Chapter Number

Impacts, Efficacy and Economics of Bushwacker Sc (Bromacil) In Controlling *Acacia* Invasion in South Africa

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1. Introduction

The widespread transition of grasslands and savannas to shrub-lands during the last 50-100 years has elicited significant debate concerning the causes of these changes and has given rise to a number of investigations (Rollins *et. al.*, 1997). Often the encroaching species suppress the growth of palatable grasses and herbs, as they grow into impenetrable thickets (Wiegand et al., 2006). This often results in reduced grazing capacities in livestock farms. As a result, livestock farmers have regarded bush encroachment as a major problem and have resorted to various control measures. The causes of bush encroachment is not clear but it suffice to say that they are diverse and complex (Smit et al., 1999), consequently, it is difficult to devise complete control measures for all encroaching species. On the bases of some comprehensive reviews of the literature (Archer 1994, Van Auken 2000, Dube et al., 2009), it can be concluded that the primary mechanism behind the increase in shrub cover has been a dramatic shift in patterns of herbivory and fire frequency, although shifts in climate and carbon dioxide (CO_2) concentrations have also been cited as possible factors.

According to Dube *et al.,* (2009), the encroachment of rangelands by *Acacia karroo* bush, in South Africa is known to greatly reduce rangeland productivity with immense economic implications, especially in systems where grazers are preferred to browsers. Bush encroachment is defined as the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass: bush ratio, a decrease in biodiversity, and a decrease in carrying capacity, causing severe economic losses in both the commercial and communal farming areas. The phenomenon of bush encroachment in savannas is seen to be part of the process of desertification (Tainton, 1999). *Acacia karroo* is one of the main species causing the encroachment problem in the Amathole Montane grassland, Bhisho Thronveld and Eastern Cape Escapement Thicket vegetation.

Various control methods viz., cultural, mechanical, chemical and biological uses have been tested and advanced to control the growth and spread of encroaching plants (Fatunbi et al. 2008). Burning, browsing with goats, cutting and application of herbicides are some of the methods that are widely used to control encroaching species.

The use of herbicide containing bromacil (5-Bromo-3-sec-butyl-6-methyluracil) for control of *A. karoo* has been observed in a number of commercial holdings in South Africa. Bromacil herbicide act by interfering with the photosynthetic pathway of the plant. It achieves a gradual kill that could span over two years. The use of herbicides have however brought about various environmental concerns (EXTONET, 1993; Rosner et al.,1999; Singh et al., 2003). This has resulted in the need to investigate the effects of different types of herbicides on components of the ecosystem (Dube et al. 2009).

A number of herbicides in South African markets are currently being used in controlling encroaching species, of particular note are herbicides containing bromacil (5- Bromo-3-sec-butyl-6-methyluracil) as the active ingredient (a.i), for example Bushwacker SC(Enviro Weed Control Systems (Pty) Ltd), Bushwacker GG (Enviro Weed Control Systems (Pty) Ltd), Rinkhals 400 PA (Dow AgroSciences LLC) e.t.c. These herbicides differ mainly in their bromacil concentration, for instance Bushwacker SC contains 500 g bromacil per litre, Bushwacker GG contains 200 g bromacil per kilogram and Rinkhals 400 PA contains 400 g bromacil per kilogram. The different concentrations of bromacil determine the specific use of the herbicide, coupled with the concentration of other reactive ingredients. Herbicides are usually selective within certain application rates, environmental conditions, and methods of application (Masters and Sherley, 2001).

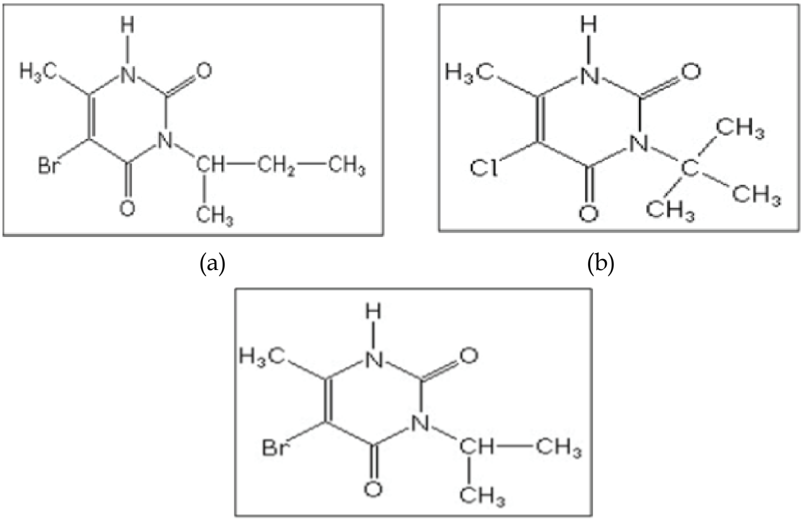
Bromacil belongs to the uracil family of herbicides (Arteca, 1994). It can be used to selectively control annual and perennial weeds, broad leaved and woody plants on cropland and non-cropland areas (EXTOXNET, 1993; Meister, 1998; Zhu and Li, 2002). It is also widely used for selective weed control in pineapple and citrus crops (EXTONET 1993). Bromacil works by interfering with the photosynthetic pathway of plants (EXTOXNET, 1993). One herbicide that is gaining importance in bush control in South Africa is Bushwacker SC. It has been reported to be an effective herbicide for general weed and bush controls in agricultural and non-agricultural areas (Zhu and Li, 2002). This herbicide can be sprayed on the plants or spread dry. It quickly dissolves in soil water and may stay in the soil for several years (EXTOXNET, 1993). Its application is usually done just before the active growth stage of plants thus, before the wet season stabilizes. Bromacil is readily absorbed through the root system (Gangstad, 1989) and is a specific inhibitor of photosynthesis. In the soil, there is little adsorption of bromacil to soil colloids therefore it moves (leaches) through the soil and it can contaminate groundwater (EXTOXNET, 1993); however, it is highly susceptible to microbial degradation (Arteca, 1995). When used as a selective herbicide it can persist in the soil for one year, however if it is applied at high concentrations it can persist for more than one year (Arteca, 1995).

There is the speculation that bromacil can destroy some grasses if it stays too long on the upper horizon of the soil profile. Grasses are assumed to extract water from the top soil layer (0 - 15 cm) due to their shallow rooting characteristics, while trees and bushes derive their nutrients from the lower layers (Wiegand et al., 2006). The movement rate of bromacil when applied is therefore important to its economic use and ecological suitability. There is the perception that phytotoxicity could occur when animals ingest plants that may have taken up bromacil from soil water. Furthermore, the relative effects of bromacil on soil microbial activity and dynamics need to be investigated.

This aim of this paper is to clear doubts about the effectiveness and safety of the use of bromacil for the control of invasive species in South African rangelands. It also aim to identify the economic implication of Bromacil use and determine the best application method at the farmers' level. To provide sufficient scientific discussion in this chapter, the authors represents a substantial proportion their comprehensive review work (Dube et al., 2009) and also report a field research.

2. The chemical basis for the use of bromacil as an herbicide

Bromacil (Figure 1) falls under the substituted uracil family; other members of the family include terbacil and isocil Terbacil is an effective herbicide for the control of annual and perennial weeds. The general characteristic of the uracil family is the presence of a methyl group located at the sixth position on the ring. The members of the substituted uracil herbicide family differ one from another by substituents at the third or fifth position of the ring, or both. The bromacil molecule consists of a uracil nucleus containing bromine, methyl and a secondary butyl substituent (Canadian Council of Ministers of the environment 1999).



(a) (b)

(c)

Fig. 1. (a). Bromacil (5-bromo-3-sec-butyl-6-methyluracil). (b). Terbacil (3-tert-butyl-5-chloro-6-methyluracil). (c). Isocil (5-bromo-3-isopropyl-6-methyluracil). Adapted from the International Organization for Standardization (ISO).

The family as a whole posses a broad toxicity to many plant species, however specific compounds differ significantly in their toxicity to plants, solubility in water, persistence in soil and other economically significant characteristics (Lakoski et al., 1993). Firstly introduction of this family of herbicides was intended for general vegetation control, mainly because the different compounds have broad spectrum activity over a wide range of plant species and they also persist long in the soil, therefore, having long residual activity for weed control in industrial areas.

The principal use of these herbicides are the selective control of many annual and perennial weed species in certain crops and general weed control in non-crop areas, such as railroads, highways, pipeline right-of-ways, lumber- yards, storage areas and industrial sites. The uracils are formulated as both wettable powders and as water soluble preparations (Dube et al,. 2009). All of the uracil herbicides in pure form are white, crystalline solids and are temperature stable up to their melting point of 335° C. The uracils are characteristically low in mammalian toxicity and are non-volatile. Their long persistence in soil, however, does create problems in crop rotations. In South Africa, bromacil is traded as Bushwhacker and it is applied as a spray, spread dry just before or during the period of active growth, preferable when rain is expected for soil activation or aerial application of granules.

The mode-of-action refers to the manner in which an herbicide affects a plant at the tissue or cellular level. Bromacil is a powerful mobile inhibitor of photosynthesis (Prostko, 2001). The target plant must be undergoing active photosynthesis for the herbicide to be effective. It is readily absorbed through the root system (Gangstad, 1989); the leaves and stems can also absorb some bromacil. It is translocated upward via the xylem to foliage and interferes with light-harvesting complexes (Prostko, 2001). It inhibits photosynthesis by blocking the photosystem II reaction; thereby preventing the conversion of sunlight into chemical energy (Prostko, 2001), thus it blocks the photosynthetic electron transport (Prostko, 2001). Bromacil blocks electron transport from QA to QB in the chloroplast thylakoid membranes by binding to the D-1 protein at the QB binding niche. The electrons that are blocked from passing through photosystem II are transferred through a series of reactions to other reactive toxic compounds. These compounds disrupt cell membranes and cause chloroplast swelling, membrane leakage, and ultimately cellular destruction (Tu et al., 2001). Inhibition of photosynthesis thus results in slow starvation of the target plant and eventual death.

Bromacil is readily absorbed through the plant root system (Bovey, 2001; Gangstad, 1989). Little or no bromacil moves from the apex downward toward the base of a treated leaf via the phloem. The early symptom of bromacil kill activities in a plant is leaf chlorosis concentrated around the veins, this is often noticed at the lower leaves and it gradually moves up the plant. The structure of the leaves' chloroplasts is altered while further cell wall development will cease. Chlorosis will then appear first between leaf veins and along the margins which is later followed by necrosis of the tissue and eventual death of the plant (Prostko, 2001).

The control of undesirable species in rangelands is a basic maintenance activity in livestock production. This could be carried out using methods that range from cultural, biological, chemical and a combination of these methods. The amount of drudgery involved in administering these methods makes some of them practically undesirable. Bromacil has many benefits in this case; it is used as an herbicide for general weed or bush control in non-croplands; it is also particularly useful against perennial grasses (Meister, 1998). The current use of bromacil in agriculture is necessary so as to sustain high productivity, reduce cost and drudgery and give high profit margins. It is used on rail road rights of way and other industrial, non-cropland areas.

Bromacil is one of the most commonly used herbicides to control weeds in citrus orchards. It is used in citrus and pineapple fields for selective control of weeds (Turner, 2003). Bromacil is also effective in the control of deep-rooted perennial broadleaf and grass weeds. Other commonly used herbicides are glyphosate, diuron, diquat, simazine, linuron, terbuthylazine and terbumeton (Gomez-Barreda et al., 1991).

3. Effectiveness of different application methods for bromacil based herbicides

Bromacil can be applied in a variety of ways. Application can be made as broadcast, band or spot treatments (Gangstad, 1989). The most appropriate application method is determined by the weed being treated, the herbicide being applied, the skills of the applicator and the application site (Tu et al., 2001). The bromacil application method is of considerable importance; since it determines the extent of contact with the target plant and its movement within the soil. Three conventional methods of application are known, these are aerial spraying with the use of an aircraft and direct application to the soil near the target plant with the use of a backpack sprayer (liquid application) or the placement of the granular form at a close proximity to the target plant.

Bromacil and lithium bromacil are often applied by ground application. Aerial application is allowed in areas where it is too dense or dangerous such as military firing ranges. Fixed boom sprayers are typically used for broadcast treatment of perennial and annual weeds; for brush control, basal spot applications are made to the specific shrubs and trees to be controlled. In citrus groves, it is often applied only in bands between the tree rows (Turner, 2003). Bromacil needs to be watered into the soil to be effective, and it is best applied to soil that is already damp. For rights-of-way use, which is not amenable to irrigation, and for un-irrigated citrus applications, this generally means that bromacil would be applied during the rainy season in the winter (Turner, 2003).

Bromacil can be applied on its own as a selective herbicide or it can be applied in mixture with other herbicides to control a broad spectrum of weeds (Gomez de Barreda Jr. et al., 1998). Generally bromacil is applied at rates of 2 - 4 kg/ha (Meister 1998), depending on soil properties and persisting environmental conditions. In citrus, pineapple, and non-crop areas, Bromacil can be applied at rates of 5 - 7, 1.5 - 3, and 1.5 - 5 kg/ha respectively (Raov, 2000). Differences in soils could affect the overall performance of bromacil and these differences must be taken into consideration, i.e. soils with low clay or organic matter content and lower application rates must be used so as to avoid high rates of leaching of the chemical (Gangstad, 1989). The type, diversity and height of the vegetation are also important factors to be considered for the effective application of bromacil (Gangstad, 1989). Other methods of bromacil application are the foliar application, where bromacil is directly applied to the leaves and stems of a plant (Tu et al., 2001). Bromacil can be applied with a backpack sprayer or a hand-held bottle to the basal bark of the target plant (Tu et al., 2001).

4. Effects of bromacil on the environment

Bromacil toxicity to mammals and birds is described by its LD50, which is the dose received either as oral or dermal that kills half the population of studied animals. The LD_{50} is typically reported in grams of bromacil per kilogram of animal body weight (Tu et al., 2001). Tests conducted by the United States Environmental Protection Agency (USEPA) for bromacil mammalian toxicity revealed an LD_{50} of 3998 mg kg^{-1} when administered on acute oral basis; this showed that bromacil is practically non toxic to mammals. A similar result was obtained for birds (LD_{50} of 2250 mg kg^{-1}) and reptiles.

Bromacil's toxicity to aquatic organisms is quantified with LC_{50}, which is the concentration of the herbicide in water that is required to kill half of the study animals. The LC_{50} is typically measured in micrograms of bromacil per liter of water (Tu et al., 2001). The USEPA test with rainbow trout and bluegill sunfish resulted in an LC_{50} of 36 and 127 ppm of the ai. This suggests that bromacil is slightly toxic to rainbow trout and non-toxic to the bluegill sunfish. Consequently, bromacil is viewed to be slightly toxic to fishes and amphibians. Determining the implication of this toxicity on the secondary component of the aquatic food chain will constitute an interesting endeavor.

Bromacil is mainly degraded by micro-organisms in the soil and several forms of micro-organisms are involved in the process such as the bacteria Psuedomans spp. Which can use bromacil as a source of carbon (Chaudhry & Cortez, 1988). Bromacil has varying effects on soil microbial populations depending on herbicide concentrations and the microbial species present. Low residue levels can enhance populations while higher levels can cause population declines (Tu et al., 2001).

Water bodies can be contaminated by direct overspray, or when herbicides drift, volatilize, leach through soils to groundwater or are carried in surface or subsurface runoffs. Amounts of leaching and runoff are largely dependent on total rainfall in the first few days after an application (Tu et al., 2001). Most environmental fate and impact concerns linked to the use of herbicides are related to offsite movement into aquatic ecosystems (Zhu & Li, 2002). Bromacil rapidly moves through the soil, as a result it has the potential to be a ground water contaminant (Gomez de Barreda Jr. et al., 1998). Bromacil may degrade in natural waters through microbial degradation and photo-sensitized degradation. Bromacil is moderately soluble in water (0.815 gl^{-1} at 25° C) (Gomez de Barreda Jr. et al., 1998; Zhu & Li, 2002). Bromacil is one of the most commonly found herbicides in groundwater; it is usually detected at higher concentrations than those of terbuthylazine and simazine (de Paz and Rubio, 2006).

Bromacil in the atmosphere is mainly degraded by light, in a process known as photo-oxidation. The hydroxyl radicals and superoxide radicals are the primary oxidizing species in the photocatalytic oxidation process of bromacil (Singh et al., 2003). Oxygen has no pronounced effect on the initiation of the photolytic process of bromacil, as compared to that of metribuzin where oxygen has a pronounced effect and hydrogen peroxide has a lesser effect (Muszkat et al., 1998). The photolytic process in bromacil is initiated by hydroxyl radicals generated by hydrogen peroxide photolysis (Muszkat et al., 1998). In a study carried out by Singh et al. (2003), the immediate photolytic products in the presence of titanium dioxide were 5-hydroxy-3-secbutyl-6-methyl uracil and diisopropyl urea.

5. Persistence and degradation of bromacil in the environment

Increasingly, herbicides are continually being applied onto the environment. Ideally a herbicide should control or eradicate the targeted species selectively, remain stationary at the site of application and degrade rapidly once its purpose is achieved, however, their persistence in the environment together with their low degradability rates have become a cause of concern especially the ecological risks they might possess (Dowd et al., 1998, Muszkat et al., 1998, Singh et al., 2003, Rosner et al., 1999, Girotti et al., 2008). The degree of bromacil persistence and mobility (Hornsby et al., 1995) is mainly dependent on soil properties and environmental conditions such as water availability.

Any herbicide's persistence in soils is often described by its half-life (also known as the DT_{50}). The half-life is the time it takes for half of the herbicide applied to the soil to be dissipated (Tu et al., 2001). Bromacil has a lengthy half-life. Its soil half-life ranges from 2 to

8 months depending upon the patterns of use and other environmental factors such as temperature and availability of water (Fishel, 2005; Meister, 1998). Bromacil activity, movement and persistence in the soil depend on the interaction of the bromacil molecule with the soil's colloids adsorption capacity (Paterson & Mackay, 1994). Soil organic carbon-water partitioning coefficient (Koc) is the the ratio of the mass of a chemical that is adsorbed in the soil per unit mass of organic carbon in the soil per the equilibrium chemical concentration in solution. Koc value of less than 100 indicates that a pesticide is very mobile in soils (Branham et al., 1995). Bromacil moves quite readily through the soil (EXTONET, 1993, Rosner et al., 1999); this is because bromacil adsorbs only slightly soil particles, with a Koc value of 32 g/ml (de Paz & Rubio, 2006; EXTONET, 1993; Gomez de Barreda Jr. et al., 1998). Bromacil is a good candidate for leaching and therefore, a groundwater contaminant (Gomez de Barreda Jr. et al., 1998).

Due to its ability to move readily through the soil and its solubility in water, concerns on the use of Bromacil arise as it is able to contaminate groundwater (EXTONET, 1993; Rosner et al., 1999, Singh et al., 2003). Relatively Bromacil behaves differently on different types of soils with different constituents. Thus Bromacil is more strongly adsorbed to by organic matter colloids rather than clay particles; as a result it is more persistent and less mobile in soils with high organic matter content (5% or more) (James & Lauren, 1995). Soils with moderate to high organic matter content may retain bromacil residues for 1 to 2 years, thus, a soil half-life of 3 to 7 months is more likely in soils with low organic matter content (less than 5%) (EXTOXNET, 1993). A soil with high organic matter content will also bind bromacil and prevent it from being available in soil solution, this obviously will affect it effectiveness on plant. In a study carried out by de Paz and Rubio (2006), involving eight of the most frequently applied herbicides in citrus orchards (glyphosate, diuron, diquat, bromacil, simazine, linuron, terbuthylazine, and terbumeton), a ranking according to the potential to leach was obtained. The leaching potential of the herbicides was as follows, from highest to potential to least; terbumeton > bromacil > simazine > terbuthylazine > diuronNlinuron > glyphosate > diquat.

On relative terms, bromacil is one of the polluters of groundwater that should be given considerable attention (EXTONET 1993, Rosner et al., 1999; Singh et al., 2003). Other report by Sanders et al., (1996) showed that bromacil was degraded within 4 to 6 months when it was applied once compared to when it was applied twice in the same season; it was also reported that Bromacil persisted in the top 75 mm of soil for nearly a year (Alavi et al., 2008). Soil with no previous bromacil use had higher chemical residue levels in lower depths and slower degradation rates than soils with a 10 year history of asparagus management and associated bromacil use.

6. The economic implications of bromacil application methods on rangelands encroached by *Acacia karroo*

The encroachment of woody plants into grassland is a global problem. Different methods have been used to control bush encroachment and most of them have been ineffective in the total elimination of bush encroachment. There are a number of chemicals that have been used in controlling bush encroachment. Consequently, large volumes of potentially hazardous chemicals, produced by various industries and agricultural operations, are entering the ecosystem. Bromacil, a broad spectrum herbicide, is used to control undesirable woody plants on noncropland so as to increase the carrying capacity of the veld. The active ingredient (bromacil) is carried into the root zone by rain. It is readily absorbed through the root system and is then translocated to foliage. The leaves then become yellow and abscise. When new leaves are formed, they also turn yellow and abscise. This process continues until the tree no longer has reserves to initiate re-growth and so it dies. Figure 2 and 3 show the efforts of bromacil application on Acacia species in the Eastern Cape Province of South Africa.

7. Encroachment of South Africa rangelands by *Acacia karoo*

(a) (b)

Fig. 2. (a). Stand of *Acacia karoo* (b). Dead stands of *Acacia karoo* form plots treated with Bromacil

Adelaide: I week before spraying

Adelaide: I year before spraying

Fig. 3. Effect of bromacil application on Acacia *Karoo* over time

Box 1: Field Research on the Economics and Effects of bromacil Application Method

The cost implication of Bromacil application methods is vital to decisions on methods which are suitable for specific vegetation density and field size.

Methodology: The bromacil experiment was conducted at the Honeydale Section of the University of Fort Hare Research farm located at 32°47'58.78" S, 26°52'25.59" E at an altitude of 517.86 m asl in Bhisho Thornveld (Mucina and Rutherford 2006). Mean annual rainfall is 480 mm with the average summer temperature of 18.7 ^{o}C. The soil is generally characterized as a silty loam of the Glenrosa form.

The two camps were identified; one of low and the other high density *Acacia karroo* were identified. In each paddock 6 x 200m^2 plots were marked. Bromacil is applied to *Acacia karroo* plants in the marked plots; 2 of the plots were subjected to liquid spraying; the other 2 to granular spreading and the remaining 2 were treated as controls as follows: Treatment 1: Ground application (liquid) 1Lt Bushwhacker in 5Lt water. 2ml was applied for every 0.5m in height of trees. Treatment 2: Ground application (granules) about 3g – 2m, 6g- 4m and 12g ≥ 8m tree. Treatment 3: Control, no bromacil applied.

After a year following a bromacil application, herbaceous and tree height were measured. A disc pasture meter was used to measure the grass height for herbaceous biomass estimation. Tree height and canopy width was measured using a 2m rod. A tuft-to-tuft point system was used to determine species composition.

The partial budget technique was used to analyze the data for the time spent on application, volume and weight of the herbicide used time spent on cutting for penetrex and access. Teams working were monitored as was the amount of herbicide used in each plot. The cost of aerial application was known before hand. Total cost of each method per hectare was calculated, it included labour and chemical costs, furthermore, it was ascertained that the minimum area that can be aerially sprayed is 50 ha. The data on time spent on application, and volume and weight of herbicide used between treatments with the analysis of variance (ANOVA) with SAS (1999).

Low density : < 500 stands/ha

High density : > 1000 stands/ha

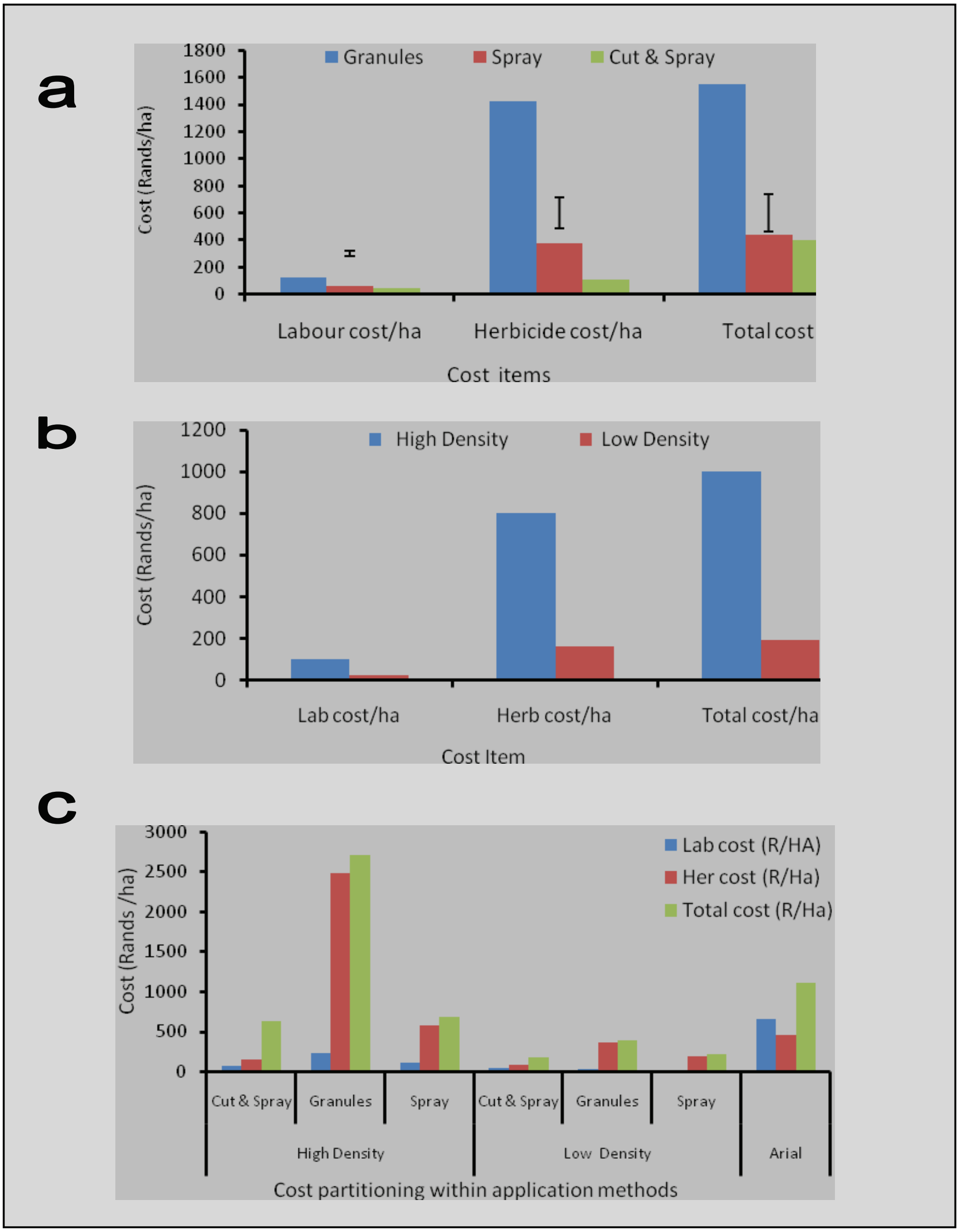


Fig. 4. (a). Absolute cost of Bromacil herbicide type and application method for the control of *Acacia Karoo* bush. (b). Absolute cost of Bromacil herbicide application on different densities of *Acacia Karoo* bush invasion. (c). A comparison aerial application cost with hand application

Box 2: Result of Field Research
Economic Implications of bromacil Application Method

The cost of bromacil was affected by bush density between the density levels. Labour was slightly higher at the high density. This could be due to large number of trees on which each has to be treated with bromacil.

The total cost of bromacil applied as granules was higher than bromacil spray and use of Penetrex and access. The time spent and labor was not different between application methods (Figure 4a). This implies that the use of granules is more expensive than the use of spray bromacil.

The time spent on bromacil application was determined by the bush density, the higher the bush density the more the time spent (Figure 4b). The amount of herbicide used was affected by the bush density. The higher density bush utilised more herbicide than the low density bush (Figure 3c). This could be due to the difficulty in movement and large number of trees and each had to get the bromacil. This implies that with hand application the high density bush will require large number of labourers for a short time or small number of labourers for a long time. In the case where labour is paid per hour per person the expenses will be high as well as herbicide purchase expenses.

The result indicated that, on a per hectare basis, it was more expensive to hand apply granules in the high density plots (R2700.ha^{-1}) compared to either spraying liquid (R675.ha^{-1}) or aerial spraying (R600.ha^{-1}). This could be due to the unease of movement for the person applying the granules, while the spray application was faster. Under low tree density aerial spraying, the cost of which does not change with density, was more expensive compared to hand application of granules (R389.ha^{-1}) compared to either spraying liquid (R207.ha^{-1}). This implies that in the low density bush, the hand application is less expensive compared with the aerial application. The cost of water used in the mixing was minimal and was not included in the calculations.

Box 3: Result of Field Research

Effects of Bromacil on Forage Productivity of Herbaceous Vegetation

Herbaceous biomass production was not affected by bromacil herbicide after one year of application. The forage yield between the plot where two forms of bromacil (granules and liquid) were applied does not vary. Rollins *et. al.*, (1988) indicated that forage yields and availability, particularly of herbaceous vegetation, is often low in dense shrub communities. Furthermore this study shows that the forage yield was similar between high and low bush densities after one year of bromacil application. The forage yield was not significantly affected by bromacil treatment after the first year of application, the pre-bromacil treatment forage yield 2083 kgDM.ha^{-1} while the post treatment forage yield was 2163 kgDM.ha^{-1}.

After the application of bromacil the forage yield under high bush density showed a higher rate of accumulation (2604 kgDM.ha^{-1}) compared to the low bush density site (1642 kgDM.ha^{-1}). Both bromacil in a granular form and in a liquid form have shown the difference in forage yield when compared with the control sites (Table 3). The bromacil treated sites have shown a great forage yield accumulation within the first year of application. The results from this study implies that there the bromacil herbicide does not affect the forage yield, regardless of the method of application.

Effects of Bush Density on the Herbaceous Vegetation and Ecological Condition Index for Herbaceous Vegetation

The grasses species are classified into their ecological status determined by their pecieved acceptability to animals and grazing. (i) Decreaser species (highly desirable species)- those species which occur in rangeland in good condition and decrease with over grazing (Sisay and Baars 2002), increaser I species (undesirable species)- those species which occur in rangeland in good condition and increase with under utilisation and increaser II species (undesirable) occur in rangeland in poor condition and increase with overgrazing. The response of grasses according to the mentioned classes the decreaser species were not affected by bromacil application, the pre-bromacil treatment and post-bromacil treatment were different after one year. Under the different bush densities the ecological index values of decreaser species was different (Table 2). The bromacil application methods (granula, spray and control) (Table 3), did not affect the ecological value of decreaser species between the granula and spray methods. However, there was a significance difference ($P<0.05$) in the ecological value index between both granular and spray application methods and control. There was no significance ($P>0.05$) in the ecological index value of increaser Ia, Ib, IIa, IIc and other species (Table 1) between pre-treatment and post-treatment. In contrast the ecological index values of increaser IIb were significantly different ($P<0.05$) between the pre-treatment and post-treatment.

Looking at the data of all species the ecological values of all species were higher in pre-treatment than in post- treatment ($P<0.05$). The ecological index values of decreasers, increaser IIa, increaser IIb, (Table 2) and other species were higher in high bush density than in low bush density sites ($P<0.05$). All the increaser I species and increaser IIc ecological values were not affected by bush density ($P>0.05$). Pooling the ecological value of all the species there were variations ($P<0.05$) between high bush density and low bush density, ecological values were higher in high bush density than in low density site. The ecological index of decreasers were significantly different ($P<0.05$) between the three bromacil treatment methods (granula, spray and control) (Table 3). There was no significant difference ($P>0.05$) in the ecological values of increaser (Ib, IIa, IIc and others) between different bromacil treatment application methods. In contrast there were variations ($P<0.05$) in the ecological index values of increaser (Ia, IIb). Concerning ecological index of the total species there were no variation ($P>0.05$) between the three treatment application methods.

Vegetation response to bromacil treatment		**Bromacil treatments**	
		Pre-treatment	**One year Post-treatment**
Biomass production (kg/ha)		2083 ± 89.7^{a}	2163 ± 89.7^{a}
Ecological status (%)	Decreaser	30.3 ± 2.2^{a}	24.3 ± 2.2^{a}
	Increaser 1a	8.2 ± 1.5^{a}	3.8 ± 1.5^{a}
	Increaser 1b	0.2 ± 0.4^{a}	0.7 ± 0.4^{a}
	Increaser IIa	15.2 ± 1.8^{a}	15.5 ± 1.8^{a}
	Increaser IIb	8.2 ± 1.8^{a}	14.3 ± 1.8^{b}
	Increaser IIc	15.8 ± 2.0^{a}	10.8 ± 2.0^{a}
	Others	2.2 ± 0.4^{a}	1.0 ± 0.4^{a}
Bush density (Plants.ha^{-1})	*A. karroo*	3221 ± 896.9^{a}	2100 ± 896.9^{a}
	Others	1442 ± 272.3^{a}	1375 ± 272.3^{a}

(a)

Herbaceous vegetation variables		**High Bush Density**	**Low Bush Density**
Biomass production.(kg-ha^{-1})		2604 ± 89.7^{a}	1641 ± 89.7^{b}
Ecological status %	Decreaser	32.7 ± 2.2^{a}	22.0 ± 2.2^{b}
	Increaser 1a	4.0 ± 1.5^{a}	8.0 ± 1.5^{a}
	Increaser 1b	0.8 ± 0.4^{a}	0.0 ± 0.4^{a}
	Increase IIa	18.5 ± 1.8^{a}	12.2 ± 1.8^{b}
	Increaser IIb	14.7 ± 1.8^{a}	7.8 ± 1.8^{b}
	Increaser IIc	15.2 ± 2.0^{a}	11.5 ± 2.0^{a}
	Others	1.8 ± 0.0^{a}	1.3 ± 0.0^{b}

(b)

Vegetation parameter		**Bromacil application methods**		
		Granular	**Spray**	**Control**
Biomass production. (kg-ha^{-1})		2159 ± 109.8^{ab}	2345 ± 109.8^{a}	1864 ± 109.8^{b}
Ecological status (%)	Decreaser	31.0 ± 2.7^{a}	32.8 ± 2.7^{a}	18.3 ± 2.7^{b}
	Increaser 1a	4.8 ± 1.8^{ab}	3.3 ± 1.8^{b}	10.0 ± 1.8^{a}
	Increaser 1b	0.5 ± 0.5^{a}	0.8 ± 0.5^{a}	0.0 ± 0.5^{a}
	Increaser IIa	16.8 ± 2.3^{a}	14.3 ± 2.3^{a}	15.0 ± 2.3^{a}
	Increaser IIb	5.8 ± 2.2^{b}	6.5 ± 2.2^{b}	21.5 ± 2.2^{a}
	Increaser IIc	12.0 ± 2.2^{a}	14.8 ± 2.2^{a}	13.3 ± 2.2^{a}
	Others	2.0 ± 2.4^{a}	1.3 ± 2.4^{a}	1.5 ± 2.4^{a}
Bush density (Plants.ha^{-1})	A. karroo	1706 ± 1098.1^{a}	3288 ± 1098.1^{a}	2988 ± 1098.1^{a}
	Others	101 ± 333.5^{a}	1881 ± 333.5^{a}	1325 ± 333.5^{a}

Means in the same row followed by same superscripts are not significantly different ($P > 0.05$).

(c)

Table 1. **(a)** Herbaceous and woody (species composition, biomass production and bush density) vegetation status before and after bromacil treatment. **(b).** Effect of bush density on herbaceous production and species composition (Mean±SE). **(c).** Effects of bromacil application methods on herbaceous biomass production, species composition and bush density (Mean ± SE).

8. Conclusion

Bromacil based herbicides are effectively used to control annual and perennial weeds. The family possesses a broad toxicity to many plant species, however, the specific compounds differ in their toxicity to plants, solubility in water and persistence in soil. The chemical is absorbed through the root system and translocated upwards via the xylem vessels to the leaves where it interferes with light harvesting complexes by blocking the photosystem II reaction. These compounds disrupt cell membranes and cause chloroplast swelling and cellular destruction. The early symptoms of bromacil kill activities in a plant is leaf chlorosis concentrated around the veins, this is often noticed at the lower leaves and gradually moves up the plant.

The current use of bromacil in agriculture is necessary so as to sustain high productivity, reduce cost, reduce drudgery and give high profit margins. There are various ways of applying bromacil; the most appropriate method is determined by the weed being treated, the herbicide being applied, the skills of the applicator and the application site. The application method determines the extent of contact with target plant and its movement within the soil. The conventional methods of application include aerial spraying and direct application to the soil. The performance of bromacil is influenced by soil characteristics, thus soils with low clay or organic matter content are highly leachable, therefore require lower application rates. The vegetation structure and composition are also very important factors to consider.

Bromacil is non-toxic to mammals, however, it is slightly toxic to fish and amphibians. The effect of Bromacil on microbial populations depends on herbicide concentration and microbial species present. Most environmental fate and impact concerns linked to the use of herbicides are related to offsite movements into aquatic ecosystems. Bromacil is mainly degraded by micro-organisms in the soil and in natural waters. The chemical is degraded mainly by light in the atmosphere through photo-oxidation. Bromacil provides for sustained weed control because of its persistence in the environment and its low degradability rates, however, this has become the cause of environmental concern especially the ecological risks. We therefore concluded that the use of bromacil in areas with important aquatic ecosystems should be carefully undertaken and monitored.

Generally granules application by hand is higher than other application methods. Bush density class had a significant effect on the cost of Bromacil application. The time and herbicide cost constitute the main items where intervention to reduce cost may be targeted. Under low tree density condition, the cost of aerial application was higher compared to hand application of granules. Full economic implication of application methods will be better assessed with; assessment of biophysical component viz., mortality rate of *Acacia karoo* plant, rate and volume of grass biomass accumulation, grass species diversity, prevalence of decreaser species and ecological benefits

In the current study bromacil herbicide did not show any effect on *Acaccia karroo* in short term. It is clear from other research that bromacil achieves its total kill in a minimum of two years under favourable conditions. The current use of bromacil in agriculture is necessary so as to sustain high productivity. The vegetation structure and composition are also very important factors to consider.

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