

Full Length Research Paper

# Chemical control of invasive *Psidium guajava* in Swaziland: A preliminary assessment of costs and efficacy

Anthony Borrel J.<sup>1,2</sup>, Leslie Brown R.<sup>1\*</sup> and Kerry Slater<sup>1</sup>

<sup>1</sup>Applied Behavioural Ecology and Ecosystem Research Unit, Department of Environmental Sciences, UNISA, P Bag X6, Florida, South Africa, 1710.

<sup>2</sup>Mlilwane Wildlife Sanctuary, P. O. Box 311, Malkerns M204, Swaziland.

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*Psidium guajava* (guava) is recognised as the third most important invasive alien plant species in the moist savanna biome of South Africa, Lesotho and Swaziland. The cost of initial clearing of alien plants reaches up to R3 000-00 per ha, therefore the application of correct control methods is essential for cost-effective reduction of the spread. The aim of this study was to test the cost effectiveness of applying various herbicides to guava in the Swaziland Sour Bushveld. Four plots were selected for standing plant treatments, five for cut stump treatments and two for controls. Within each of these plots, five sub-plots were randomly located and the number of plant stems, base diameter, maximum height, and crown diameter was recorded before application of the herbicides. Picloram, fluroxypyr, bromacil, tebuthiuron and imazapyr were used either alone or in combinations. Eleven months after herbicide application, the treated plants were measured again. Bromacil/tebuthiuron liquid soil application gave the best results in terms of cost (0.09 c/stem) for standing plant treatments. The picloram/fluroxypyr cut stump treatment (4.5% concentration) cost the least to apply (0.05 c/stem), and no resprouting was observed. Results from this study can be used as baseline figures for managers planning to control guava.

**Key words:** Alien plant control, herbicides, picloram, fluroxypyr, bromacil, tebuthiuron, imzapyr.

## INTRODUCTION

*Psidium guajava* (guava) is a crop plant introduced to South Africa from South America by early European settlers (Macdonald et al., 1986). Guava has been classified as a widespread and abundant invader plant in South Africa, Lesotho and Swaziland. It is well established in these areas and has a substantial negative impact on both natural ecosystems and agricultural areas (Nel et al., 2004). According to the Conservation of Agricultural Resources Act of 1983 (Act no 43, 1983), *P. guajava* is listed as a category 2 species, and is also listed as the third most important invasive alien plant species in the moist savanna biome after *Lantana camara* and *Chromolaena odorata* (Triffid weed) (Van Wilgen et al., 2008). Yet in contrast, it receives little research focus; in a woody invasive alien plant

bibliography database, guava only appears twice, as compared to 76 times for *Lantana* and 69 times for Triffid weed (Musil and Macdonald, 2007).

It is widely spread throughout Swaziland in almost all habitat types, occurring mostly in the upper and lower Middleveld in medium to high rainfall areas (650-1000 mm per annum) (Loffer and Loffer, 2005). The Agricultural Research Council's Institute for Soil, Climate and Water in South Africa was commissioned by the government of Swaziland to conduct a helicopter-based survey of selected invasive alien plants in Swaziland (June to September, 2009). The preliminary results of the survey indicated that the worst infestations of guava were in the frost-free areas of the Middleveld, and distribution was strongly correlated to areas of high human population density and old cultivated fields (A. Brown, pers. comm). Fast spread rates of guava are attributed to it being a nutritious fruit easily spread by humans and wildlife. Dispersal is also assisted through vegetative

\*Corresponding author. E-mail: [Slatek@unisa.ac.za](mailto:Slatek@unisa.ac.za).



Figure 1. Location of Mlilwane Wildlife Sanctuary in western Swaziland.

regeneration by suckering (Dean et al., 1986).

The costs of controlling alien woody plants are high, reaching up to R3 000-00 ha<sup>-1</sup> for initial clearing of dense infestations of sprouting species (Marais et al., 2004). This makes the application of the correct control methods essential for cost-effective reduction of the spread. The aim of this study was to test the various cost effectiveness of different type of control methods on *P. guajava*.

## MATERIALS AND METHODS

The study area was located in the southern section of Mlilwane Wildlife Sanctuary in the Upper Middleveld of Swaziland (Figure 1), which is classified as Swaziland Sour Bushveld (Mucina and Rutherford, 2006). The Upper Middleveld comprises tall grassland with scattered trees and shrubs at an altitude of 600-900 m above sea level. The mean annual temperature is 20°C, with a summer mean of 24°C in January and a winter mean of 15°C in July. The mean annual rainfall is 800-1000 mm (Loffer and Loffer, 2005). The soils in the lower part of the study area are of the Funebizo series (orange loam on soft pan), and in the upper area the Ingoje series (mottled sand loam to clay) (Murdoch, 1970).

### Experimental design

The study was conducted from August 2008 to July 2009. A total of

nine 0.5 ha plots were marked out in an area with uniform terrain and vegetation type (26°28'20"S; 31°11'22"E). The slope was an even 4.2% with a North-easterly aspect. A six metre gap was kept between the different plots.

Four of the plots were on the higher lying area and were selected for standing plant treatments utilising one as a control and three for treatments. The remaining five plots on the lower lying area were utilized for cut stump treatments, utilising one as a control and four for treatments. Within each of the nine plots, five 100 m<sup>2</sup> (5.6 m radius) circular sub-plots were randomly located and marked. Every guava plant in these sub-plots was labelled with a standard weather-resistant marker used to identify small trees in a nursery. The number of plant stems, base diameter, maximum height, and crown diameter of each plant was recorded. The base diameter was measured with a diameter tape as close to the ground as possible, whilst the height and crown diameter were measured with a rod marked in increments of centimetres. Herbicide applications were made and approximately eleven months later, the base diameter, height, and crown diameter of each plant was measured again.

Long-term rainfall records for the Malkerns Agricultural Research Station were obtained from the National Meteorological Services, Mbabane. Daily rainfall records were collected from a rain gauge, 1 km from the study site for the duration of the study. Additionally, four soil samples were taken from equidistant localities at different altitudes in the study area.

### Herbicide application

Treatments were divided into standing plant treatments and cut

**Table 1.** The mean measurements of four standing plant treatments, before and after application of herbicide.

Name of application	Number of plants	Mean number of stems/plant	August 2008			July 2009			Change (mm)		
			BD (mm)	H (cm)	W (cm)	BD (mm)	H (cm)	W (cm)	BD (mm)	H (cm)	W (cm)
Control	221	4.55	84.00 (±3.78)	103.46(±2.21)	80.99(±2.43)	99.47(±4.45)	156.30(±2.87)	91.17(±2.56)	15.47	52.84	10.18
Picloram/fluroxypyr foliar spray	130	3.95	95.60 (±7.05)	123.39(±3.91)	89.21(±4.10)	95.69(±7.15)	120.56(±3.87)	63.15(±3.32)	0.09	-2.82	-26.05
Tebuthiuron granular soil treatment	186	3.69	75.27(±4.82)	104.94(±2.52)	72.69(±2.62)	75.46(±4.79)	121.12(±3.08)	51.58(±2.10)	0.19	16.18	-21.12
Bromcil/Tebuthiuron liquid soil treatment	136	4.02	70.68(±4.06)	94.46(±2.18)	73.11(±3.23)	68.15(±3.95)	107.64(±2.66)	52.86(±2.52)	-2.52	13.18	-20.25

BD, Basal diameter; H, height; W, crown diameter.

stump treatments. The treatments were chosen after reading various literature sources (Vermeulen et al., 1996; Anonymous, 2005; South Africa Department of Agriculture, 2007) and discussions with Mr F. Jordan. One of the cut stump treatments (picloram/fluroxypyr) and one of the standing plant treatments (bromcil/tebuthiuron) are not recommended for the control of guava, but are herbicides commonly used to control other woody invasive plants.

#### **Standing plant treatments**

The following three treatments were applied to standing plants in August/September 2008:

1. Foliar spray, a systemic herbicide picloram: (Pyridine compound as tri-isopropanolamine salt), 80 g/l/fluroxypyr (Pyridine compound as methyl heptyl ester) and (trade name: Plenum 160 ME, Dow Agrosiences). Application to the plants was to the point of run-off at a 1.5% mixture with water. Application was with a standard knapsack sprayer with a solid cone nozzle. A recommended emulsifiable oil adjuvant (Mineral oil, 820 g/l, trade name: Actipron Super, Ecoguard Distributors) was added at a 1% mixture;
2. Soil-applied granular herbicide, tebuthiuron (urea), 200 g/kg (trade name: Limpopo 200 GG, Volcano Agrosience). One small scoop (2.2 g) of granules per stem was placed onto the soil in a scraped hollow at the base of each plant;
3. Soil-applied liquid concentrate, Bromacil (substituted

uracil), 250 g/l/tebuthiuron (urea compound), (trade name: Bundu SC, Volcano Agrosience) applied as 18% mixture with water. 2 ml per stem was applied with a syringe at the base of each plant.

#### **Cut stump treatment**

The following three treatments were applied to cut stumps during August/September 2008:

1. Systemic herbicide: picloram (Pyridine compound as tri-isopropanolamine salt), 80 g/l/Fluroxypyr (pyridine compound as methyl heptyl ester) and (trade name: Plenum 160 ME, Dow Agrosiences) applied at a 4.5% mixture with water, and with actipron added at a 0.5% mixture. This solution was applied with a 1.5 L hand-held pump to cover the cut surface of each stem immediately after it was cut;
2. The same herbicide and application method as above, but at a 2% herbicide mix;
3. Non-selective systemic herbicide, Imazapyr (Imidazolinone), 100 g/l (trade name: Hatchet, Volcano Agrosience). Application was at a 12.5% mix with water and applied with a 1.5 L hand-held pump to cover the cut surface of each stem immediately after it was cut. As each herbicide was applied, the following was recorded, the total labour hours used for each application, the amount of each herbicide used per treatment and the costs thereof. To test

if there were significant changes in the height, basal diameter or crown diameter of plants eleven months after herbicide treatment, and paired T-tests were conducted.

## **RESULTS**

### **Efficacy of treatments**

#### **Standing plant treatments**

The mean plant measurements before and after each standing plant treatment are shown in Table 1. Within the control plots, there was a statistically significant increase in the basal diameter ( $p = 0.000$ ,  $T = -11.74$ ), height ( $p = 0.000$ ,  $T = -32.75$ ), and the crown diameter ( $p = 0.000$ ;  $T = -6.23$ ) of the guava plants ( $n = 221$ ) during the study.

All the treatments yielded good results in reducing foliage volume (crown diameter) compared to the control. Crown diameter decreased significantly by 26.05 cm ( $p = 0.000$ ,  $T = 12.58$ ,  $n = 130$ ) using the picloram/fluroxypyr foliar spray, 21.12 cm ( $p = 0.000$ ,  $T = 16.43$ ,  $n = 186$ ) using the tebuthiuron granular soil treatment and 20.25 cm ( $p = 0.000$ ,  $T = 11.67$ ,  $n = 136$ ) using the

**Table 2.** Costs per hectare for each of the treatments used in this study. All costs are in South African rands (ZAR).

Application method, active ingredient, and concentration	A	B	C	D	E	F	G	H	I	
	Amount herbicide used (concentrate) per hectare	Cost per herbicide unit	Total cost herbicide (AxB)	Man hours	Labour costs @R3/h	Total cost (C+E)	Number of plants	Mean stems per plant	Total stems (GxH)	Total cost per stem (F/I)
<b>Standing plant treatments</b>										
Picloram/fluroxypyr foliar spray (1.5%) + Adjuvant (0.5%)	16.3 L 5.4 L Adjuvant	R 125/ L, R 35-45/ L	2229	31	93	2322	3215	3.8	12217	0.19
Tebuthiuron granular soil	24.3 Kg	R74-40/Kg	1808	165	495	2302	3588	3.6	12917	0.18
Bromacil/tebuthiuron liquid soil (18%)	4.3 L	R156-30/ L	672	75	225	897	2384	4.1	9774	0.09
<b>Cut stump treatments</b>										
Picloram/fluroxypyr (4.5%) + adjuvant (0.5%)	1.44 L 0.166 L Adjuvant	R125/ L, Adjuvant: R35-45/ L	186	52	156	342	1952	3.8	7418	0.05
Picloram/fluroxypyr (2%) + adjuvant (0.5%)	0.69 L 0.174 L Adjuvant	R125 / L, R35-45/ L	92	69	207	299	1024	4.0	4096	0.07
Imazapyr (12.5%)	5.02 L	R137-51/ L	690	96	288	978	3146	3.7	11640	0.08

bromacil/tebuthiuron liquid soil treatment (Table 1).

After application with the picloram/fluroxypyr foliar spray, a decrease in the height (2.82 cm;  $p = 0.003$ ,  $T = 3.06$ ,  $n = 130$ ) was observed. Although increase in height of the plants treated with the tebuthiuron granular soil treatment (16.18 cm;  $p = 0.000$ ,  $T = -10.70$ ,  $n = 186$ ) and the bromacil/tebuthiuron liquid soil treatment (13.18 cm;  $p = 0.000$ ,  $T = -10.41$ ,  $n = 136$ ) were observed, they were less than that of the increase observed in the control plants. The bromacil/tebuthiuron liquid soil treatment was the only treatment that had a reduction in mean basal diameter (-2.52 mm;  $p = 0.005$ ,  $T = 3.57$ ,  $n = 136$ ), whereas the other two treatments had insignificant increase in the basal diameter.

Of the three standing plant treatments, the picloram/fluroxypyr foliar spray was the most effective in short-term biomass reduction (greatest reduction in crown diameter and the only reduction in height).

#### **Cut stump treatments**

The mean height growth of the plants in the cut stump control plot during the one year study was 73 cm. With the exception of the plots that were treated with the reduced picloram/fluroxypyr (2%) application, no re-sprouting of guava plants in the treatment plots was observed. However, the re-growth in the 2% application plot at the end of the study was very low and all sprouts observed were

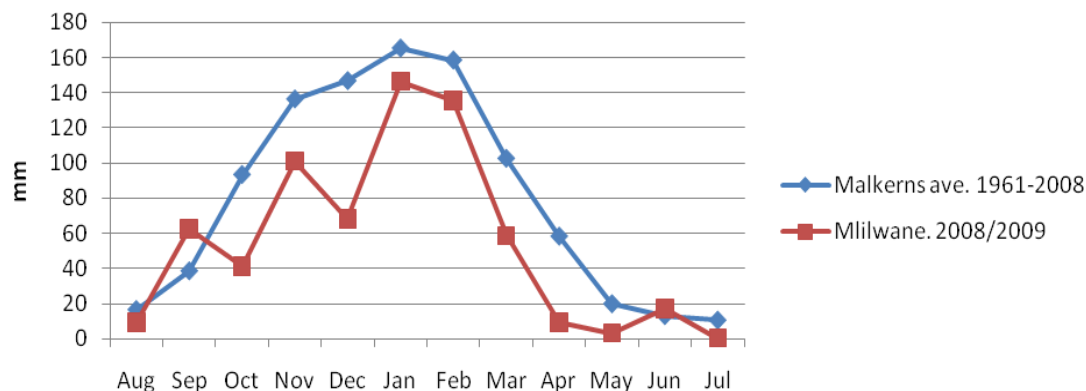
below the height of the cut stump. Furthermore, the highest re-growth in this plot was observed to be in the lowest lying area nearest to a drainage line.

#### **Costs of treatments**

Table 2 provides a summary of the costs of all the applications used in this study.

#### **Standing plant treatments**

Within the standing plant treatments, the picloram/fluroxypyr foliar spray and Tebuthiuron granular soil treatments were the most costly



**Figure 2.** Comparison of monthly rainfall totals during study period against long-term monthly means.

**Table 3.** Soil analysis for the study area: from the highest altitude (A) to the lowest altitude (D).

Characteristic	Altitude			
	A	B	C	D
pH	5.05	4.60	4.55	4.85
Clay (%)	32	35	49	42
Silt (%)	11	18	15	7
Sand (%)	57	47	36	51
Organic material as Carbon (%)	1.26	0.60	1.02	1.05
Texture Class (Macvicar and de Villiers, 1991)	Sandy clay loam	Sandy clay loam	Clay	Sandy clay
Soil series <sup>9</sup>	Funbizo orange loam	Funbizo orange loam	Ingoje mottled sand, loam to clay	Ingoje, mottled sand, loam to clay

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treatments (0.19 c/stem and 0.18 c/stem, respectively), while the liquid soil treatment was the lowest costing standing plant treatment at 0.09 c /stem. This was due to the low herbicide volumes needed (4.3 l/ha) and relatively low man hours (75 h/ha) of the liquid soil treatment in comparison to the very high chemical costs of the foliar and (R2 229–00 per hectare) granular soil (R1 808–00 per hectare) treatment. The granular soil standing plant treatment involved the most man hours (165 h/ha) whereas the foliar treatment had the lowest number of man hours (31 h/ha) for all standing plant.

### Cut stump treatments

The overall costs of the cut stump treatments ranged from 0.05 to 0.08 c/stem therefore, being lower than any of the standing plant treatments which ranged from 0.09 to 0.19 c/stem.

### Rainfall amount and soil conditions

Monthly rainfall totals during the study period were lower

than the means for the area during the period 1961-2008 (Figure 2). The period just after treatment applications (September, 2008) was the only recording where the monthly total was higher than the long-term mean. The mean total annual rainfall at Malkerns for the period 1961-2008 was 959 mm, and the total annual rainfall at Mlilwane for the period 2008-2009 was only 654 mm. Results of the soil analysis (Table 3) show very acidic soils (mean pH: 4.76, SD: 0.20) and the percentage of clay ranging from 32 to 42%, being highest in the samples from the lowest lying areas within the study area.

## DISCUSSION

### Standing plant treatments

The rapid biomass reduction abilities and low labour costs of the picloram/fluroxypyr foliar spray application are evident (Table 1), but are offset by the high herbicide costs and water requirements in this study. The familiarity/availability of the equipment to land managers in African countries make the knapsack sprayer a

common choice for alien plant control, yet the non-use/unavailability of safety masks make it a risky method (Nielson et al., 2005). It was noticed that a patch of plants was missed by the sprayers, which did not happen with the two soil-applied treatments. This was because the soil-applied granules and soil-applied suspension were brightly coloured, making it more difficult to miss plants. The solution to this would be to add any one of the compatible dyes produced locally to the foliar application mixtures. The tebuthiuron soil-applied granules cost (0.18 c/stem) almost the same as the picloram/fluroxypyr foliar spray to apply (0.19 c/stem), but had the advantage of needing no water to be transported to the site, no mixing to be done, and presented no drift hazard (Bovey, 1971).

Soil-treatment methods have the advantage of being applied in any weather conditions, whereas foliar spray efficacy is influenced by wind speed and direction, occurrence of rain after application, light intensity (stomata opening) and humidity (Trollope et al., 1989). The soil-applied treatment can be more selectively applied to individual plants than the foliar application, but there is the possibility of the roots of nearby plants that extend beyond their canopy being affected (Smit et al., 1999). However in this study, this was not observed/applicable since the natural vegetation has mostly been displaced by the guava trees. Granular soil treatments do not need high rainfall amounts to be effective, as they are released slowly into the soil, and can remain effective in the soil for up to four years (Trollope et al., 1989).

The average rainfall during the study period (Figure 2) and the initial effectiveness of the granular application confirms this, but the plots and rainfall amounts should be monitored for several years. During application of tebuthiuron pellets to control invasive bush in Texas, it was found that desirable grass standing crops and crude protein concentrations of the grasses were significantly increased one, two and three years after treatment (Scifres and Mutz, 1978; Masters and Scifres, 1984). In the same studies, botanical composition was also altered by tebuthiuron granule application. Research is needed on this aspect under local conditions.

### Cut stump treatments

The cut stump treatments all yielded very good results with almost 100% die off observed. The only cut stump treatment where re-sprouting was observed was for the 2% concentrate picloram/fluroxypyr treatment, but even plants given this treatment did not show a marked increase in height. Using a reduced concentration (2%) of picloram/fluroxypyr did not reduce the total costs per stem in this study (2% concentration: 0.06 c/stem, 4.5% concentration: 0.05 c/stem). This suggests that reducing cut stump herbicide concentrations are not worth the risk of reduced herbicide efficacy in the search for reducing overall costs. The low application costs (0.05 to 0.08

c/stem) of the cut stump treatments could be further reduced with experimental use of a shear that simultaneously cuts and apply a dose of herbicide to the cut surface (Wahlers et al., 1997).

### Soil conditions and herbicide use

Organic matter content, clay content and pH levels are the soil factors that most influence herbicide adsorption, activity and efficacy (Blumhorst et al., 1990). Less herbicide is available to plants at lower pH levels, higher organic matter content (Stougaard et al., 1990), and higher clay content of the soil (Blumhorst et al., 1990). The herbicides were effective despite the highly acidic soils in the area of this study (Table 3). The clay contents of the soils in this study site were also higher than the recommended <20% clay for cost-effective herbicide use (Trollope et al., 1989). The effective soil applied treatments in soils with clay content between 40 and 49% (Table 3) contradict other studies (Trollope et al., 1989) which suggest that soil applied herbicides are ineffective in soils with clay contents exceeding 35%. The cut stump application of a reduced picloram/fluroxypyr rate (2%) showed more observed re-growth at the lower end of the plot where the proximity to a drainage line corresponded with increasing clay contents. This observation is in agreement with another study (Zhang et al., 2000) which found that, applying lower than recommended rates is only advisable in coarse-textured soils. The high cost of accurate soil analyses and the self-funded nature of this study prevented further investigation of the relationship between soil conditions and herbicide efficacy on guava.

### Conclusions

Although the picloram/fluroxypyr foliar spray performed the best within the standing plant treatments in terms of foliar reduction, the two soil-applied herbicides were more precise, carried less risk, and were easier to apply than the foliar treatment. The liquid soil application yielded the best results in terms of a combination of cost and foliar reduction. This study shows results after only one growing season, yet the effects of most of the herbicides are slow acting; the herbicide labels suggesting that plants may take up to 24 months to die, and second applications may be necessary depending on the species targeted, soil type, and rainfall. Therefore, continued monitoring of the experiments are particularly important for the soil-applied applications, and the applications used in this study that have not been tested extensively on guava. Also due to the labour/supervision factor playing a role in total costs, this experiment would have to be repeated to achieve more representative costing data. The total costs of individual plant application methods have been reduced with the use of an all-terrain

vehicle (4-wheeler) carrying a tank of herbicide and distributing the herbicide to several operators via a 12 V pump (McGinty and Uekert, 2001).

All the herbicides used in this study were very effective in the short-term in causing desiccation of the foliage in the standing plant treatments (mostly within two weeks of application), and the cut stump treatments (no re-sprouting except in the 2% concentration). This is in contrast to the control of guava in the past, where it was considered an excellent test species for herbicide control because it was resistant to most herbicides (Tschirley et al., 1967). Cut stump treatments had several advantages over standing plant treatments: they were less costly to apply, had immediate aesthetic effect and potentially exposed non-target species to less risk. Soil-applied herbicides have been suggested as being the cheapest method of the chemical applications (Smit et al., 1999), yet the results of this study suggest that cut stump treatments are less costly.

The influence of soil properties on the efficacy of herbicides and the possibilities of reducing costs with lower application concentrations needs further investigation. The economic benefits of completing accurate soil maps with a high number of soil samples for target areas would make the effort worthwhile for planning purposes.

It is suggested that the management of Mlilwane Wildlife Sanctuary protect the plots from fire, and that the plots used in this study and climate are monitored for the next two or three years.

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