0.805	0.88	0.549	0.79	0.606	1.07	0.430	1.01	0.466	0.95	0.502
C.V %		32.7		27.5		15.1		43.8		14.2		37.7		20.9	

Table B6. Maize grain yield, yield and vegetative growth parameters during season 2 at Tigane

		Yield		5 Ear mass		100 Kernel mass		Plant population 2 WACE		Plant height 2 WACE		Plant population at harvest		Plant height at harvest	
Source	DF	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P
Cultivar	1	0.22	0.685	31.57	0.030	28.39	0.034	11.33	0.078	0.22	0.688	14.83	0.061	9.65	0.089
Weeding	7	14.65	0.001	4.64	0.007	4.75	0.006	0.58	0.765	0.69	0.678	1.67	0.195	0.85	0.564
Cult X weed	7	0.54	0.790	0.73	0.650	0.23	0.971	0.31	0.936	1.23	0.350	1.07	0.432	1.41	0.275
C.V %		28.4		35.4		13.8		38.4		8.7		42.5		12	

Table B7. Weed records at Mogopa 3 WACE in season 2

		***C. dactylon* Inter-row dry mass**		***C. lanatus* Inter-row dry mass**		***C. esculentus* Intra-row density**	
Source	DF	F-value	P	F-value	P	F-value	P
Cultivar	1	0.08	0.803	90.85	0.011	22.6	0.042
Weeding	7	0.27	0.956	0.85	0.565	4.85	0.006
Cult X weed	7	3.05	0.036	0.85	0.568	1.48	0.252
C.V %		66.7		19.5		10.4	

Table B8. Weed records at Mogopa 9 WACE in season 2

		***C. esculentus* Inter-row dry mass**		***C. rubella* Inter-row dry mass**		***C. rubella* Inter-row density**		***E. coracana* Intra-row dry mass**	
Source	DF	F-value	P	F-value	P	F-value	P	F-value	P
Cultivar	1	0.03	0.877	12.64	0.071	19.69	0.047	0.57	0.529
Weeding	7	4.34	0.009	7.8	0.001	6.69	0.001	3.25	0.029
Cult X weed	7	0.47	0.837	4.5	0.008	2.53	0.066	3.48	0.022
C.V %		15.5		13.1		19.7		10.5	

Table B9 a. Weed records at Tigane 3 WACE during season 2

		C. dactylon **Inter-row dry mass**		***T. terrestris*** **Inter-row dry mass**		***D. ferox*** **Intra-row dry mass**		***P. oleracea*** **Intra-row density**		***C. esculentus*** **Intra-row density**		***C. esculentus*** **Intra-row dry mass**		***C. dactylon*** **Intra-row density**		***S. pinnata*** **Inter-row dry mass**		***S. pinnata*** **Intra-row dry mass**	
Source	DF	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P
Cultivar	1	1.39	0.359	21.98	0.042	0.46	0.569	0.41	0.587	1.33	0.367	1.93	0.299	30.77	0.031	2.06	0.28	27.7	0.03
Weeding	7	2.83	0.046	0.51	0.813	3.3	0.027	5.94	0.002	1.32	0.310	2.66	0.056	0.91	0.523	4.03	0.01	1.35	0.30
Cult X weed	7	0.67	0.694	0.63	0.724	0.42	0.875	0.08	0.998	5.59	0.003	5.41	0.003	0.80	0.600	0.70	0.67	1.33	0.30
C.V %		51.2		74.6		63.1		33.2		61		64.1		52.5		62.4		64.8	

Table B10. Weed records at Tigane 9 WACE during season 2

		P. oleracea **Inter-row density**		***D. ferox*** **Inter-row density**		***D. ferox*** **Inter-row dry mass**		***D. ferox*** **Intra-row density**		***D. ferox*** **Intra-row dry mass**		***C. dactylon*** **Intra-row dry mass**	
Source	DF	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P	F-value	P
Cultivar	1	0.04	0.865	1.84	0.307	0.21	0.695	0.08	0.802	0	0.994	0.81	0.463
Weeding	7	3.76	0.016	3.35	0.025	4.38	0.009	3.67	0.018	3.96	0.013	3.09	0.034
Cult X weed	7	0.23	0.970	1.75	0.176	0.72	0.657	0.49	0.827	0.3	0.941	0.48	0.830
C.V %		39.2		48.0		46.1		93		41.5		40.9	