The Rising role of Biotechnology: A new Wave of Innovation

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Abstract

The time of cheap labour and wholesale chemical usage are drawing to a close. Environmental degradation, cost and health issues are increasingly on the agenda of any sector. Agriculture is no different. Each day consumers become more aware of what they are buying and how it was produced. The long-term health and safety effects of many conventional practices are brought up time and again. This paper seeks to add impetus to the increasing move towards more sustainable and clean production practices. The role of biotechnology as a cost effective and safe production input is explored. The study uses the example of the biological control of invasive alien plants as a means of illustrating the potential that this emerging sector holds for the global economy.

Keywords

Biotechnology
Economy
Agriculture

Long-term

1. Invasive alien plants and their control

An equivalent of over 12% of total land area of South Africa (121 909 000 ha) has been claimed by invasive alien plants (IAPs) (Henderson, 2011). These invasions impose serious economic costs, with negative impacts on the quality and availability of water resources (Van Wilgen & De Lange, 2011), biodiversity (Turpie & Heydenrych, 2000), fire intensity and erosion (DiAntonio, 2000) and human and animal health (Wise *et al* (2007). These impacts highlight the urgent need for sustainable solutions to current and future invasions, as higher levels of invasion pose a greater long run cost to the economy. Van Wilgen *et al* (2001) noted that the environmental and economic impacts of IAP invasions are not fully understood, but indications are that total costs imposed are substantial. This was supported by Le Maitre *et al* (2002) who argued that in light of the available literature regarding the range of negative impacts and rate of spread of IAPs, a failure to clear and effectively control these species will result in an exponential increase in the clearing and control costs in the future. The spread of invasive alien plant species is a problem affecting large areas of the globe, and imposes a range of costs onto local economies and environments that are set to increase into the future. Considering this, Zimmermann *et al* (2004) remarked that given limited budgets and a range of other pressing social and environmental needs, a management solution needs to be found that is able to deal with the problem at least cost and highest effectiveness.

In terms of the ability of IAPs to invade an environment, Hobbs (2000) stated that the rate of spread and level of distribution and density of IAPs can be alarming, and can lead to full scale invasions in a short period of time. This is not just a phenomenon facing South Africa, the spread of alien species is becoming an increasing problem throughout the world, as factors such as globalisation and world trade aid their distribution to environments in which they are non-native (Crowl *et al*, 2008. and Mack, 2000). Naylor (2000) noted that the spread of species across the globe poses a serious risks to native fauna and flora, as well as economic potential, and mitigates the development of effective control strategies that are minimally harmful to the environment and impose least cost on the economy. Focussing on alien plant invasions, Hobbs (2000) reported that the presence of an invasive plant species imposes negative changes on the nature of an ecosystems functioning and integrity. Considering existing pressures on biodiversity, the risks posed by IAPs are large since many indigenous species are at risk due to the spread of these plants and the subsequent change in ecosystem dynamics (Van Wilgen *et al*, 2001).

For an invasive alien plant (IAP) to invade an environment there needs to either be a vacant niche such as woody invaders (*Acacia)* exploit in generally shrubby fynbos, or the environment needs to in some way be disturbed or imbalanced to create an opportunity for the weeds to exploit such as a recently cleared area, or a lack of naturally occurring predator species (Turpie & Heydenrych, 2000). Without some sort of initial disturbance like mechanical clearing, overgrazing or erosion, IAPs generally struggle to become properly established. Hobbs (2000) however remarked that once having established, the presence of the IAP itself causes further disturbance to an environment, which, in turn creates further opportunity for new or more IAPs to invade. What is seen is that having entered an environment, IAPs initiate a cycle of environmental degradation and biodiversity loss. This is exacerbated by a lack of naturally occurring predator species that would otherwise aid in regulating the plants population and spread (Joubert, 2009). Hill and Greathead (2000) suggested that to combat such opportunistic organisms requires a solution that restores a natural balance to the environment and does not cause further disturbance and therefore create further opportunity for invasion.

Three methods of IAP control exist: mechanical, chemical and biological (Joubert, 2009). Each of these methods are discussed with conclusions as to the most appropriate method, or combination of methods, in the following section.

1.1. Mechanical

Mechanical methods of IAP control involve the felling, clearing or burning of invaded areas with labour using machinery and hand tools. This form of control is labour intensive as it requires a large number of operators who continuously remove invading species from affected areas (Working for Water, 2013). Mechanical control can, however, often be damaging to the environment and produce more opportunities for invasion. Joubert (2009) noted that when clearing weed species the surrounding vegetation and soil is disturbed, creating an opportunity for more invasive seeds to germinate and therefore cause higher levels of infestation.

In discussion of the various means of IAP control available, Hill (1999) stated that mechanical methods of control are generally suitable for smaller areas due to its labour intensive nature. Even when used only in small areas this form of IAP management still requires concerted effort to achieve success. It is also noted that once an area has been cleared using this technique, the opportunity for plants to re-establish themselves is high meaning that new invasions soon arise therefore requiring renewed clearing efforts.

1.2. Chemical

Joubert (2009) described the chemical control of IAPs as entailing the application of herbicides to invading plants or invaded areas. This form of control is therefore labour intensive as an entire area must be meticulously treated with the chosen poison. Well trained personnel are required to administer chemicals to ensure safety in application (Hill, 1999). Unintended environmental pollution or degradation may however arise through the use of this method since some herbicides are not specific to the target IAP and may therefore negatively affect indigenous species. As Hill (1999) observed, the use of chemical control methods poses the danger associated with chemical spray drift, which can be extremely harmful to surrounding vegetation and waterways.

From a cost perspective, chemical methods of IAP management often prove to be highly expensive, especially in the long run (Joubert, 2009). Hill (1999) observed that chemical control imposes a high cost due to the need for follow-up treatments in sprayed areas to ensure that invaders do not re-establish and therefore cause new or continued invasions. There is also the possibility that some plants, especially smaller ones, will be missed during application, leaving them to continue growing and therefore act as a nucleus from where the IAP can spread (Turpie & Heydenrych, 2000).

1.3. Biological

The biological control of invasive alien plants involves the introduction of foreign species of plant-feeding insects, mites or plant pathogens to reduce the target weeds' fitness and invasiveness, therefore leading to declining populations and rate of spread of problem plants (Van Wilgen & De Lange, 2011). Joubert (2009: 219) stated that: "Biological control as a means of containing an invasive alien infestation is simple in theory: Go back to the invaders native country and find organisms that curb its growth and reproduction". The control of plants can be achieved using insects, parasites, fungus or bacteria that naturally predate on the target plant (Hill & Greathead, 2000). Depending on the effectiveness of biological agents, this form of IAP control can have either complete, partial or no impact on the target species.

South Africa is a world leader in the combat of invasive alien plants (IAPs) both in terms of actual control and related research (Van Wilgen *et al*, 2004). The Working for Water (WfW) programme, a division of the Department of Environmental Affairs (Department of Environmental Affairs, 2013), is the main body pioneering large scale eradication of IAPs in the country. It was the negative impacts caused by IAPs on water availability that initially motivated for the creation of the WfW programme, especially considering that the majority of river systems in the country were in some way affected by invasive plants (Van Wilgen *et al*, 2001). The aim of the programme is to control IAPs that pose a threat to water resources thereby protecting this essential asset and ensuring long-term security of water supply (Van Wilgen *et al*, 2001). Between its inception in 1995 and April 2000, the State had spent approximately R1 billion on the WfW programme to aid in the eradication of weed species. One of the WfW's most important management tools has been the use of biological control. The research into finding and determining the safety of potential control agents is the responsibility of the ARC PPRI Weeds Research Division (Agricultural Research Council, 2012). The WfW is one of the Weeds Division's major funders, since it is the best equipped in the country to conduct much needed research into the use of biocontrol as an economically and environmentally viable control mechanism for IAPs such as *Port Jackson* and *Blackwattle.* Not only does the Division conduct research into this field, but it also creates employment opportunities for many people in the science and IAP eradication and control sector (Working for Water, 2012).

Investment in projects such as researching biological control for invasive alien plants is almost entirely driven by the public sector, as is the case with the Weeds Research Division (Hill & Greathead, 2000). This is because biological control is largely seen as a public good, where the benefits of the research are distributed throughout communities and generally cannot be captured by private interests (Black *et al*, 2008). At a time of increased financial pressures due to turbulence in world markets and increased domestic demand for state funding, the necessity of identifying the impact that such a research institution has on the economy is increasing. This is to justify the large expenditure of public funds on the Weeds Division's work, which totals about R34 million per year (Khan, 2013).

Turpie (2004) noted that the main challenge with invasive management is that mitigating the development of control strategies generally requires a quantitative assessment of why an intervention should be made. This was supported by Perrings *et al* (2000) who remarked that one of the most notable difficulties with conducting a valuation exercise on biological entities is the extent of unknowns and imprecision. The very nature of biological objects, especially invasive species, creates difficulty in taking precise measurements without going to extensive effort and cost to conduct a census or audit. Depending on environmental factors including rainfall, soil type and quality, aspect, temperature and predation, one species will perform in a variety of ways within even a small area. Without full understanding in this regard, it is difficult to comprehend exactly what the extent and impacts of an invasion are. This problem is equally experienced with invasions by alien plant species. Henderson (2013) remarked that understanding population dynamics of an IAP species is difficult because of the variance of density across the species range. This makes quantification of the impacts of IAPs and biological control challenging.

Support for IAP control needs to be shown as the financially sensible thing to do. In this regard, Van Wilgen *et al* (2001) stated that there exists no standard system for the objective quantification of the variety of impacts IAPs pose on the environment. This is because of the difficulties associated with the valuation of environmental goods and services, especially those that are of a non-market public good nature (Parker, 1999). Promoting the development of IAP management strategies therefore needs to make use of non-market valuation techniques and strong argument to quantify both the damage that IAPs impose, and the relative value of available control methods.

2. The role of biological control: Is it valuable?

Regarding the importance of preserving biodiversity, Dr Peter Schei, the International Negotiations Director at the Norwegian Directorate for Nature Management, put so aptly: "Biodiversity is the life insurance of life itself." (Weed Research Division, 2001). Hobbs (2000) reinforced this idea by noting that as globalization proceeds, there is a tendency to replace local biodiversity with global homogeneity, which increases the probability of widespread disease. The need to prevent the loss of biodiversity that occurs through IAP invasions is therefore highlighted as essential from a long-term sustainability perspective.

To deal with the increasing trend of biological invasions and pest resilience to chemicals, Orr *et al* (2008) suggested the use of integrated pest management (IPM). This was described as the process of using knowledge regarding the biology and ecology of pests and their natural predators to aid in the development of a management system that reduces the cost of pest control. This process incorporates traditional chemical and mechanical pest management practices with biological control techniques. Higgins *et al* (2001) explained that integrated pest management uses knowledge regarding the behaviour of pests and beneficial organisms to develop a method of control, which has as minimal an impact on the environment as possible. By combining traditional control measures with biological control, Higgins *et al* (2001) stated that it is possible to achieve effective pest control at the lowest possible cost, thereby providing a sustainable solution to the pest problem in the long term. Concerning the sustainability aspect, Orr *et al* (2008) noted the importance of IPM research in terms of ensuring continued crop productivity and quality, as well as minimising production costs. The same could therefore be said for the importance of research into biological control of invasive plants for preserving biodiversity and the provision of ecosystem services (Turpie & Heydenrych, 2000).

Expanding on the cost and sustainability aspects, Bale *et al* (2008) remarked that integrated pest management (IPM) has a highly favourable cost benefit ratio when compared to traditional methods of pest control. It was further stated that IPM is integral in combating the spread of chemical resistant pests and decreasing conventional agricultures reliance on chemical pesticides and insecticides. The importance of an integrated approach for ensuring sustainability is therefore once again highlighted. The idea of biological control was introduced by Bale *et al* (2008) as the use of one organism in the reduction of another organism's population. Biological control is not aimed at eradicating a pest, but rather controlling its numbers in such a way as to maintain a stable balance without having to continually apply chemical or mechanical control techniques.

Hill (1999) stated that IAPs present a problem because they generally have no predators in the environment in which they establish. They are therefore able develop a competitive advantage over native species and ultimately outcompete them. It was noted by Hayes *et al* (2007) that the aim of biological control is to restore some sort of natural balance to a disturbed environment. This is achieved by introducing a natural predator that will not prey on indigenous species but will instead specifically target the invader. Having controlled the target to natural levels, the agent will remain largely dormant due to low levels of food supply. This continues until a population boom in the target occurs. At this point, there is an increase in the availability of food which stimulates an increase in the population of the agent. Over time, the agent again controls the target to a level that re-establishes a balance (Nesser, 2013). What is seen is a process of establishing a natural equilibrium. In the absence of a natural predator, the alternative is for people to perform this function by mechanically or chemically controlling invasive species. This however proves expensive and time consuming and requires high levels of input on a continuous basis. Given the large land area of South Africa, the control of invasive species through human effort alone is prohibitive (Van Wilgen & De Lange, 2011). As an answer to this, Van Wilgen *et al* (2001) proposed the incorporation of biological control into current IAP management practices as the only viable long-term solution.

The use of biological control as a weed management tool presents a variety of benefits when compared to conventional forms of control (Joubert, 2009). According to Van Wilgen and De Lange (2011) biological control is cheaper and safer when compared to herbicide development and use. It is noted in the same paper that when well integrated with conventional forms of control, the biological control of invasive plants proves self-sustaining ensuring that long-term control costs are minimised. This is achieved through the living nature of the control agents, which respond accordingly to fluctuations in the populations of their target species. In some instances biological control agents will completely exterminate the target weed (Hill, 1999). However, in most cases, control is not complete but results in small populations of the target surviving at levels that do not adversely impact on the local environment. Klein (2011) observed that this reflects the natural balance that would have been achieved in the target's home environment under pressure from its natural predators.

Considering the persistent nature of biological invasions, such as that of invasive alien plants, the need for a sustainable control strategy is highlighted (Hill, 1999). Nesser (2013) remarked that the use of biological control presents such a solution as the control agents re-establish a natural balance in invaded environments, preventing homogenous infestations of IAPs from occurring. Instead, invasive plants become a part of the local ecosystem without imposing drastic negative impacts on local biodiversity and ecosystem service provision. Once having been established, biological agents remain in an environment and are able to respond to changes in the populations of the target plant. If there is a sudden increase in the IAP population then the population of the agent will respond to take advantage of the increased availability of food, thereby preventing an infestation from occurring (Van Wilgen & De Lange, 2011). White and Newton Cross (2000) commented that the incorporation of biological control into an IAP management strategy ensures the long-term cost of control is minimised, with only limited amounts of conventional control required where necessary. Biological control is therefore shown as an integral component of any long-term IAP management strategy. Without the use of this component the cost of control will remain high and will increase as the new invasions arise (Hobbs, 2000).

2.1. Host specificity

Although biological methods of invasive alien plant control have been identified as highly effective (Joubert, 2009), there are however some wider concerns that need to be taken into account when considering biological control as a management tool for IAPs. To begin with there are the moral and ecological considerations of introducing another foreign species into an already invaded environment (White & Newton Cross, 2000). Concerns exist as to the long-term impact that such an introduction might have on the local environment (Van Wilgen *et al*, 2001). This concern is addressed below, with evidence illustrating that there are no long-term side effects experienced as a result of the release of control agents (Joubert, 2009). A further concern is who is responsible for the final decision of whether to release an agent for control or not (White & Newton Cross, 2000). This issue is also dealt with below through reference given to relevant regulation.

Van Wilgen and De Lange (2011) stated that to ensure the introduction of a biological control agent does not have unexpected and damaging impacts on the indigenous flora and fauna, stringent host specificity testing must first be conducted. Moran *et al* (2005) described host specificity as the characteristic of a control agent to target only the invasive plant in question, therefore posing no threat of feeding or attack on indigenous or other important species such as commercial crops. This is done to properly understand the full range of impacts that an agent would have on the native environment. To achieve this understanding requires thorough research and testing, and must be carried out under strict quarantine conditions to prevent an agent escaping before its host specificity has been established (Louda *et al*, 2003). As Joubert (2009) noted, the concern exists that the introduction of a biological control agent into an already destabilised environment could lead to a further invasion, which has additional detrimental impacts on the native flora or fauna. If for example an agent is introduced that does not specifically target the host plant, then it is possible that the agent could attack certain indigenous species and cause problems equivalent to or greater than those experienced as a result of the target plant. With regards to this, Louda *et al* (2003) noted that target or host specificity is one of the main areas of focus when identifying suitable control agents. Researchers must conduct stringent host specificity testing on all potential control agents to ensure that they will only target the invader in question and not any indigenous species.

In the South African context, Klein *et al* (2011) stated that host specificity tests are conducted to comply with the strict requirements imposed by the Department of Agriculture, Forestry and Fisheries (DAFF) and the Department of Environmental Affairs (DEA), which regulate the importation, quarantine and release of foreign species for control purposes. Sandham *et al* (2010) remarked that these regulations have been developed to ensure only agents that are proven safe for release and that will cause minimal damage to indigenous species are allowed for use in the control of invasive alien plants. Locally, it is the responsibility of the ARC PPRI Weeds Research Division to conduct this host specificity testing (Plant Protection Research Institute, 2005). It was noted by Joubert (2009) that, to date, no unanticipated effects of biological control agents have been experienced in South Africa for the control of IAPs. This, however, is not the case with generalist species that have been introduced by other groups in the past, such as fish and mammals. Klein (2011) asserted that the fastidiousness of weed biocontrol researchers in South Africa has ensured released agents are strictly host specific.

2.2. Biological vs conventional

Van Wilgen and De Lange (2011) observed that the debate about which control option is the most appropriate in the South African context is one that involves a trade-off between the creation of a large number of jobs though conventional control methods, versus the long term cost saving achieved through implementation of biological control research.

In a country with an unemployment rate of 25.5% (Statistics South Africa. 2014), the argument for the use of public works programmes such as Working for Water (WfW) to create large amounts of employment opportunities is strong (McQueen *et al*, 2001). More than 20 000 jobs per annum have been created through WfW since 1995 (Working for Water, 2013). The majority of these have been targeted at the marginalised and individuals with low skill levels. The programme has social upliftment as one of its main drivers, with targets such as creating 18 000 jobs per year for previously unemployed people (60% for women and 20% for youth) and compulsory training for all staff including HIV/AIDS awareness. Employment creation is therefore at the centre of this initiative, which is the likely reason for the continued political and financial support it has received.

In terms of the value realised through public works programmes, Subbarao *et al* (1997) remarked that investment into these types of projects is a useful tool for carrying out countercyclical interventions. It was further noted that such programmes have been used throughout the world with success in aiding consumption smoothing for poor households. Adato *et al* (2005) supported this with the finding that participation in public works programmes has a positive effect on labour and employment, particularly in terms of opportunities for women. Subbarao *et al* (1997) however concluded that, while such interventions are useful as temporary safety nets for the social challenges of unemployment and poverty, these should not be viewed as permanent or sustainable solutions to said issues.

McCord (2006) provided endorsement for this view by noting that available literature suggests that investment into public works programmes does not present long-term solutions for transformative social protection. Rather, this sort of investment is useful for smoothing consumption of poor households during cyclical or structural dips.

Regarding the strategy for IAP management, Moran *et al* (2005) stated that biological control is an important tool for dealing with IAP invasions, especially considering the long-term threat that these pose to the South African environment, economy and society. Although the Working for Water (WfW) programme is able to use conventional methods to create a large number of employment opportunities in the current period, these jobs could largely prove unsustainable in the long run given the many other social, environmental and economic constraints experienced in this country (Zimmermann *et al*, 2004). If funding were to be shifted away from the WfW programme then the invasive nature of IAPs would soon undo all the work that has already been put into gaining control over these species (Van Wilgen *et al,* 2001). With no funding, salaries cannot be paid meaning people cannot be employed and IAPs cannot be cleared. Invasive plants would therefore be left without natural predators or other forms of control, and could quickly spread and infest large tracts of pristine land. Under such circumstances the investment that has been made to date into conventional control of IAPs would be pointless.

Noting that clearing of IAPs is worthwhile simply to protect and conserve water resources (Van Wilgen *et al*, 2001), the argument for the use of biological control as a means of eradicating these species is promoted. This is because this form of control is cheaper than conventional methods and is more sustainable in the long run (Moran *et al*, 2005). Biological control was identified by Van Wilgen *et al* (2001) as the most cost effective means of controlling the spread of IAPs. This is because the costs involved in biological control are limited to the initial research and quarantine of potential agents, followed by the subsequent rearing, release and monitoring costs involved when a suitable agent is found (Plant Protection Research Institute, 2006). Once an agent has been established, no further costs are incurred except for possible further releases in areas where the agents cannot themselves gain access. For the rest, the agents are able to spread by themselves and will respond to new invasions of the target by increasing their own population through natural processes in response to the increased availability of food. This is compared to the cost of conventional control, which is fairly constant over time (Joubert, 2009) and is associated with the cost of labour, training, transport, equipment and chemicals. These costs will continue to be incurred for as long as control is necessary, with costs rising over time. Considering that total eradication of IAPs is highly unlikely (Hill, 1999) and that new invasions are likely to arise through the spread of species across the globe, the cost of conventional control will increase in the future in response to increased need for management. Hobbs (2000) suggested this means that, over time, progressively more state funding would need to be dedicated to IAP control to prevent massive costs incurred through a loss of biodiversity, land degradation, water management and agricultural activities. White and Newton Cross (2000) stated that it is important to realise the use of biological control does not eliminate control costs completely, rather it significantly reduces these costs.

Joubert (2009) remarked that, as a nation, it is necessary to develop a variety of strategies for the control of invasive species. Amongst these strategies biological control is given a high ranking as a management tool that is constantly prepared to deal with the spread of an IAP at minimal cost, and should therefore be a primary focus of the national control strategy (Van Wilgen & De Lange, 2011). What this suggests is that although biological methods should be used as the primary tool for IAP control, conventional methods should still form an integral part of the management approach. This is especially necessary in cases where no safe biological agents can be found or where biological methods are not 100% effective (White & Newton Cross, 2000). In such instances the use of conventional control will need to be adopted to ensure that these species are not allowed to establish themselves as large scale invaders. This suggests that while biological methods should become an increasing area of focus for IAP control, there still remains an important role for conventional methods, but that this should be confined to species for which biocontrol is not possible. As such, it is still possible to reap the benefits of employment creation through the WfW programme, however, these will be more limited in nature and directed towards those species that cannot be controlled biologically.

2.3. Cost considerations

Considering the relative value of investment into conventional and biological control respectively, Van Wilgen *et al* (2001) estimated the cost of controlling all local invasions using each option. The total cost of bringing IAPs under control in South Africa using conventional means only was estimated to be approximately R12 billion, or R600 million per year for the next 20 years. With the use of biological control however, the total cost of control is estimated to decrease to a total of R4 billion, or R200 million per year (Van Wilgen *et al*, 2001). This presents a massive saving of state funds, which could then be used elsewhere to create meaningful employment and training opportunities for unskilled or semiskilled labour. Such investment could be in education and healthcare, or creating productive public works programmes where options for decreased spending do not exist. Pursuing biological methods to control IAPs therefore present a much more manageable expenditure option for a developing country with a range of other social, environmental and economic challenges. Pimental *et al* (2001) noted that an investment into biological control research in the current period will produce large dividends over the long term. This is because it will no longer be necessary to carry out continuous control using conventional methods, which impose a sustained cost to the economy. An interesting question to consider in this regard is what the long term cost implications would be if biological control were not used to combat IAP invasions. Although not given in this study, such an aspect would highlight the value of biological methods for keeping long-term control costs to a minimum (White & Newton Cross, 2000). Overall however, implementing the research work of the Weeds Division leads to massive savings in the total cost of controlling IAP invasions.

This point was re-iterated by Joubert (2009), who stated that although biological control agents are at times expensive and difficult to find, they offer a solution to the IAP problem not only within South Africa, but also beyond its borders. Specific reference is given to the countries that boarder South Africa, as these also suffer large negative impacts from the spread of invasive plant species (Mack, 2000). These countries are however largely unable to effectively deal with this challenge, due to limitations of poor economic performance and human capital development. Considering the relatively developed and well financed nature of the South

African economy, as compared to the underdevelopment and financial constraints largely experienced by our neighbours, biological control offers an opportunity for increased regional cooperation and support, which positively impacts on especially the lives of rural poor. This highlights the importance of biological control research for the Southern African region as a whole, with South Africa as the leader in this regard.

3. Closing remarks

An extremely important facet to remember when considering an investment into environmental research is the time dimension over which the subsequent payoff will be realised. True, an investment into manual control does hold a high redistributional value at that point in time, however the payoff from such an investment ceases the moment the investment stops: no more money invested, no more jobs, and no more redistribution. This effect is compounded by the back-track in the progress of controlling invasive alien plants. As soon as the investment stops, the clearing stops, and the weeds can once again invade largely unabated – with the benefits achieved from clearing soon to be lost. Biological control research on the other hand continues to provide a payoff long after the investment stops, with that payoff often only being realised years after the initial investment (Price, 2013). It is this delay in receiving payoff that often leaves investment into biological control seemingly unappealing. The reality, however, is that an investment in the current period into biological control research will produce large positive benefits in the future. These benefits far outweigh the benefits of current spending on conventional control (Joubert, 2009). Biological control research will result in the need for lower expenditure on IAP control in the future, representing a significant economic cost saving. The need to appreciate the existence of a delay in payoff must be recognised for biological control research to be properly supported. This is especially the case given that in some instances a delay of up to 20 years is experienced between initial research investment and the achievement of control (Nesser, 2013).

It is important to note that although biological control methods may often not result in immediate control of target species, their role is rather to re-establish a more natural functioning of invaded areas that in time allows the re-establishment of indigenous vegetation (Nesser, 2013). Degraded land does not provide the same level of opportunities as land in its natural state. Pimental *et al* (2001) noted that this state may be slightly altered by a low degree of invasion by foreign species, however as long as it retains its natural equilibrium it will be able to provide bountifully. Weed species are typical pioneers, and largely arise in areas that suffer from land degradation due to poor management practices. These weeds do however play an important role in preparing the degraded land for recolonisation by indigenous species that otherwise would struggle to establish themselves. The slow acting nature of biological control can therefore be seen to be more supportive of the natural process of re-establishment of indigenous species than conventional methods of control, which cut short the cycle of pioneer weeds followed by successive growth of indigenous species (Van Wilgen & De Lange, 2011).

In terms of the use of biological control as a component in a larger IAP control strategy, Bale *et al* (2008) noted that biological pest management has the potential to be highly successful in controlling problem species, but that more research into this area is needed in order to improve effectiveness. Such research includes investigation into the nature of a variety of different pests' predators. With hundreds of predators for each pest, much research still needs to be conducted into which of these is the best at controlling a specific pest, and how predator populations can be grown to a size where they can effectively combat such a pest. Work must also be focussed on changing the agricultural industries perception of biological control. Currently it is still viewed by many as an ineffective mechanism of pest management. The value of biocontrol needs to be conveyed to key individuals in order to increase the number of practitioners using this technique (Bale *et al*, 2008).

As part of a larger research area in South Africa, the Weeds Research Division holds value through its contribution to the biotechnology sector, which has been identified as one of South Africa's strategic areas of future development (Uctu & Essop, 2012). It has previously been noted in the study that South Africa is a global leader in biocontrol research, already providing a competitive advantage in the sector (Van Wilgen *et al*, 2004). Ashiem and Coenen (2005) noted that as a result of globalisation, competition between nations has increased and therefore so has the need for development of competitive advantages in unique areas. Research into biological control of IAPs fosters the development of strategic scientific competencies, which are increasingly in demand considering the shifting nature of world economies and society towards a more sustainable or 'green' mode of conducting business (Jordaan & Jordaan, 2010). By providing increased support for existing biological control research, a small yet established industry will be encouraged to develop further, creating improved national scientific competencies and therefore possibilities for growth. The work of the Division positions South Africa as a potential global leader in the development of biological environmental and agricultural management systems. An increase in the support for biological control research will in turn support the decreased need for conventional control methods and chemical reliance.

The biological control of invasive alien plants is but one example of the possibilities that investment into biotechnology can provide for the agricultural sector. Although this study focusses more on the environmental aspects associated with this form of control, the use of other biotechnology inputs in the agricultural sector could yield significant long-term cost savings and other benefits associated with lower environmental impact. Issues such as soil fertility can be addressed through nematology, reducing the need for chemical fertilizer (Plant Protection Research Institute, 2005). The use and cost of chemical herbicides, pesticides and fungicides could be drastically reduced through the implementation of improved biological control regimes for agricultural pests. Biotechnology could even be used to produce biofuel to decrease society's reliance on oil (Benemann, 2008). What this study aims to show is that the opportunities for the implementation of biotechnology are vast. This study has only focused on the use of biological control in the management of invasive plants, but the underpinning principles and theory hold true across many sectors. The green revolution was followed by a period of high reliance on chemical inputs into agriculture. The effects of this reliance are becoming increasingly apparent, with lands becoming infertile and the need for ever increasing applications of chemical inputs necessary to sustain production. This is not a solution that is going to last forever. The soil is a living organism that needs to be treated as such with living inputs. The use of biotechnology in agriculture presents the next wave of innovation in the sector, and promises to result in practices that are more sustainable and which build the environment that we so basically depend on. By increasingly implementing these technologies into everyday practice, it will be possible to nurture a flourishing environment that in turn nurtures flourishing societies.

References

ADATO, M., HODDINOTT, J. and HADDAD. L. (2005). *Power, Politics, and Performance: Community Participation in South African Public Works Programs.* International Food Policy Research Institute. [online]. Available: http://www.ifpri.org/sites/default/files/publications/ab143.pdf. [accessed 30 October 2013].

AGRICULTURAL RESEARCH COUNCIL. (2012). *ARC Strategic Plan 2012/13-2016/17*. Agricultural Research Council. Pretoria.

ASHIEM, B.T. and COENEN, L. (2005). Knowledge bases and regional innovation systems: Comparing Nordic clusters. *Research Policy.* 34: 1173–1190.

BALE, J.S., VAN LENTEREN. J.C. and BIGLER, F. (2008). Biological control and sustainable food production. *Philosophical transactions of the Royal Society.* 363: 761-776.

BENEMANN, J.R. (2008). *Opportunities and challenges in algae biofuels production.* Algae World Conference. Singapore.

BLACK, P., CALITZ, E. and STEENKAMP, T. (2008). *Public Economics.* Oxford University Press Southern Africa. Cape Town.

CROWL, T.A., CRIST, T.O., PARMENTER, R.R., BELOVSKY, G. and LUGO, A.E. (2008). The spread of invasive species and infectious disease as drivers of ecosystem change. *Frontiers in Ecology and Environment.* 6(5): 238-246.

DEPARTMENT OF ENVIRONMENTAL AFFAIRS. (2013). *Working for Water*. Department of Environmental Affairs. [online]. Available: https://www.environment.gov.za/projectsprogrammes/wfw. [accessed 10 May 2014].

DiANTONIO, C.M. (2000). *Fire, plant invasions, and global changes.* In MOONEY, H.A. and HOBBS, R.J. (eds). (2000). *Invasive species in a changing world.* Island Press. Washington.

HAYES, L., FOWLER, S., PAYNTER, Q., GROENTEMAN, R., PETERSON, P., DODD, S. and BELLGARD, S. (2007). Biocontrol of weeds: achievements to date and future outlook. In

DYMOND, J.R. (ed). (2007). *Ecosystem services in New Zealand – conditions and trends*. Manaaki Whenua Press. New Zealand.

HENDERSON, L. (2013). *Personal communication.*

HENDERSON, L. (2011). Mapping of Invasive alien plants: the contribution of the Southern African Plant Invaders Atlas (SAPIA) to biological weed control. *African Entomology*. 19(2): 498-503.

HOBBS, R.J. (2000). *Land use changes and Invasions.* In MOONEY, H.A. and HOBBS, R.J. (eds). (2000). Invasive species in a changing world. Island Press. Washington.

HIGGINS, S.I., RICHARDSON, D. and VAN WILGEN, B. (2001). Integrated control of invasive alien plants in terrestrial ecosystems. *Land Use and Water Resources Research*. 1(5): 1-6.

HILL, M.P. (1999). Biological control of red water fern, *Azolla filiculoides* Lamarck (Pteridophyta: azollaceae), in South Africa. *African Entomology Memoir*. 1: 119–124.

HILL, M.P. and GREATHEAD, D. (2000). *Economic evaluation in classical biological control*. In PERRINGS, C., WILLIAMSON, M. and DALMAZONE. S. (eds). (2000). *The economics of biological invasions.* Edward Elgar Publishing Limited. Cheltenham.

JORDAAN, A.S. and JORDAAN, D.W. (2010). *Reality bites: Biotech innovation in South Africa.* [online]. Available: https://web.up.ac.za/sitefiles/file/44/1026/2163/8121/Reality%20bites%20-%20biotech%20innovation%20in%20South%20Africa(1).pdf. [accessed 12 October 2014].

JOUBERT, L. (2009). *Invaded: The biological invasion of South Africa.* Wits University Press. Johannesburg.

KHAN, A. (2013). *Personal communication.*

KLEIN, H. (2011). A catalogue of the insects, mites and pathogens that have been used or rejected, or are under consideration, for the biological control of invasive alien plants in South Africa. *African Entomology*. 19(2): 515–549.

LE MAITRE, D.C., VAN WILGEN, B.W., GELDERBLOM, C.M., BAILEY, C., CHAPMAN, R.A. and NEL, J.A. (2002). Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. *Forest Ecology and Management.* 160: 143

LOUDA, S.M., PEMBERTON, R.W., JOHNSON, M.T. and FOLLETT, P.A. (2003). Nontarget effects – the Achilles heel of biological control? Retrospective analyses to reduce risk associated with biocontrol introductions. *Annual Review of Entomology*. 48: 365–396.

MACK, R.N. (2000). *Assessing the extent, status, and dynamism of plant invasions: current and emerging approaches.* In MOONEY, H.A. and HOBBS, R.J. (eds). (2000). *Invasive species in a changing world.* Island Press. Washington.

MORAN, V.C., HOFFMANN, J.H. and ZIMMERMANN, H.G. (2005). Biological control of invasive alien plants in South Africa: necessity, circumspection, and success. *Frontiers in Ecology and the Environment.* 3: 77–83.

McCORD, A. (2006). *Are Public Works an Alternative to a Basic Income Grant?* Southern Africa Labour and Development Research Unit. University of Cape Town. South Africa.

McQUEEN, C., NOEMDOE, S. and JEZILE, N. (2001). The Working for Water Programme. *Land use and water resources research.* 1(4): 1-4.

NAYLOR, R. (2000). *The economics of alien species invasions.* In MOONEY, H.A. and HOBBS, R.J. (eds). (2000). *Invasive species in a changing world.* Island Press. Washington.

NESSER, S. (2013). *Personal communication*.

ORR, L.M., STEVENS, M.M. and MULLEN, J.D. (2008). *An evaluation of the economic, environmental and social impacts of NSW DPI investments in IPM research in invertebrate rice pests*. NSW Department of Primary Industries. Australia.

PARKER, I.M. (1999). Impact: toward a framework for understanding the ecological effect of invaders. *Biological Invasions.* 1: 3-19.

PERRINGS, C., WILLIAMSON, M. and DALMAZONE, S. (eds). (2000). *The economics of biological invasions.* Edward Elgar Publishing Limited. Cheltenham.

PIMENTAL, D., MCNAIR, S., JANECKA, J., WIGHTMAN, J., SIMMONDS, C., O'CONNELL, E., WONG, L., RUSSEL, J., ZERN, T., AQUINO, T. and TSOMONDO, T. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems, and Environment.* 84: 1-20.

PLANT PROTECTION RESEARCH INSTITUTE. (2005). *Plant protection services in the ARC.* Unpublished Report. Agricultural Research Council. Pretoria.

PLANT PROTECTION RESEARCH INSTITUTE. (2006). *Research and technology report.* Agricultural Research Council. Pretoria.

SANDHAM, L.A., CARROLL, T.H. and RETIEF, F.P. (2010). The contribution of Environmental Impact Assessments (EIA) to decision making for biological pest control in South Africa – the case of *Lantana camara. Biological Control.* 55: 141-149.

STATISTICS SOUTH AFRICA. (2014). *Quarterly labour force survey, Quarter 2, 2014*. Statistics South Africa. [online]. Available: http://beta2.statssa.gov.za/publications/P0211/P02112ndQuarter2014.pdf. [accessed 9 October 2014].

SUBBARAO, K.., BONNERJEE, A., BRAITHWAITE, J., CARVALHO, S., EZEMENARI, K., GRAHAM, C. and THOMPSON, A. (1997). *Safety Net Programs and Poverty Reduction, Lessons from Cross Country Experience.* The World Bank. Washington.

TURPIE, J. (2004). The role of resource economics in the control of invasive alien plants in South Africa. *South African Journal of Science.* 100: 87–93.

TURPIE, J. and HEYDENRYCH, B. (2000). *Economic consequences of alien infestation of the Cape Floral Kingdom's Fynbos vegetation.* In PERRINGS, C., WILLIAMSON, M. and DALMAZZONE, S. (eds). (2000). *The Economics of Biological Invasions*. Edward Elgar Publishing Limited. Cheltenham.

UCTU, R. and ESSOP, H. (2012). *The Role of the South African Government in Developing the Biotechnology Industry – from Biotechnology Regional Innovation Centres to the Technology Innovation Agency.* Stellenbosch Economic Working Paper 19(12). Stellenbosch.

VAN WILGEN, B.W. and DE LANGE, W.J. (2011). The costs and benefits of biological control of invasive alien plants in South Africa. *African Entomology.* 19(2): 504–514.

VAN WILGEN, B.W., DE WIT, M.P., ANDERSON, H.J., LE MAITRE, D.C., KOTZE, I.M., NDALA, S., BROWN, B. and RAPHOLO, M.B. (2004). Costs and benefits of biological control of invasive alien plants: case studies from South Africa. *South African Journal of Science.* 100: 113–122.

VAN WILGEN, B.W., RICHARDSON, D.M., LE MAITRE, D.C., MARAIS, C. and MAGADLELA, D. (2001). The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa. In PIMENTAL, D. (ed). (2002). *Biological invasions: economic and environmental costs of alien plant, animal and microbe species*. CRC Press. London.

WEEDS RESEARCH DIVISION. (2001). *Nomination of the Weeds Research Division of the ARC-Plant Protection Research Institute for the 4th NSTF Science & Technology Awards for 2001 in the category*: “Those corporate organizations which have made the most significant contribution to SET in the last ten years”. Agricultural Research Council. Pretoria.

WHITE, P.C. and NEWTON CROSS, G. (2000). *An introduced disease in an invasive host: ecology and economics of rabbit calicivirus disease (RCD) in rabbits in Australia.* In PERRINGS, C., WILLIAMS, M. and DALMAZZONE, S. (eds). (2000). *The economics of biological invasions*. Edward Elgar Publishing Limited. Cheltenham.

WORKING FOR WATER. (2012). *Home page*. Department of Water Affairs. [online]. Available: http://www.dwaf.gov.za/wfw/. [accessed 6 September 2012].

WORKING FOR WATER. (2013). *Working for Water (WfW) Programme.* Department of Environmental Affairs. [online]. Available: https://www.environment.gov.za/projectsprogrammes/wfw. [accessed 10 June 2013].

ZIMMERMANN, H.G., MORAN, V.C. and HOFFMANN, J.H. (2004). Biological control in the management of invasive alien plants in South Africa, and the role of the Working for Water programme. *South African Journal of Science*. 100: 34-40.