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Implications of Weed Control Methods on *Sandanezwe* (*Chromolaena odorata*) in Swaziland

[1]Ekpo Ossom, [2]Bheka Lupupa, [3]Sazi Mhlongo and [3]Luyanda Khumalo

[1]Department of Crop Production, Faculty of Agriculture,
University of Swaziland, Private Bag Luyengo, Luyengo M205, Swaziland
[2]Nkhalashane Sisa Ranch, Ministry of Agriculture and Cooperatives, Mbabane, Swaziland
[3]Range Management Division, Ministry of Agriculture and Cooperatives, Mbabane, Swaziland

Abstract: The most disruptive invasive weed in Swaziland is *Sandanezwe* (*Chromolaena odorata*). Information is lacking on how to control *Sandanezwe* in Swaziland. Therefore, a field experiment was conducted to determine the effectiveness of different control methods and assess the environmental impact associated with them. Results showed that controlled burning was the most effective control method (weed score mean, 2.6 out of 6.0); manual slashing was the least effective method (weed score mean, 4.9 out of 6.0), with slashing resulting in weed regeneration, because of the removal of apical dominance. Of the two herbicides investigated, Roundup was more effective (weed score, 3.3 out of 6.0) than Chopper (weed score, 4.2 out of 6.0). The lowest labor requirement (2.4 man-days) was from Chopper herbicide; the highest labor requirement (9.5 man-days) was attained by digging up and drying *Sandanezwe*. There was no significant difference between the labor requirements of the two herbicides. It is recommended that controlled burning be used to control *Sandanezwe*, but where technical knowledge is no hindrance, a combination of manual slashing and spraying with Roundup be adopted.

Key words: Weed control · *Chromolaena odorata* · *Sandanezwe* · weed management · invasive species

INTRODUCTION

An invasive plant species has been defined [1] as any species that is likely to spread into native flora or managed plant systems, develops a self-sustaining population and becomes dominant or disruptive to those native systems. Invasive species are also known as weeds - plants that are objectionable or interfere with the activities and welfare of humans [2]. There are about 340 invasive plant species that are listed in Swaziland's alien plants database [3]. In 2006, the University of Swaziland (UNISWA) organized a workshop on "*Sandanezwe*, The Menace," where four of the most problematic invasive species in Swaziland were identified as *Chromolaena odorata* (L.) R.M. King and H.E. Robins (commonly known as '*Sandanezwe*' and 'Wandile' in Zulu and as 'Sathane' in siSwati), *Lantana camara* L. ('Bukhwebeletane' in siSwati), *Solanum mauritianum* ('Gwayana' in siSwati) and *Psidium guajava* L. or guava ('Umgwava' in siSwati). *Parthenium* species has also been shown to be troublesome and causing immeasurable, ecological devastation in ranches and game reserves, in addition to the other invasive species. *Chromolaena odorata* has more than 20 names by which it is known. Other names for this noxious weed are: Siam weed, Jack in the bush, Triffid weed, Kingweed, Paraffinweed, Turpentine weed and Bitter bush. *Sandanezwe* is a dicotyledonous plant of the family, Asteraceae; it branches and flowers profusely, producing thousands of seeds in one season. The seeds are airborne, transported by vehicular traffic and can also cling to animal fur, human hair and clothing. It is thought to have been introduced, in the 1940s, from the Caribbean into South Africa via Durban, from where it has spread to other countries including Swaziland [4, 5]. *Sandanezwe* has a smothering habit and allelopathic properties; it is highly prolific, reproducing vegetatively and through the production of in the form of thousands of light, wind-dispersed seeds [6]. The weed demonstrates environmental plasticity in the habitat types that it invades and takes advantage of both natural and anthropogenic disturbances; it increases the intensity, range and frequency of fires. In all areas, *C. odorata* impacts on cropping and pastoral agriculture, on biodiversity and on human welfare [6]. *Sandanezwe* is

Corresponding Author: Dr. E.M. Ossom, Agronomist, Department of Crop Production, Faculty of Agriculture, University of Swaziland, Private Bag Luyengo, Luyengo M205, Swaziland

seriously encroaching on agricultural and recreational land in Swaziland and in other Southern African countries such as South Africa, Malawi, Lesotho and Zambia, to name a few. In 2006, the Government of Swaziland allocated E8.0 million (about US $1.0 million) for *Sandanezwe* control, but this amount clearly excluded research.

Sandanezwe devastation is commonplace in Swaziland. At Magoga Sisa Ranch in Northern Hhohho administrative region, the ranch Manager, Mr. Solomon Khumalo, reported [7] that a number of the King's cattle were lost in the ranch and could not be found because *Sandanezwe* plants were too tall to manage or search for lost cattle. Between August 2005 when Mr. Khumalo sounded the alarm and January 2006, *Sandanezwe* infestation forced Magoga Sisa Ranch to reduce its cattle population from 2,000 to 800 [8]. Another Government-owned ranch, Nkhalashane Sisa ranch, was completely closed down and all cattle moved out, solely because of unmanageable *Sandanezwe* infestation. Bhalekane Fattening Ranch is also badly invaded by both *Sandanezwe* and Lantana and livestock numbers are dwindling. The possible loss of this major cattle-fattening facility implies that the lucrative export of beef cattle from Swaziland to Europe and other foreign markets would decline. With more *Sandanezwe* flowering every May/June in Swaziland, the continual increase in the seed bank of this weed every year is observed, especially as no concerted efforts are made to control the weed. The economic costs due to invasive species can be separated into direct costs due to production loss in agriculture and forestry and management costs of invasive species. Forage loss due to invasive weeds on pastures amounts to nearly one billion US dollars in the U.S. alone [9].

Weeds can cause a reduction in crop yield [2, 10, 11]. Most weed species are accidental introductions with crop seeds and imported plant material. Many introduced weeds in pastures compete with native forage plants and are toxic e.g. leafy spurge, *Euphorbia esula*, to cattle, or are non-palatable due to thorns and spines e.g. yellow star thistle, *Centaurea solstitialis* [2]. Considering the human impact of invasive weeds, the ecosystem disturbances arising from human activity was categorized [12] into four: conservation, utilisation, replacement and removal. It was noted [12] that it is within these four land-related decisions that many of the mechanisms of weed invasiveness come into play.

Different methods of control have been devised for invasive weeds [13]. These include manual and mechanical techniques, cultural methods, prescribed fire, biological control and the use of chemicals (herbicides). It was reported [14] that in an effort to control *Sandanezwe*, manual slashing was carried out in timber plantations annually, but that was only effective in the short-term because once-a-year slashing did not prevent seeding by *Sandanezwe*. Mulching around the bases of trees, as a weed control measure for *C. odorata*, was attempted in plantation crops; although this method effectively suppressed weeds, high labor cost and problems with availability of mulching materials was a major limitation [15]. Signalgrass (*Brachiaria decumbens*) was reported [16] to successfully compete and reduce the incidence of *Sandanezwe* in pastures. The fire hazard potential of triffid weed was frequently emphasized in South Africa, where it was believed that the replacement of previously fire-excluding fringes of riverine forest communities by triffid weed made these communities vulnerable to fire [17]. Frowning upon the use of uncontrolled fires in Ghana, it was recommended [18] that appropriate by-laws banning the use of uncontrolled fires should be enacted and/or enforced. Several chemical control experiments on *C. odorata* have been conducted in South Africa, the Philippines, Indonesia, India and West African countries [14, 19-21]. Some of the herbicides used include: triclopyr; 2,4-D (2,4-dichlorophenoxy acetic acid); 2, 4, 5-T (2, 4, 5-Trichlorophenoxy acetic acid; Roundup; Gramoxone (Paraquat 20%), MCPA and 2, 4-D (amine salt), in various crops and countries. There has been no conclusive work on biological control for *Sandanezwe* in any country; after some frustrating attempts [22] and good news [23] in South Africa, it was concluded that the future of the control of *C. odorata* rested primarily on finding *Sandanezwe's* exact origin to ensure compatibility and success with biological control agents. In India, a strain of *Pareuchaetes pseudoinsulata* was introduced from Sri Lanka but no successful control was effected [24]. The closest to being successful was an international project funded by the Australian Centre for International Agricultural Research (ACIAR), in which biological control agents [arctiid moth (*Pareuchaetes pseudoinsulata*), the tephritid stem gall fly (*Cecidochares connexa*) and the leaf-mining fly (*Calycomyza eupatorivora*)] were introduced into Papua New Guinea [25]. Good weed control was achieved by the activity of the first two species [26]. Thus, many attempts have been made to control *Sandanezwe*, but no scientific studies have been attempted in Swaziland. Therefore, this field investigation was conducted to determine the effectiveness of different methods in controlling *Sandanezwe* and assessing the environmental impact associated with each control method.

MATERIALS AND METHODS

Experimental site, experimental design and management: The investigation was conducted at the Government-owned Bhalekane Fattening Ranch (26.07°S, 31.57°E; altitude, 320 m above sea level) in the Lowveld ecological zone of Swaziland. The site was heavily infested by a combination of *Sandanezwe* and Lantana. The experimental design was a randomized complete block having five treatments: 1), slashing of all weeds to the soil level (Control); 2), slashing of all weeds, followed by stump treatment with the herbicide, 'Chopper'; 3), slashing of all weeds, followed by spraying with the herbicide, 'Roundup'; 4), slashing, digging up and exposing weed roots to dry; and 5), controlled burning. Plot sizes were 10.0 m × 10.0 m; a 2-m space between plots was allotted to prevent treatment effects of one plot from affecting contiguous plots. The investigation area was fenced-off using a diamond mesh fence and a height of 2.0 m was maintained all around the investigation area, to keep out all animals and unauthorised persons; the 2.0 m height was the minimum height that could prevent animals from jumping into the enclosed area. The fenced area measured 52.0 x 64.0 m. A 3.0-m perimeter space, left between the fence and the experimental plots made it possible for a vehicle to move around the perimeter of the investigation area, if necessary. It became essential to first slash the vegetation before spraying the herbicides because the ranch plants were nonpenetrable. The herbicides used were Roundup or glyphosate [active ingredient: Isopropylamine salt of N-(phosphonomethyl) glycine, 360 g L^{-1}] and Chopper (active ingredient: Imazapyr, 100 g L^{-1}). The concentration of Roundup applied was 30.0% (6.0 L in 200.0 L of water). Chopper was applied at 2.0% and prepared by mixing 100 mL of Chopper in 400 mL of water and sprayed on the stumps of slashed invasive weeds. Roundup was sprayed using a 16-L knapsack sprayer; Chopper was sprayed using a 1.5 mL hand-held sprayer.

Data collection and analysis: Data were collected on weed density, weed species distribution and biomass assessment; labor requirement and soil temperature. Rainfall data were collected using a rain gauge that was installed at the site. Ecological impact was assessed through the observation of the relative abundance of different weed species that were either destroyed or re-established after the imposition of the control treatments. Weed density (weed density m^{-2}) and weed species distribution were assessed at the beginning of the investigation and thereafter, every 4 weeks, using a 100-cm square quadrat (three readings/plot), to determine the level of infestation by invasive weed species. During the first assessment, done at 4 Weeks after Treatment (WAT), weeds within the quadrat were removed at the soil level, taken to the laboratory, identified and dried in a hot-air over at 90°C for 72 hours [27] for dry matter determination. It was reasoned that, if during subsequent samplings, weeds continued to be removed from the plots, such an action might jeopardise the re-establishment of forage species in the plots. Thereafter, all species assessments were done *in situ*, using a 50-cm square quadrat (three readings/plot). Weed species were evaluated based on the species density within the quadrat. The rating scale descriptions [11] were as follows: 1), zero weeds on soil within the quadrat; 2), sparse weed coverage on soil within the quadrat; 3), intermediate weed coverage on soil within the quadrat; 4), general weed coverage on soil within the quadrat; 5), severe weed coverage on soil within the quadrat; and 6), total weed coverage on soil within the quadrat. Data were analyzed with MSTAT-C (version 1.3) statistical software [28]; mean comparisons were made using the F-protected least significant difference test [29] at $P < 0.05$.

RESULTS AND DISCUSSION

Weed scores and weed dry matter: Table 1 shows the weed scores from 0-16 WAT and the weed biomass at 4 WAT. There were no significant differences among the plots at the time (0 WAT) when the weed control methods were applied.

However, from 4-16 WAT, the controlled burning was significantly better in checking invasive weeds, resulting in the lowest weed scores (mean, 2.6 out of 6.0); slashing all weeds to the soil level gave the highest weed scores (mean, 4.9 out of 6.0), indicating that it was the least effective of the five control methods. Controlled burning was the most effective weed control method because it was the only method that effectively killed all aboveground and underground parts of the invasive species and probably also caused a total depletion of the seed bank in the soil. No regeneration of any part of *Sandanezwe* could take place if the fire was sufficiently large and was lit at the time of day when it was hot, dry and there was also sufficient dry grass and little or no winds to help fuel the fire. It was suggested [30] that it would be useful to plant forage legumes such as *Calopogonium mucunoides* and *Centrosema molle* (Mart. ex Benth.) and the grass, Setaria verticillata (L.) Beauv. in the burnt plots. The most plausible explanation for the least effective control of *Sandanezwe* obtained

Table 1: Weed scores and dry matter of invasive species from 0-16 weeks after treatment

	Weeks after Treatment (WAT)						
Weed control method	0	4	8	12	16	Weed score means (4-16 WAT)	Weed biomass (kg ha^{-1} at 4 WAT
Slashing	5.1	3.7	5.4	5.3	5.3	4.9	4.8
Slashing + Chopper	5.2	2.9	4.4	4.7	4.9	4.2	3.8
Slashing + Roundup	5.4	2.1	4.3	4.2	2.6	3.3	1.8
Slashing + drying of roots	5.1	3.5	4.0	4.8	4.3	4.2	2.5
Controlled burning	5.1	2.2	3.3	3.2	1.7	2.6	0.8
Means	5.2	2.9	4.3	4.4	3.8	3.85	2.8
[1]LSD $_{(0.05)}$	1.62	1.54	1.62	1.12	0.856	-	3.57
Significance	Ns	*	*	*	**	-	*

[1]Least significant difference;

Ns, not significant at P > 0.05;*, significant at P < 0.05;

**, significant at P < 0.01.

from the slashing, was the regeneration of branches or side-shoots from the weeds after the slashing. Such regeneration usually occurs in flowering plants when there is an interruption or suppression in the normal production of the plant-growth hormone, indole acetic acid (IAA), an auxin. With the apical bud removed, apical dominance would be nonexistent and the lengthening of lateral buds would result [31-33]. Our results that slashing caused plant regeneration agreed with previous reports, which stressed that manual slashing caused regeneration, unless followed by other control methods [15, 34].

Relative effectiveness of the two herbicides: Stump treatment with Chopper was only effective if the weed species had big stems, which could be readily identified and the stumps sprayed or painted. Thus, Chopper was effective against plants such as *Lantana camara* and *Psidium guajava*, many of which had large stems that could be painted. From the weed scores (Table 1), Roundup was a more effective weed control herbicide than Chopper, probably, for the reason that the knapsack sprayer resulted in greater coverage area than the application tank of the Chopper. A possible reason why Roundup was not as effective as initially envisaged was the time of application. The slashed vegetation covered the cut stumps and foliage of the invasive weed species, with the result that the sprayed Roundup settled more on the slashed vegetation, while the invasive species underneath were protected from much harm by the Roundup. The two herbicides used in this investigation, Roundup and Chopper are known, non-selective, post-emergence herbicides [34, 35].

Weed species distribution: Tables 2-5 show the distribution of weed species in the respective weed control methods at 4-16 WAT. At 4 WAT, controlled burning resulted in the lowest number (6) of weed species, with no *Sandanezwe* (0.0%) and maximum of 2.6% (*Lantana camara*), in terms of relative abundance. At the same time, *Sandanezwe* was most prevalent (0.8-60.1%) under the slashing method. An explanation had earlier been offered (see Relative effectiveness of the two herbicides above) for the relative ineffectiveness of slashing, as well as the two herbicide treatments. By 16 WAT, the superiority of controlled burning over the other four weed management methods was still evident-0% *Sandanezwe* and 0% *Lantana camara* (Table 5). There was regeneration of forage grasses (primarily *Panicum maximum*, *Cynodon dactylon* and *Setaria verticillata* (L.) Beauv. and legumes (chiefly *Centrosema*) that could be grazed by livestock. Thus, the environmental impact of burning, in terms of regeneration of forage species, was positive and encouraging. For the other control methods, the environmental impact was undesirable, especially where *Sandanezwe* was not effectively controlled or where there was a preponderance of other weeds.

Our observations that controlled burning was the most effective control measure for *Sandanezwe* was in agreement with earlier observations at Mlawula Game reserve in Swaziland, that planned and controlled use of fire was very effective and beneficial in controlling *Sandanezwe* and *Parthenium* (Farm manager, Mlawula Game reserve, personal communication, 2007). From the perspective of weed species distribution, controlled burning was the most effective and slashing was the least effective of the control methods. Slashing, accompanied by the spraying of Roundup, at the appropriate

Table 2: Effects of weed management methods on the relative dry mass (kg ha^{-1}) of weed species[1] at four weeks after treatment

Weed family	Weed species	Common name	Slashing	Slashing +Chopper	Slashing + Roundup	Drying roots of dug plants	Controlled burning
Poaceae	*Panicum maximum*	Guinea grass	23.6	45.8	11.1	25.0	70.3
Asteraceae	*Chromolaena odorata*	*Sandanezwe*	60.1	46.4	66.6	30.8	0.0
Acanthaceae	*Hypoestis* species	(Unknown)	8.4	1.3	0.0	5.0	0.0
Acanthaceae	*Barleria* species	(Unknown)	0.0	0.0	4.2	0.0	0.0
Asparagaceae	*Asparagus plumosus* Baker	(Unknown)	3.4	0.0	0.0	0.0	0.0
Fabaceae	*Centrosema molle* (Mart. ex Benth.)	Centro	0.5	0.0	8.3	10.0	8.1
Euphorbiaceae	*Euphorbia heterophylla L.*	Milk weed	0.4	0.7	0.0	0.8	0.0
Fabaceae	*Sesbania bispinosa* (Jacq.)	Spiny sesbania	0.0	0.0	0.0	0.0	13.0
Celastraceae	*Maytenus boaria* (Mayten)	Mayten tree	0.0	5.2	8.3	14.2	0.0
Poaceae	*Setaria verticillata* (L.) Beauv.	Sticky bristle grass	0.0	0.1	0.1	0.0	0.0
Verbenaceae	*Lantana camara*	Lantana	0.0	0.1	0.0	4.2	2.6
Tiliaceae	*Grewia caffra* Meissn.	Lavender star flower	0.0	0.7	0.0	0.0	0.0
Malvaceae	*Sida cordifolia L.*	Flannel weed	0.0	0.0	1.4	0.8	0.0
Poaceae	*Digitariasanquinalis* (L.) Scop.	Crab fingergrass	0.0	0.0	0.0	3.3	0.0
Fabaceae	*Teramnus labialis* (L.) Spreng	Blue wiss	0.0	0.0	0.0	0.8	0.0
	Solanum mauritianum	'Gwayana'	0.0	0.0	0.0	0.0	0.5
Fabaceae	*Crotalaria globulus*	Sunnhemp	0.0	0.0	0.0	0.0	5.5
Ranunculaceae	*Clematis brachiata* Thunb.	(Unknown)	3.3	0.0	0.0	0.0	0.0
Relative totals	N/A	N/A	99.7	100.3	100.0	99.9	100.0

[1]Because of rounding up of the percentages, the totals may not equal 100%

N/A, not applicable

Table 3: Effects of weed management methods on the relative abundance of weed species[1] at eight weeks after treatment

Weed family	Weed species	Common name	Slashing	Slashing +Chopper	Slashing +Roundup	Drying roots of dug plants	Controlled burning
Acanthaceae	*Barleria* species	(Unknown)	2.0	0.8	2.9	3.1	0.0
Amaranthaceae	*Achyranthes splendens*	(Unknown)	0.0	0.8	0.0	0.0	0.0
Asteraceae	*Chromolaena odorata*	*Sandanezwe*	0.8	4.6	9.2	0.0	0.0
Asteraceae	*Bidens pilosa* L.	Common blackjack	2.9	2.5	0.4	0.0	0.4
Celastraceae	*Maytenus boaria* (Mayten)	Mayten tree	2.5	0.0	3.3	5.3	0.0
Combretaceae	*Combretum microphyllum* Klotzsch.	Flame creeper	0.0	0.0	0.0	0.9	0.0
Commelinaceae	*Commelina benghalensis* L.	Wandering Jew	3.3	0.0	0.0	7.0	13.5
Convolvulaceae	*Convolvulus arvensis* L.	Field bindweed	0.0	0.0	2.5	1.8	0.0
Convolvulaceae	*Ipomoea purpurea* (L.) Roth.	Morning glory	0.0	0.0	0.0	0.9	0.0
Cyperaceae	*Cyperus esculentus* L.	Yellow nutgrass	0.0	0.0	0.0	0.0	0.4
Fabaceae	*Centrosema molle* (Mart. ex Benth.)	Centro	0.4	1.7	5.0	0.9	14.8
Fabaceae	*Sesbania bispinosa* (Jacq.)	Spiny Sesbania	0.0	1.3	0.0	0.0	8.6
Fabaceae	*Desmodium triflorum* -	Tick clover	0.0	0.0	0.0	3.5	0.0
Fabaceae	*Crotalaria globulus*	Sunnhemp	0.0	0.0	0.0	0.0	1.2
Malvaceae	*Sida cordifolia* L.	Flannel weed	0.2	4.6	2.5	0.4	5.7
Malvaceae	*Hibiscus cannabinus* L.	Kenaf	0.8	0.8	0.8	2.6	5.3
Poaceace	*Chloris virgata* Swartz.	Feather-top chloris	5.7	0.0	0.0	0.0	0.0
Poaceace	*Sporobolus africanus* (Poir.) Robyns and Tournay	Sand sagebrush	1.6	0.0	0.0	0.0	0.0
Poaceae	*Panicum maximum* L.	Guinea grass	78.3	81.3	70.0	72.8	50.0
Poaceae	*Setaria verticillata* (L.) Beauv.	Sticky bristle grass	0.0	0.0	0.0	0.9	0.0
Poaceae	*Bothriochloa bladhii* Kuntz.	Australian beardgrass	0.4	0.0	0.0	0.0	0.0
Solanaceae	*Solanum mauritianum* Scop.	'Gwayana'	1.0	0.0	0.0	0.0	0.0
Verbenaceae	*Lantana camara*	Lantana	0.0	1.7	3.3	0.0	0.0
Relative totals	N/A	N/A	99.9	100.1	99.9	100.1	99.9

1Because of rounding up of the percentages, the totals may not equal 100%;

N/A, not applicable

Table 4: Effects of weed management methods on the relative abundance of weed species[1] at 12 weeks after treatment

Weed family	Weed species	Common name	Slashing	Slashing +chopper	Slashing +roundup	Drying roots of dug plants	Controlled burning
Acanthaceae	*Barleria* species	(Unknown)	8.3	8.8	3.1	7.8	2.7
Asteraceae	*Chromolaena odorata*	*Sandanezwe*	7.9	16.1	8.3	0.9	6.4
Asteraceae	*Bidens pilosa* L.	Common blackjack	7.5	0.0	6.7	0.8	0.0
Asteraceae	*Ageratum conyzoides* L.	Invading Ageratum	0.0	0.0	0.0	7.1	0.0
Celastraceae	*Gymnosporia heterophylla*	Spike thorn	0.4	1.2	2.9	2.8	2.7
Commelinaceae	*Commelina benghalensis* L.	Wandering Jew	0.0	0.0	0.0	0.4	9.5
Convolvulaceae	*Convolvulus arvensis* L.	Field bindweed	0.0	0.0	0.0	0.0	3.6
Euphorbiaceae	*Phyllanthus nuriri*	(Unknown)	0.0	0.0	0.0	0.8	0.0
Fabaceae	*Centrosema molle* (Mart. ex Benth.)	Centro	1.7	0.0	2.1	7.1	7.3
Fabaceae	*Teramnus labialis*	Blue wiss	0.0	2.9	0.0	0.0	0.0
Fabaceae	*Phaseolus vulgaris* L.	Sugar bean	0.0	0.0	0.0	0.8	0.0
Fabaceae	*Crotalaria globulus*	Sunnhemp	0.0	0.0	0.0	0.0	12.7
Fabaceae	*Sesbania bispinosa* (Jacq.)	Spiny Sesbania	0.0	0.0	0.0	0.0	12.7
Malvaceae	*Sida cordifolia* L.	Flannel weed	0.2	2.1	1.0	0.0	8.2
Malvaceae	*Hibiscus cannabinus* L.	Kenaf	0.0	0.0	0.0	0.0	6.8
Poaceae	*Panicum maximum*	Guinea grass	69.0	62.3	60.0	58.8	18.6
Poaceae	*Digitariasanquinalis* (L.) Scop.	Crab fingergrass	0.0	0.0	0.0	7.1	0.0
Solanaceae	*Solanum mauritianum*Scop.	'Gwayana'	0.0	0.0	0.0	0.0	0.9
Tilliaceae	*Corchorus* species	'Ligusha'	0.0	0.0	0.0	0.0	7.7
Verbenaceae	*Lantana camara*	Lantana	5.0	6.6	15.8	5.6	0.0
Relative totals	N/A	N/A	100.0	100.0	99.5	100.0	99.8

1Because of rounding up of the percentages, the totals may not equal 100%

N/A, not applicable

Table 5: Effects of weed management methods on the relative abundance of weed species[1] at 16 weeks after treatment

Weed family	Weed species	Common name	Slashing	Slashing +Chopper	Slashing +Roundup	Drying roots of dug plants	Controlled burning
Acanthaceae	*Barleria* species	(Unknown)	0.0	0.8	0.0	0.2	2.5
Amaranthaceae	*Aerva leucura* Moq.	(Unknown)	0.0	2.1	0.0	0.0	0.0
Asparagaceae	*Asparagus plumosus* Baker	(Unknown)	1.8	0.0	0.0	0.0	0.0
Asteraceae	*Chromolaena odorata*	*Sandanezwe*	6.4	0.8	4.6	1.7	0.0
Asteraceae	*Ageratum conyzoides* L.	Invading Ageratum	0.0	0.0	0.0	7.5	0.0
Celastraceae	*Gymnosporia heterophylla*	Spike thorn	1.1	2.5	0.8	2.7	0.0
Commelinaceae	*Commelina benghalensis* L.	Wandering Jew	0.0	0.0	8.3	0.0	7.9
Euphorbiaceae	*Phyllanthus niruri*	(Unknown)	0.0	0.0	0.0	0.8	1.8
Fabaceae	*Crotalaria globulus*	Sunnhemp	0.0	0.0	0.0	0.0	30.4
Fabaceae	*Sesbania bispinosa* (Jacq.)	Spiny Sesbania	0.0	0.0	0.0	0.4	13.8
Fabaceae	*Centrosema molle* (Mart. ex Benth.)	Centro	0.0	0.0	14.6	4.2	0.0
Malvaceae	*Sida cordifolia* L.	Flannel weed	0.2	0.8	0.4	3.8	2.8
Malvaceae	*Hibiscus cannabinus* L.	Kenaf	0.0	0.4	0.4	0.0	2.1
Poaceae	*Panicum maximum* L.	Guinea grass	86.9	81.3	70.4	67.6	18.3
Poaceae	*Cynodon dactylon* (L.) Pers.	Star grass	0.0	0.0	0.0	0.0	0.4
Poaceae	*Setaria verticillata* (L.) Beauv.	Sticky bristle grass	0.0	0.0	0.0	7.9	0.0
Pteridaceae	*Adiantum* species	Maidenhair fern	0.9	0.0	0.0	0.0	0.0
Solanaceae	*Solanum mauritianum* Scop.	'Gwayana'	0.0	0.0	0.0	3.3	0.0
Solanaceae	*Solanum sisymbriifolium* (Lam.)	'Gwayana'	0.0	0.4	0.0	0.0	18.3
Verbenaceae	*Lippia javanica* L.	Fever tea	2.0	3.3	0.4	0.0	1.7
Verbenaceae	*Lantana camara*	Lantana	0.0	7.5	0.0	0.0	0.0
Relative totals	N/A	N/A	99.9	99.9	100.0	100.1	100.0

1Because of rounding up of the percentages, the totals may not equal 100%

N/A, not applicable

Table 6: Effects of weed control methods on labor requirement for each control method

Weed control method	Man-days per hectare
Slashing all weeds to soil level	5.70
Slashing + chopper	2.40
Slashing + roundup	3.10
Digging up and drying plants	9.50
Controlled burning	5.10
Means	5.10
[1]CV	29.40
[2]$LSD_{(0.05)}$	2.33
Significance	**

[1]Coefficient of variation (%);
[2]Least significant difference;
**, significant at $P < 0.01$

Table 7: Effects of weed control methods on soil temperatures at six weeks after imposing control methods

Weed control method	Soil depth	Temperature
Slashing	Surface	27.2
	5-cm	26.8
	10-cm	25.4
	15-cm	22.9
Slashing + chopper	Surface	27.5
	5-cm	26.3
	10-cm	22.5
	15-cm	22.1
Slashing+roundup	Surface	26.0
	5-cm	27.8
	10-cm	23.4
	15-cm	21.4
Digging up and drying of dug plants	Surface	26.3
	5-cm	27.3
	10-cm	26.4
	15-cm	22.8
Controlled burning	Surface	29.8
	5-cm	28.8
	10-cm	28.3
	15-cm	26.0
Mean	Surface	27.3
	5-cm	27.4
	10-cm	25.2
	15-cm	23.0
[1]CV (%)	Surface	7.2
	5-cm	15.0
	10-cm	8.8
	15-cm	9.6
[2]$LSD_{(0.05)}$	Surface	3.02*
	5-cm	6.30 Ns
	10-cm	3.44*
	15-cm	3.40*

[1]Coefficient of variation (%); [2]Least significant difference;
*, Significant at $P < 0.05$; Ns, not significant at $P > 0.05$

concentration, methods and time of application, could be a useful weed control method, as was reported earlier [15]. It should be stressed that burning of vegetation could have ecological implications: destruction of both unwanted and desirable biological life, including ranch livestock and animals in games reserves; fire spreading out of control and causing damage in non-target areas and slow re-establishment of desirable forage species.

Labor requirements: Table 6 shows the trends in labor requirements under each weed control method. There were highly significant differences ($P < 0.01$), among weed control methods.

The control method with the lowest labor requirement (2.4 man-days) was slashing, followed by spraying with Chopper herbicide, whereas the control method with the highest labor requirement (9.5 man-days) was digging up invasive species and drying them. There was no significant difference between the labor requirements of the Chopper treatment and the Roundup treatment. Our findings were in agreement with the earlier observations of other researchers [16, 21, 22], who, after comparing different control methods, concluded that mechanical control was labor-intensive, was not long lasting, whereas cultural control was long lasting. Furthermore, they suggested that chemical control was the most effective, but also the most expensive and posed some environmental problems. They recommended that either a mechanical or chemical control programme had to be carried out initially to implement the cultural control. Manual weeding (including the use of bush-cutter or tractor-drawn implements) is known to be labor intensive [34-36], but an effective weed control method, though only in the short-term [15].

Soil temperatures: Soil temperatures taken at 6 WAT, are shown in Table 7. Surface temperatures as well as 10-cm and 15-cm temperatures were significantly higher in plots where the vegetation had been burnt. This is likely to have resulted from the soil surface being exposed to solar radiation. It was reported [39] that soil temperatures were controlled more evenly if the soil was covered.

The observation that soil temperature was higher at 5-cm depth than at 10- and 15-cm depths agreed with earlier observations [40, 41] who also reported that the deeper the site or location of the soil temperature reading was, the lower the temperature that was recorded. Soil temperature has been reported to influence some

Table 8: Rainfall data during the period of the investigation

Month	Total rainfall (mm) for the month	Mean rainfall (mm) for the month	Total rainfall (mm) for the month in 1987-2006	Mean rainfall (mm) for the month in 1987-2006
Mar-07	46.1	1.5	78.4	2.5
Apr-07	73.2	2.4	45.1	1.5
May-07	0.0	0.0	15.3	0.5
Jun-07	48.4	1.6	12.1	0.4
Jul-07	0.0	0.0	5.1	0.2
Totals	167.7	5.5	156.0	5.1

physiological processes including seed dormancy and germination [42], seedling emergence and growth [43]. The soil temperature range (21.1-29.8°C) recorded in our investigation was consistent with soil temperatures in tropical areas [40, 41, 44]). Low temperatures are never a problem in the Lowveld of Swaziland. Among the possible reasons that might be advanced for higher soil temperatures at 5-cm depth than at lower depths are the following: greater solar radiation impacts the soil nearer the soil surface; greater microbial activities in the topsoil where the higher organic matter content might enhance microbial life; greater intensity of physiological activities (respiration, decay and/or fermentation) caused by plant roots and other macro-organisms (flora and fauna alike) in the soil, less soil moisture compared to lower depths of the profile where the water table is deeper than at the soil surface and reduced air circulation in the soil environment than in the atmosphere [45].

Rainfall during the investigation: Rainfall during the investigation (Table 8) was low. However, the rainfall during the experiment (total, 167.7 mm) was slightly greater than the 20-year, long-term (1987-2006) rainfall (total 156.0 mm) for the same months.

Thus, the less-than-ideal re-establishment of both invasive weeds and desirable forage species in the plots, might be as would be expected, given the usual rainfall of the locality. Other ecological zones with different rainfall amounts might have different results from a similar investigation.

CONCLUSION AND RECOMMENDATIONS

This investigation has shown that controlled burning was the best method for controlling *Sandanezwe* and other invasive species, but slashing of weeds was the least effective method. Roundup was a more effective chemical control measure than Chopper. It is recommended that controlled burning be adopted as the best control method of *Sandanezwe* in the Lowveld of Swaziland, but concerted efforts should be made to avoid the fire burning out of control. Chemical control with Roundup, following slashing and sprouting of slashed stumps, could be attempted as a compromise control method, if there is adequate technical knowledge of herbicide-use technology among farmers. Further investigations would be appropriate.

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REFERENCES

1. Anonymous, 2006a. Definitions of invasive plant on the Web.www.hornsby.nsw.gov.au/environment/index.cfm. 07/27/06.
2. Zimdahl, R.L., 1999. Fundamentals of weed science. 2nd Edn. Academic Press, San Diego.
3. Anonymous. 2006d. Swaziland's alien plants database. http://www.sntc.org.sz/alienplants/specieslist.asp. 12/08/06.
4. Anonymous, 2006b. http://www.kbraunweb.com/alienplants/speciesinfo.asp?spid=111. 04/25/06.
5. Zachariades, C., I. von Senger and N.P. Barker, 2004. Evidence for a northern Caribbean origin for the southern African biotype of *Chromolaena odorata*. *In*: Day, M.D. and McFadyen, R.E. (Eds.) *Chromolaena* in the Asia-Pacific region. Proceedings of the 6th International Workshop on biological control and management of *Chromolaena*, held in Cairns, Australia, May 6-9, 2003, pp: 25-27.
6. Timbilla, J.A., C. Zachariades and H. Braimah, 2006. Biological control and management of the alien invasive shrub *Chromolaena odorata* in Africa. http://www.3eme-cycle.ch/biologie/JC-Villars06/T2%20Neuenschwander/CHAPT.10%20Chromolaena%20TimbillaFinal.doc.08/24/07.
7. Jele, L., 2005. Magoga Sisa Ranch most affected by *Sandanezwe*. Times of Swaziland. August 12, 2005. Mbabane, Swaziland, pp: 16.

8. Shongwe, F., 2006. *Sandanezwe* invades Magoga Sisa Ranch. Times of Swaziland. January 30, 2006. Mbabane, Swaziland, pp: 17.
9. Pimentel, D., R. Zuniga and D. Morrison, 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol. Econ., 52: 273-288.
10. Dastgheib, F., 2004. Optimising tine weeding in organic pea crops. New Zealand Plant Protection 57: 45-48.
11. Ossom, E.M., 2005. Effects of weed control methods on weed infestation, soil temperature and maize yield in Swaziland. UNISWA J. Agric. Sci. and Tech., 8 (1): 5-15.
12. Bright, C., 1998. Life out of bounds: bioinvasion in a borderless world. 1st ed. New York: W.W. Norton.
13. Tu, M., C. Hurd and R.M. Randall, 2005. Weed control methods handbook: Tools and techniques for use in natural areas. http://tncweeds.ucdavis.edu/handbook.html. 07/28/06.
14. Erasmus, D.J., 1988. A review of mechanical and chemical control of *Chromolaena odorata* in South Africa. Proceedings, First International workshop on biological control of *Chromolaena odorata*. Bangkok., Thailand, pp: 34-40.
15. Muniappan, R. and M. Marutani, 1998. Mechanical, cultural and chemical control of *Chromolaena odorata*. http://www.ehs.cdu.edu.au/chromolaena/2/2muni.html. 07/31/01.
16. Wu, R. and X. Xu, 1991. Effect of planting signal grass (*Brachiaria decumbens* Stapf.) on feijicao (*Chromolaena odorata* King and Robinson) in Southern Yunnan, PRC. Second International Workshop on biological control of *Chromolaena odorata*, Bogor, Indonesia, February 4-8, 1991.
17. MacDonald, I.A.W., 1984. Infiltration of dreaded weed alarms experts. Custos, 13: 33-35.
18. Gyasi, E.A. and L. Enu-Kwesi, 2001. Managing agricultural resources for biodiversity conservation: Policy dimension. Final report presented to University of Ghana, Legon.
19. Liggitt, B., 1983. The invasive alien plant *Chromolaena odorata*, with regard to its status and control in Natal. Monograph 2, Institute of Natural Resources, University of Natal, Pietermaritzburg.
20. Erasmus, D.J. and J. van Staden, 1986. Screening of candidate herbicides in field for chemical control of *Chromolaena odorata*. S. Afr. J. Pl and Soil, 3: 66-70.
21. Erasmus, D.J. and J. van Staden, 1987. Chemical control of *Chromolaena odorata*: efficacy of triclopyr and glyphosate applied to regrowth. Appl. Pl. Sci., 1: 39-42.
22. Kluge, R.L. and P.M. Caldwell, 1998. Failure and frustrations of biocontrol of *Chromolaena odorata* in South Africa. http://www.ehs.cdu.edu.au/chromolaena/3/3kluge.html. 07/31/06.
23. Den Breeÿen, A., 2002. *Chromolaena odorata*: biological control using plant pathogens - a South African perspective. In: Zachariades, C., Muniappan, R. and Strathie, L.W. (Eds). Proceedings of the Fifth International Workshop on Biological Control and Management of *Chromolaena odorata*, Durban, October 2000, (In Press).
24. Chacko, M.J. and A. Uma Narasimham, 1998. Biocontrol attempts against *Chromolaena odorata* in India. A Review. CAB International Institute of biological control. http://www.ehs.cdu.edu.au/chromolaena/1/1att.html. 07/31/06.
25. Bofeng, I., G. Donnelly, W. Orapa and M.D. Day, 2004. Biological control of *Chromolaena odorata* in Papua New Guinea. In: Chromolaena in the Asian-Pacific region: Proceedings of The Sixth International Workshop on the Biological Control and Management of *Chromolaena odorata*. Australian Centre for International Agricultural Research (ACIAR) Technical Reports No. 55. pp: 14-16.
26. Day, M., 2005. Biological weed control. http://www.nrm.qld.gov.au/alan_fletcher/projects/chromolaena.html. 07/31/06.
27. Anonymous, 2005. Mulching enriches and protects soil, helping provide a better growing environment. www.nrcs.usda.gov. 03/24/2006.
28. Nissen, O., 1983. MSTAT-C – A microcomputer program for the design, management and analysis of agronomic research experiments. Michigan State University, East Lansing, USA.
29. Steel, R.G.D., J.H. Torrie and D.A. Dickey, 1997. Principles and procedures of statistics: A biometrical approach. 3rd Edn. McGraw-Hill, New York.
30. Torres, D.O. and E.C. Paller Jr., 1989. The devil weed (*Chromolaena odorata* R.M. King and H. Robinson) and its management. Southeast Asian Weed Information Center (SEAWIC) Weed Leaflet 4:1-5.
31. Prasad, T.K., X. Li, A.M. Abdel-Rahman,, Z. Hosokawa, N.P. Cloud, C.E. Lamotte and M.G. Cline, 1993. Does auxin play a role in the release of apical dominance by shoot inversion in *Ipomoea nil*? Ann. Bot., 71: 223-229.

32. Cline, M., T. Wesse and H. Iwamura, 1997. Cytokinin/auxin control of apical dominance in *Ipomoea nil*. Plant and Cell Physiology, 38(6): 659-667.
33. Koning, R., 2007. Apical dominance. http://plantphys.info/apical/apical.html. 08/16/07.
34. Invasive species specialist group (ISSG, 2007). Management information on *Chromolaena odorata*. http://www.issg.org/database/species/references.asp?si=47&fr=1&sts=tss. 08/16/07.
35. Pandey, S., 2000. Technologies for the Southeast Asian Uplands. 2020 Focus No. 04 - Brief 04, International Food Policy Research Institute, Los Baños, Philippines.
36. Zipern, E., 2003. Ban on pulling weeds irks farm groups. Debate over labor-intensive hand weeding in organic community. Organic Consumers Association, 6771 South Silver Hill Drive, Finland MN 55603, USA.
37. Anonymous, 2007. Herbicides. http://www.pestproducts.com/herbicides/herbicidetypes.htm. 08/16/07.
38. Staff, O., 2006. Guide to weed control: Publication 75. Ministry of Agriculture, Food and Rural Affairs. http://www.omaf.gov.on.ca/english/crops/facts/notes/glyphosate.htm. 08/16/07.
39. Bell, G.D.H., R.R., Evans, J. Hamond, B. Keen, J.E. Russell, R.K. Schofield and F. Yates (Eds.), 1960. Effect of black polythene mulch on soil microclimate and temperature and nitrate level. Agron. J., 52: 307-309.
40. Ossom, E.M., P.F. Pace, R.L. Rhykerd and C.L. Rhykerd, 2001. Effect of mulch on weed infestation, soil temperature, nutrient concentration and tuber yield in *Ipomoea batatas* (L.) Lam. in Papua New Guinea. Trop. Ag. (Trinidad), 78(3): 144-151.
41. Ossom, E.M., 2003. Effect of cucumber management methods on weed infestation and soil temperature in Swaziland. Trop. Ag. (Trinidad) 80(4):205-210.
42. Relf, D., 1997. Seed germination and soil temperature. Virginia Cooperative Extension, Virginia State University. http://www.ext.vt.edu/departments/envirohort/articles2/sdgrmtmp.html. 08/23/07.
43. Singh, N, T. and G.S. Dhaliwal, 1972. Effect of soil temperature on seedling emergence in different crops. Pl. and Soil, 37(2): 441-444.
44. Sanchez, P.A., 1976. Properties and management of soils in the tropics. Wiley, New York.
45. Ossom, E.M. and F.T. Dlamini, 2006. Influence of filter cake on weed infestation, soil temperature and yield of maize (*Zea mays* L.) in Swaziland. Bots. J. Agric. Appl. Sci., 2(1): 58-66.