University of the Witwatersrand
School of Animal, Plant and Environmental Sciences

Towards sustainability of harvesting the medicinal plant *Pelargonium sidoides* DC. (GERANIACEAE)

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Dissertation
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ABSTRACT

Pelargonium sidoides has been used for centuries in traditional medicine in Lesotho and South Africa as well as globally in modern medicine. Consequently *P. sidoides* tubers have been wild-harvested extensively in Eastern Cape and Lesotho to meet the growing trade demand. In recent years, the number of plant gatherers intending to supply markets and generate incomes have increased. Tubers are targeted because they contain medicinal properties. The medicinal compounds in the tubers are thought to be highly correlated with colour, with their concentration increasing as the colour develops towards dark-red. Dark-red coloured tubers seem to be preferred by the Pelargonium industry and are considered to be mature. Repeated harvesting of *P. sidoides* plants from the wild has been reported to result in localized population declines. This is exercabated by harvesting methods currently used which involve entire removal of the plant and not filling up harvest holes to safeguard tuber remnants left in the soil. Although various studies have investigated the impacts of such harvesting operations on *P. sidoides* wild populations, these studies have not provided information on tuber recovery rate and suitable recommendations to ensure sustainable harvest of *P. sidoides* from the wild. Therefore this study investigated (i) rate of tuber recovery in *P. sidoides* plants, (ii) impacts of wild harvest on its tuber recovery and (iii) made recommendations on sustainable harvest options for the species. The investigations were made using linear and non-linear regression models and ANOVA. Comparisons were done for “lowveld” (Eastern Cape) and “highveld” (Lesotho and Free-State) vegetation regions.

The rate of *P. sidoides* tuber recovery was measured by tuber recovery colour and biomass in previously wild-harvested sites. Tuber regrowth rate in cultivated sites was also investigated in the same manner to determine prospects for cultivation. Time since last harvest was found to affect tuber recovery colour and biomass. As time since last harvest increased in the “lowveld” and “highveld” vegetation regions, tuber recovery colour and biomass also increased (lowveld- r^2= 0.63, P < 0.05, d.f = 7 and highveld- r^2= 0.55, P < 0.05, d.f = 5). In cultivated sites, only tuber regrowth using biomass was found to increase positively with time when study sites from the “lowveld” and “highveld” vegetation regions were combined (r^2= 0.68, P < 0.03, d.f = 8).

P. sidoides tuber recovery size was found to be smaller in previously wild-harvested sites compared to tuber size in unharvested control sites in the “lowveld” and “highveld” vegetation regions (lowveld- $F_{11,95}$= 9.7226, P < 0.001, highveld- $F_{23,99}$= 7.0519, P < 0.001). Cultivated plants also had more tuber regrowth size than tuber recovery size of previously wild-harvested sites showing that cultivation can be a viable option to produce the resource and contribute to the conservation of the wild resource.

To ascertain under which scenarios *P. sidoides* can be harvested sustainably in the wild, factors which affect sustainable harvesting of *P. sidoides* such as effects of depth of harvest hole, mother tuber size (biomass), canopy area and altitude on tuber recovery biomass, tuber recovery colour and number of stems/plant were explored. Although results that were obtained varied, filling harvest holes with soil post-harvest increased tuber recovery biomass meaning that this factor can be included in *P. sidoides* harvesting guidelines. Furthermore, tuber and tuber recovery biomass tended to increase with an increase in canopy area suggesting that canopy size can be used as a surrogate for tuber size (tuber recovery biomass r^2= 0.81, P < 0.05, df = 7, tuber biomass- r^2= 0.57, P < 0.05, df = 7).

The findings of this study revealed that tuber recovery colour and biomass in previously wild-harvested sites increased positively with time. *P. sidoides* plants were found to require ≥8 years for tuber recovery to develop the dark-red colouration and ≥10-15 years for previously wild-harvested plants to reach pre-harvest biomass. Furthermore, tuber recovery size in previously wild-harvested sites was found to be smaller compared to tuber size in unharvested sites even after 8 years since last harvest suggesting that tuber recovery size has not reached pre-harvest size after this period. Hence this confirms that even a single return harvest event within a 10 to 15 post harvest period can negatively affect wild populations of *P. sidoides*. This period is however too long for a sustainable Pelargonium industry thus questioning wild harvest as a viable methodology without rigorous ongoing monitoring and management of wild harvest sites. This is despite training on sustainable harvest, such as harvest methods provided by the Pelargonium industry. Conversely, prospects for cultivation as a viable alternative to wild harvest seem promising since cultivated plants only required ≥9 years to attain similar biomass to that of unharvested wild plants. Given that it is unclear what the Pelargonium industry considers as commercially acceptable for *P. sidoides* tuber characteristics, the tuber regrowth rate of ≥8years in cultivation may be shortened to meet trade specifications.

The study also showed that for sustainable wild harvest of *P. sidoides*, harvest operations should entail effective closure of harvest holes with soil to ensure the survival of tuber remnants. Additionally, plants with bigger canopies may be targeted when harvesting *P. sidoides* in previously wild-harvested and new harvest areas. It must be noted though that a thorough investigation is needed to ascertain whether canopy size can be confidently used as surrogate for tuber size. Therefore further research into sustainable harvest methods for *P. sidoides* is recommended, and direct longer term monitoring of selected sites would be useful. More research is also needed on tuber colour development in cultivated plants and what constitutes commercially harvestable tubers.

DECLARATION

I declare that this dissertation is my own original work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before either in part or in full for any degree or examination at any other university.

Motjotji

Lisebo Motjotji

6th day of September 2011

DEDICATION

This work is dedicated to my children; my son Kopano Wilfred and my daughter Retšepile Hope.

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I will forever be grateful for the assistance that my three supervisors provided throughout the entire study and their unwavering support.

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LIST OF SYMBOLS AND ACRONYMS

APCV:	Annual Precipitation Coefficient of Variation
BMP:	Biodiversity Management Plan
CBD:	Convention on Biological Diversity
CITES:	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DEA:	Department of Environmental Affairs
DoE:	Department of Environment
DEDEA:	Department of Economic Development and Environmental Affairs
GoL:	Government of Lesotho
MAP:	Mean Annual Precipitation
MAPs:	Medicinal and Aromatic plants
MAT:	Mean Annual Temperature
ISSC-MAP:	International Standard for Sustainable Wild Collection of Medicinal and Aromatic plants
TESA:	TRAFFIC East/ Southern Africa

GLOSSARY OF TERMS

Point of cut: where the mother tuber was chopped off during harvest.

Tuber recovery: New tuber formation post-harvesting that formed from the point of the cut.

Tuber regrowth: New tuber formation from tuber cuttings used for initial propagation in cultivated sites.

Tuber: All tubers from unharvested control sites.

Mother tuber: This referred to the original tuber that possessed the point of cut.

Remains: All the original pre-harvest tubers, as well as the mother tuber, remaining in the ground post-harvest.

Cultivated plants: This referred to plants from semi-wild and agricultural sites.

Chapter 1

1.0. INTRODUCTION

1.1. Medicinal plant use, trade and sustainability

All over the world, wild plants have been utilized by people as food, ornaments, fuel, spices and most importantly in traditional medicine (Cunningham, 2001). For thousand of years, wild plants have formed the basis of traditional medicine systems and continue to provide mankind with new remedies (Samuelsson, 2004; Cragg and Newman, 2005). In traditional medicine, wild plants are used as medicinal plants to build health, stave off disease or even promote recovery from illness or misfortune (*Anon*., 2000; Hamilton, 2008). Medicinal plants can also be used for spiritual, cultural and cosmetic purposes (Dold and Cocks, 2002). This is mostly true for the poor and marginalized people who cannot afford modern medicine and are therefore left with few alternatives but to resort to traditional medicine (Hamilton, 2008). Moreover many people, mostly in developing countries, also derive a large part of their subsistence needs and income from wild plants (Iqbal 1993; Walter 2001). Thus during financial difficulties, collection of medicinal plants to sell can be a useful source of income for the economically marginalized communities (Hamilton, 2008). The high demand for traditional medicine is also caused among others by high cultural value placed on traditional medicine, high population growth and rapid urbanization (Williams *et al.,* 1997, 2007; Dold and Cocks, 2002).

It is estimated that 50 000- 70 000 plant species are used in traditional and modern medicine systems throughout the world. Out of these, 3000 Medicinal and Aromatic Plants (MAPs) species are involved in international trade (Schippmann *et al.*, 2005). For example, in both Lesotho and South Africa, medicinal plant species such as *Pelargonium sidoides*, *Harpagophytum procumbens* and *Harpagophytum zerheri, Agathosma betulina* and *Aloe ferox* are used locally in traditional medicine and by international phytomedicine companies (van Wyk and Gericke, 2000). In South Africa, it is estimated that 27 million people use traditional medicine (Botha *et al*., 2001) and the trade in medicinal plants is estimated to be worth R270 million per annum (Cunningham, 1991; Mander, 1998; Dold and Cocks, 2002). However, due to increased demand for medicinal plants, harvesting of wild plants which used to be done by experienced traditional healers is being carried out by untrained commercial gatherers to supply formal trade (Cunningham, 1991). Commercial harvesting is often more destructive than customary harvesting practices (Williams *et al*., 1997) and hence can have devastating effects on targeted plants.

Commercialization of medicinal plants becomes a particularly difficult problem if these plants are collected from the wild (Pen-gen, 1991; Srivastava *et al.,* 1996; Lange and Schippmann, 1997) thus putting pressure on the wild populations to supply local and international markets. This is probably because commercialization has been reported to exacerbate difficulties associated with mananaging harvested populations sustainably (Godoy and Bawa 1993; Luoga *et al.,* 2004).This is especially the case when demand is high and harvesters lack tenure or strong usufruct rights and/or the customary rules of uses have been eroded (Godoy and Bawa 1993; Luoga *et al.,* 2004).

On the other hand commercialization of wild plants can be an important strategy in underdeveloped countries where people are economically vulnerable and governments have been unable to provide some basic services (Shackleton *et al.,* 2007). Thus harvesting of medicinal plants for trade becomes an integral component of rural livelihoods throughout the developing world, especially for women who are the most vulnerable sector of rural society and who may have no other means of income generation (Shackleton and Shackleton, 2004). Hence the significance of medicinal plant conservation stems from the cultural, livelihood or economic roles that the plants play in people's lives (Hamilton, 2003). However this may be at odds with conservation objectives (Shackleton *et al.,* 2007). Therefore finding a balance between natural resource use and conservation of these plants can become a challenge when dealing with the commercial use of wild resources, especially by the rural poor (Emanuel *et al*., 2005; Shackleton and Shackleton, 2007). This becomes even more so if the majority of the medicinal plants are collected unsustainably and the plants are collected for their tubers. This is because there is currently a lack of information on sustainable harvest levels for species collected for their tubers (Cunningham, 2001). Furthermore, intensive harvesting of medicinal plants is considered as one of the serious threats to biodiversity and many wild populations of indigenous plants are in danger of over-exploitation and extinction (Williams *et al*., 1997; Dold and Cocks, 2002).

Pelargonium sidoides is one such plant species which is harvested from the wild for its tubers. The plant has been used for centuries as a traditional medicine in Lesotho (Phillips, 1917 cited in Brendler and van Wyk, 2008; *Anon*., 1931 cited in Brendler and van Wyk, 2008) and South Africa (Watt and Breyer-Brandwijk, 1962; Hutchings, 1996; Matsiliza and Barker 2001; Lewu *et al*., 2007; Brendler and van Wyk, 2008) as well as globally in modern medicine for the treatment of respiratory problems (Brendler and van Wyk, 2008). Several studies have reported unsustainable harvest from the wild as a result of extensive harvest to supply local and international markets (Vlok, 2003, 2005; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008; Newton *et al*., *in prep.*). These studies focused mainly on, among other things, estimation of plant densities, number of leaves per plant, resprouting and flowering ability but not on how *P. sidoides* tubers are affected by harvest. Although these previous studies have generally been helpful, key information is lacking regarding sustainability of wild harvest for plants harvested for their tubers such as *P. sidoides* and hence has implications for conservation.

1.2. Species description and distribution

Pelargonium sidoides DC. (*Geraniaceae* section *Reniformia)* commonly known as geranium, umckaloabo, kalwerbossie (Afrikaaans), rabassam (Afrikaans), icwayiba (isiXhosa), uvendle (isiXhosa), ikhubalo (isiXhosa), khoara (Sesotho) or khoara e nyenyane (Sesotho) is a perennial plant with velutinous, rosulate, fairly aromatic and velvety leaves arranged in a basal cluster (van der Walt and Voster, 1988; Dreyer and Marais, 2000). The leaf shape is described as ovate-cordate and the base as cordate (van der Walt and Voster, 1988; Dreyer and Marais, 2000) (Figure 1.1 A).

The flowers of *P. sidoides* are dark-red or reddish purple in colour and are situated at the top of 20-30 cm long stalks (Watt and Breyer-Brandwijk, 1962; van der Walt and Vorster, 1988; Dreyer and Marais, 2000; Lawrence, 2001; *pers. obs*.). These flowers are present almost throughout the year but occur mostly from late spring to summer peaking in December (October-January) (Watt and Breyer-Brandwijk, 1962; van der Walt and Vorster, 1988; Dreyer and Marais, 2000; Lawrence, 2001) (Figure 1.1 B). The inflorescence comprises of a branched system of two-four pseudo-umbels, each with three to seven (occasionally up to 14) flowers (van der Walt and Vorster 1988). The flowers are 15 to 17 mm in diameter with a short pedicel (Vlok, 2005). It is very easy to confuse *P. sidoides* with another similar species called *Pelargonium reniforme* Curtis as the two plants look morphologically similar except when in flower. *P. sidoides* is distinguished from *P. reniforme* by maroon to dark-brown petals with sepals that are green with white margins whereas *P. reniforme* has pink to purple petals with sepals that are red with pink margins (Dreyer and Marais, 2000) (Figure 1.1 C).The species identification becomes problematic in South Africa as the two plants often occur together whereas there is no species confusion in Lesotho as *P. sidoides* occurs on its own (Newton *et al*., *in prep.*). *P. sidoides* undergoes both sexual (by seed) and asexual propagation (by means of tubers).

According to van der Walt and Vorster (1988), *P. sidoides* has a thickened underground system as well as aerial parts sparsely branched from base. The plant is evergreen in cultivation but dies back in the wild during winter. In large plants, the underground tuber system can produce more than one aboveground stem (Vlok, 2003). Therefore it becomes extremely difficult to determine the number of aboveground stems (ramets) that one clump of plants (genet) has, because it is not easy to excavate the often extensive tuber system without breaking part of the system (Vlok, 2003).

P. sidoides seems to prefer periodic disturbance, such as fire and/or grazing, to remove competition from other plants (Vlok, 2003). The species also seems to be displaced by *Acacia karroo*, as plants growing under these trees die back once the trees are large. Thus bush encroachment by *A. karroo*, a common feature in the Eastern Cape where rangelands are mismanaged by overgrazing, threatens *P. sidoides* wild populations (Vlok, 2003). *P. sidoides* is more abundant in partially disturbed sites, but seemingly absent from transformed habitats such as fields (Vlok, 2003). For example several plants were observed in one site in Thomas Baine Nature Reserve around an 18 year old hut and along road sides (*pers. obs.).*

The thickened underground system that penetrates deep into the ground appears to be a special adaptation which enables the plant to survive grass fires which occur almost annually throughout much of its range (Vlok, 2003) (Figure 1.1 D). The same pattern to fire adaptation is also demonstrated by a rare clonal species called *Banksi goodii* which is a rhizomatous evergreen subshrub of South-western Australia (Witkowski and Lamont, 1997). *B. goodii* is capable of resprouting from concealed buds after fire (e.g. Lamont and Markey, 1995) and is less likely to be exposed to local extinction due to frequent fires than non-resprouting species (Witkowski and Lamont, 1997).

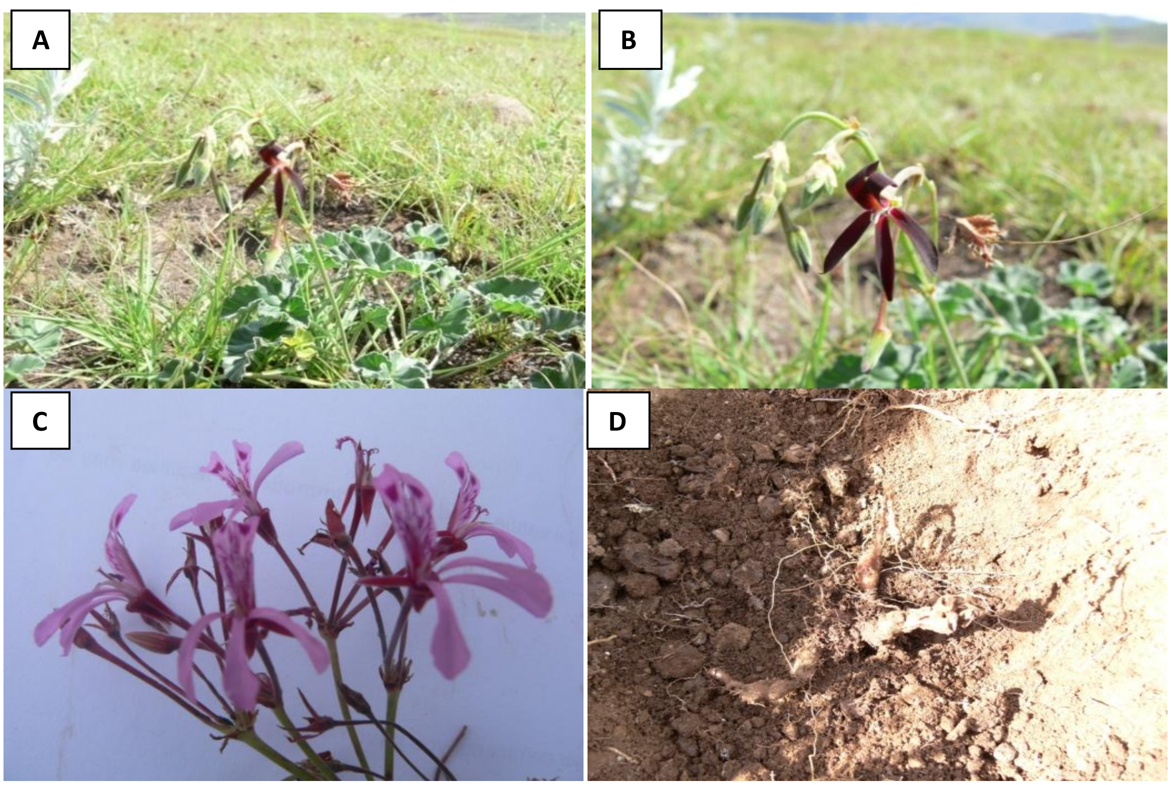

Figure 1.1. Appearance of P. sidoides plants with leaves arranged in a basal cluster (A), dark-red flowers (B), and purple flowers of its close relative, P. reniforme (C) and P. sidoides' extensive root system (C).

P. sidoidies occurs naturally in short grasslands and sometimes on stony soils that vary from sand to clay loam, shale or basalt. It is usually restricted to the Grassland and Savanna biomes and Grassy Fybnos (Vlok, 2003, 2005). It inhabits steep slopes in Lesotho Basalt Grassland vegetation and some parts of the Afroalpine Grassland Zone (Newton *et al*., *in prep*.). The species has been recorded at altitudes ranging from near sea-level in South Africa (van der Walt, 1988) and to 2,746metres above sea level (m.a.s.l.) in Lesotho (Newton *et al*., *in prep.*). Thus *P. sidoides* can tolerate a wide range of environmental conditions. It is indigenous to Lesotho and South Africa and is predominantly found in the Eastern Cape, Free State, Gauteng, Mpumalanga, North-West and Western Cape provinces of South Africa. In both Lesotho and South Africa, the plant is found in areas which receive rainfall in summer (November-March) varying from 200-800mm per annum (van der Walt and Voster, 1988; Dreyer and Marais, 2000) (Figure 1.2).

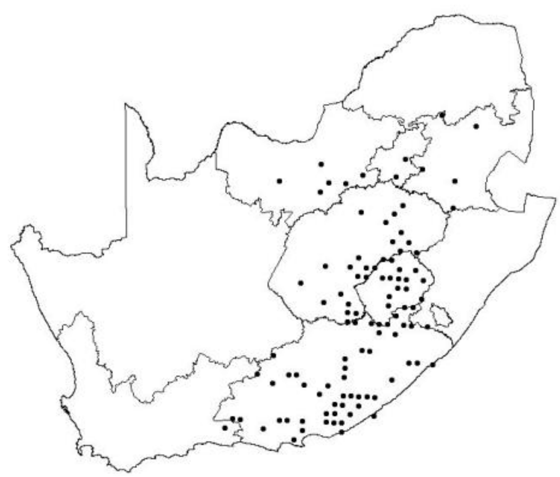

Figure 1.2. Distribution map for P. sidoides in South Africa and Lesotho – Source: PRE (National Herbarium, SANBI, Pretoria), SAM (South African Museum Herbarium - transferred to NBG in 1956), NBG (Compton Herbarium, SANBI, Cape Town), NMB (Herbarium, National Museum, Bloemfontein), GRA (Selmar Schonland Herbarium, Albany Museum, Grahamstown), NH (KwaZulu-Natal Herbarium, SANBI, Durban), KEI (Herbarium, Walter Sisulu University, Umtata) locality data in Lesotho identified during fieldwork for a non-detriment finding in Lesotho (Newton et al., in prep.) and PUC: A.P. Goossens Herbarium, North-West University, Potchefstroom.

1.3. Medicinal use and pharmacology

The tubers of *P. sidoides* plants have been used for centuries in traditional medicine as a therapeutic remedy providing relief for colic, diarrhea, dysentery, bronchitis, asthma, fatigue and for removing worms in calves (Phillips, 1917 as cited by Brendler and van Wyk, 2008; Watt and Breyer-Brandwijk, 1962; Hutchings, 1996; Matsiliza and Barker, 2001; Lewu *et al*., 2007; Brendler and van Wyk, 2008). The plants are prepared as decoctions in water or milk (Watt and Breyer-Brandwijk, 1962) after which they are administered orally to both humans and livestock. Globally the tubers of *P. sidoides* have been used to treat respiratory ailments (Brendler and van Wyk, 2008). Recently the species has become an ingredient in a number of commercially produced medicinal remedies, including one called "Umckaloabo" used to treat bronchitis in both adults and children (van Wyk *et al.,* 1997). The products containing *P. sidoides* tuber extracts have been used internationally in countries like Germany, Ukraine, Russia, Latvia, United Kingdom, Northern America and Mexico (Brendler and van Wyk, 2008) (Figure 1.3).

Figure 1.3. P. sidoides containing medication called kaloba sold in England. Source: R. Wynberg cited in van Niekerk (2009).

Various metabolites extracted from *P. sidoides* tubers including phenolic, cinnamic acids, tannins, flavonoids and coumarins have been isolated and scientifically proven in various clinical trials to have antibacterial (Kayser and Kolodziej, 1997; Daschner *et al.,* 2004; Hansmann, 2005; Thale *et al.,* 2007, Wittschier *et al.,* 2007a,b; Beil and Kilian, 2007; Conrad *et al*., 2007a,b,c; 2008a,b,c) antimycobacterial, antifungal (Taylor, 2003a,b; Seidel and Taylor, 2004; Godecke, 2003; Mativandlela *et al.,* 2006, 2007) and immunomodulatory properties (Kayser *et al.,* 1999, 2001, 2003; Kolodziej *et al.,*2003; Kolodziej, *et al.,* 1999, 2005; Kolodziej and Kiderlen, 2007; Trun *et al.,* 2006; Koch *et al.,* 2002; Janecki *et al.,* 2007; Koch and Wohn, 2007). These scientifically proven clinical trials which have shown positive clinical effects are likely to encourage continued commercial harvesting of the species from the wild and hence the vulnerability of the species to over-exploitation.

The three *P. sidoides* extracts namely umckalin, gallic acid and 6,8-dihydroxy-5,7dimethoxycoumarin seem to be the most active single compounds in fighting infections (Kayser and Kolodziej, 1997). However pharmacological action of these extracts in fighting infections seems unclear and hence more research is needed (Kayser *et al*., 2003). This is because it seems the efficacy in treating respiratory infections might be due to the interactions of several components rather than that of a single main constituent (Brendler and van Wyk, 2008).

1.4. Legal status

P. sidoides is legally protected in Lesotho and South Africa. In Lesotho, the species is protected under the Historical Monuments, Relics, Fauna and Flora Act 41 of 1967 legal notice of 2004 (Newton, *et al., in prep*). According to the Act, a person must obtain a permit from the Protection and Preservation Commission (PPC) for collection purposes. However the Act does not allow for trade in protected flora and permits are only issued for collection in connection with research purposes (Newton, *et al*., *in prep*.). Additionally, the PPC no longer exists and when it existed had never issued permits (Newton, *et al*., *in prep.*). Currently *P. sidoides* traders are issued a bioprospecting permit by DoE which stipulates the conditions of bioprospecting activities as per the Environment Act 2008. Other pieces of legislation which directly address biodiversity conservation in Lesotho are the Local Government Act 1997, National Parks Act 1975, Managed Resources Areas Order 18 of 1993 and the Environment Act 2008 (Newton *et al., in prep.*; N. Ntsohi, Lesotho Department of Environment [DoE], *pers. comm*., 2010; *Anon*., 2010). However, a major problem in implementing biodiversity laws in Lesotho is weak institutional systems and fragmented laws which are contradictory and unable to support the country's ecological needs (*Anon*., 2010). This situation will hopefully be addressed by the umbrella Nature Conservation bill (*Anon*., 2010).

In South Africa, the permit system has to be used when harvesting, transporting, and exporting protected species but for indigenous species such as *P. sidoides*, only a letter of consent from the landowner or relevant municipality is needed. Additionally a bioprospecting permit is also issued by the South African Department of Environmental Affairs (DEA) [as per the Bioprospecting, Access and Benefit Sharing (BABS) Regulations 2008]. Issuance of other types of permits mentioned above is as stipulated in the Nature and Environmental Conservation Ordinance 19 of 1974, the Ciskei Nature Conservation Act

10 of 1987 (Eastern Cape), Nature Conservation Ordinance 8 of 1969, Qwaqwa Nature Conservation Act 8 1976 (Free State), Nature Conservation Ordinance 12 of 1983 (Gauteng), Mpumalanga Nature Conservation Act 10 of 1998 (Mpumalanga), Nature and Environment Conservation Act 19 0f 1974, Nature Conservation Ordinance 12 of 1983 (North West) and Nature Conservation and Environment Management and Conservation Ordinance 19 of 1974 (Western Cape) (Newton, *in prep*.; Newton *et al., in prep*.; White, 2007; *Anon*., 2008). However under all these pieces of legislation, the species is only protected as an indigenous plant but not a protected plant and therefore the control measures for the species will not be as strict as for a protected plant. Additionally in most cases the implementation of the legislation is often reactive rather than preventive (Newton *et al., in prep*.). This means whilst legislation and regulations may exist at district, provincial, national and international levels to protect taxa and regulate trade involving threatened and protected species, in many instances conservation measures are only enforced once a species has become threatened (Lange, 1998). This has been the case with *P. sidoides* management in both countries. For instance, *P. sidoides* was not legally protected in Lesotho and following various reports of over harvesting in some parts of the country and the confiscation of wild harvested plants by the police (*pers. obs.*), it was only then that the Government of Lesotho (GoL) included the species under the Historical Monuments, Relics, Fauna and Flora Act of 1967.

1.5. Red Listing Assessment

Species classified according to the IUCN Red List system are preferred in indices that track the state of biodiversity internationally (Butchart *et al*., 2006). Up until recently, no population assessments had been carried out for *P. sidoides* so that the species can be listed in the IUCN Red Data book. But, by 2008, the South African Red Listing Assessment for *P. sidoides* had been carried out (Raimindo *et al*., 2009). According to the assessment, the species has a huge distribution with the Extent of Occurrence (EOO) of 480, 000 km^2 in South Africa; however it is currently under severe harvesting pressure (Raimindo *et al*., 2009). Although the plants coppice after harvesting, local extirpations can occur when harvesting takes place too regularly and in the absence of adequate rainfall (Vlok, 2003, 2005, Raimondo *et al*., 2009). Therefore the species has been classified as Declining because there are some localized declines at sub-population level. Declining is one of the categories developed specifically for the South African plant conservation context (Raimindo *et al*., 2009). The assessment does not include *P. sidoides* Area of Occupancy (AOO) and this may be because the plant is also found in Lesotho which has different conservation priorities as well as economic status.

There has been no Red List assessment carried out for Lesotho to date. The next best set of information in terms of the species threat assessment is contained in the Lesotho NDF study (Newton *et al., in prep*.) which has been conducted for the Lesotho CITES (Convention on International Trade in Endangered Species of wild fauna and flora) Scientific Authority. According to the study, *P. sidoides* occurs in small clusters throughout a relatively large area (EOO= approximately 2,100 km^2) of the country and is also thought to be experiencing localized population declines due to severe harvesting.

Pelargonium industry however argued that all the research done so far on distribution of *P. sidoides* does not present the true picture of the resource in the wild and hence is under-estimated (U. Feiter, Parceval, *pers. comm*., 2008). Consequently the industry volunteered to fund a thorough resource assessment for the species throughout its range (U. Feiter, Parceval, *pers. comm*., 2008). After funding was approved for the assessment from the South African Department of Environmental Affairs (DEA) and Lesotho DoE, fieldwork was carried out in both countries in 2010. According to the assessment, *P. sidoides* is widely distributed across Lesotho and South Africa and is mainly threatened by habitat destruction (de Castro *et al*., 2010).

The Global Red List assessment for the species is to be completed for the species and hopefully the results of the resource assessment will be helpful.

1.6. Traditional use and access rights

The people of South Africa and Lesotho have traditionally used the tubers of *P. sidodies* for generations to treat various ailments (Phillips, 1917 as cited by Brendler and van Wyk, 2008; Watt and Breyer-Brandwijk, 1962; Hutchings, 1996; Matsiliza and Barker 2001; Lewu *et al*., 2007; Brendler and van Wyk, 2008) however, the actual origin of the intellectual knowledge remains unknown (van Wyk, 1997). In traditional management systems of natural resource management, collection of medicinal plants was the domain of knowledgeable traditional healers (Cunningham, 1992) although locals could also harvest occasionally when a child or an animal was sick. Thus the people of these two countries had customary and access rights to harvesting the resource without any strict regulations on harvesting as is the case currently due to over-exploitation. For instance as soon as *P. sidoides* was protected under the Historical Monuments, Relics, Fauna and Flora Act 41 of 1967 through legal notice 63 of 2004 in Lesotho, there was confusion from locals, local councils, chiefs and traditional healers on the implication of the regulation on the use of *P. sidoides* (M. Letsie, ward chief of Ha Tlhaku, Quthing*, pers. comm*., 2009). The fear was that people would be prosecuted for any form of harvesting and that they would have no access to the resource they have been using for years. This is because conservation practices that take resources away from local people or in this case limits their access to such resources imposes undue welfare loss (Letsela, 2004). For example, some conservation practices exclude communities from direct utilization of resources by locking them in protected areas thus favoring non-utilitarian values (Pearce and Turner, 1990). In the case of *P. sidoides*, right to access the resource can be detrimental to people's livelihoods as poverty is widespread in areas where it occurs (Dold and Cocks, 2002; Lewu *et al*., 2007; van Niekerk, 2009). The protection of the plant under biodiversity laws has not limited access to the resource by the local people (M. Letsie, ward chief of Ha Tlhaku, Quthing*, pers. comm*., 2009).

1.7. Benefit sharing

Benefits from medicinal plant trade have developed along unequal lines of benefit distribution (van Niekerk, 2009). Instruments that address these problems include the adoption of the Convention on Biological Diversity (CBD) by the international community. The CBD was developed after the realization that benefits accruing from medicinal plant trade were concentrated in northern user countries (Laird and Wynberg, 2003) as opposed to producer countries. These producer countries are mostly rich in significant biodiversity and endemism as well as least developed (Pomela *et al*, 2000). However ever since the CBD was adopted in 1992, many countries have struggled with creating enabling environment for the implementation of benefit sharing. Lesotho and South Africa are among those countries that have been struggling with benefit sharing agreements especially those relating to *P. sidoides*. While this is the case, both countries have to date been able to implement benefit sharing agreements between traders and communities involved in harvesting the resource (P. Mosana, South African DEA, *pers. comm*., 2010; R. Nts'ohi, Lesotho DoE, *pers. comm*., 2010). Thus the Pelargonium industry became the first industry in the two countries to comply with access and benefit sharing requirements as per national and international laws (van Niekerk, 2009). South Africa has benefit sharing regulations (i.e. BABS regulations 2008) while Lesotho still lacks access and benefit sharing regulations and hence it has no guidelines on how to draft and implement access and benefit sharing agreements. It is not clear as to which guidelines were used in drafting the access and benefit sharing agreements but the assumption is that international guidelines such as the "Bonn Guidelines" may have been used as a framework.

Although benefit sharing agreements have been developed for *P. sidoides*, van Niekerk (2009) believes there is still a restricted amount of benefits to harvesters compared to benefits accruing to the

Pelargonium industry (e.g. prices paid to harvesters [Table 1.1] compared to money the traders get i.e. **Gowarenterprises** [R48], **BZH** [R85], **Parceval** [R120] and **Schwabe** [R600]).

Table 1.1: Comparison of prices paid to P. sidoides harvesters in South Africa and Lesotho, van Niekerk (2009)

	Lesotho	**South Africa**
Price harvesters received (wet weight)	R4.00 ~ R4.50/kg	R1.60 ~ R4.00 /kg
Income per harvester per month from *P. sidoides*	R570 ~ R850	R200 ~ R700
Income per harvester per year from *P. sidoides*	R4 000 ~ R6 000 (7-month season)	R1 600 ~ R5 600 (8-month season)

1.8. Supply chain, market and trade volumes

Ever since the successful commercialization of *P. sidoides* as a western medicine, wild harvesting of the resource has intensified. The dominant exporter of *P. sidoides* raw material (in the form of dried tubers) is a South African company called Parceval that is based in Cape Town (van Niekerk, 2009). The raw material is exported to Germany where a company called Schwabe processes the raw tubers into the famous cough mixture known as umckaloabo (van Niekerk, 2009). The same company holds several patents relating to extraction methods (Brendler and van Wyk, 2008). Because Schwabe has intellectual property rights on *P. sidoides* containing products, it is able to export the tincture from the raw tubers of the plant to several other countries such as Ukraine, Russia and Latvia (Brendler and van Wyk, 2008).

In Lesotho there is only one middleman that collects harvested material fortnightly from the local harvesters to directly supply Parceval (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2007).

There is a different scenario in South Africa where there are several middlemen. The local harvesters supply the harvested tubers to one middleman who in turn passes it on to another trader (K. Paulsen, BZH, *pers. comm*., 2008). The latter mentioned trader supplies Parceval who exports to Germany. The supply chain is illustrated below (Figure 1.4).

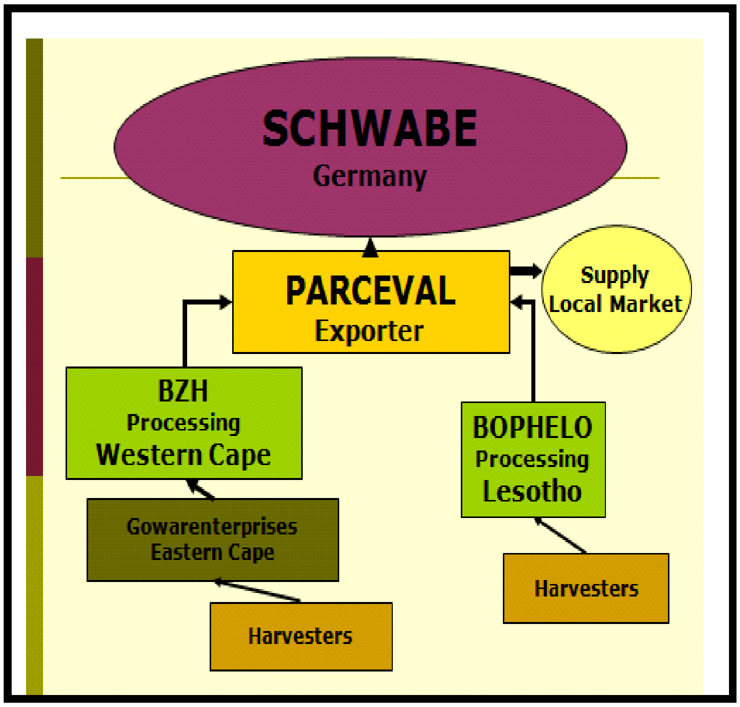

Figure 1.4. P. sidoides main supply chain from Lesotho and South Africa to local and international markets, source: van Niekerk (2009).

Locally, Parceval supplies South African companies such as Nativa (which makes a cough mixture called Linctagon), Phyto Nova and Bioharmony who manufacture upper respiratory tract medications containing *P. sidoides* (van Niekerk, 2009). Therefore the popularity of *P. sidoides* containing medication can contribute to an already booming market and hence more wild collection of raw material. For instance, according to Brendler and van Wyk (2008), Umkaloabo is a fully licensed liquid herbal medicine on the German market with approximately €80 million turnover in 2006.

Up to now, no thorough and formal research has been conducted on trade volumes of *P. sidoides* in Lesotho and South Africa. Therefore there is lack of formal information on trade volumes of the species in both countries. Additionally it is very difficult to get trade volumes data from the industry and nature conservation officers (Newton, *in prep*.; Newton *et al*., *in prep*.; Lewu *et al*., 2007; van Niekerk, 2009).

This is primarily because the industry are cautious about giving out their confidential trade information (H. Nieuwoudt, Bophelo Natural Products*, pers. comm.,* 2007) and conservation officers have to respect the confidentiality of data collected in the course of their duties in terms of national laws.

Even under these circumstances, some studies have attempted to estimate the trade volumes for both countries. According to Newton *et al*. (*in prep*.) the estimated trade volumes for South Africa are about 45 tonnes for an eight month period and between 26-96 tonnes for a seven month period in Lesotho

(Newton *et al*., *in prep*.). In another study, Lewu *et al*. (2007) recorded 26 tonnes of *P. sidoides* tubers for a one-month period in the Amathole region and this translates to 208 tonnes a year (van Niekerk, 2009).

1.9. Tuber characteristics preferred

There is limited information on *P. sidoides* tuber characteristics required by the Pelargonium industry (White, 2007). van Niekerk (2009) also cited unwillingness of the Pelargonium industry to share information as a major limitation to her study on the contribution of *P. sidoides* trade to rural livelihoods in Lesotho and South Africa. The reluctance to share information seems to be characteristic of all natural product industries and the *P. sidoides* trade in particular seems to be surrounded by secrecy (van Niekerk, 2009). This reluctance may have been aggraved due to patent challenges by African Centre for Biosafety (ACB) (van Niekerk, 2009). Consequently this may explain why where such information exists; it is generally not clear, often changing, contradictory and difficult to obtain (*pers. obs.*).

P. sidoides harvesters are often instructed by middlemen to collect large tubers with dark-red colouration (White, 2007; H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008; M. Letsie, area chief of Ha Tlhaku village, Quthing, 2009; *pers. obs*.) as these tubers are believed to be more potent and thought to have higher concentrations of the desired medicinal compounds (White, 2007; H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008; M. Letsie, area chief of Ha Tlhaku village, Quthing, 2009; *pers. obs*.). Other role players in the Pelargonium industry however insist that there is no relationship between tuber colour, tuber size and the concentration of medicinal compounds. Apparently a pale-coloured tuber can have the same concentration of medicinal compounds as a dark-red tuber and harvesters are only requested to collect dark-coloured tubers to discourage harvest of recovering plants with pale-coloured tubers (U. Feiter, Parceval*, pers. comm*., 2008). Attempts to verify relationships between tuber colour and concentrations of medicinal compounds in *P. sidoides* are limited to the work of White (2007) and White *et al*. (2008). Their study investigated the relationship between umckalin concentration and tuber colour of *P. sidoides* plants. Their results did not reveal any significant relationships between the two variables. This may have been due to their usage of single extracts as opposed to the complex of extracts reported by the Pelargonium industry to represent the medicinal fraction of *P. sidoides* (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008; U. Feiter, Parceval*, pers. comm*., 2008). Kolodziez *et al*. (2003) also hypothesized that there may be several possibilities for the medicinal effect of *P. sidoides* namely that various constituents work synergistically to fight infections and that unknown compounds yet to be isolated are responsible.

It can therefore be argued that the demand for dark-coloured tubers by the Pelargonium industry is not exclusively for sustainability purposes, but rather that there is a relationship between tuber size, tuber colour and medicinal compounds. This argument is raised because if pale-coloured tubers contained similar amounts of the active compounds; the Pelargonium industry would have ceased wild-harvest a long time ago, be freed from wild-harvest permitting requirements and concentrated on cultivated stocks. It seems unlikely though that the Pelargonium industry is willing to pursue cultivation to the exclusion of wild-harvest considering that only few cultivation projects have been set up in Lesotho and South Africa (van Niekerk, 2009).

For the purposes of this study, it was deduced that tuber colour was correlated with higher levels of the desired medicinal compounds based on the above-mentioned information summarized as (a) the difficulty of obtaining consistent information from the trade on the type of tubers preferred, (b) what harvesters are instructed to collect, (c) the zero value placed on pale-coloured tubers (d) inconclusive results from the work of White (2007) and White *et al*. (2007) and (e) the possible medicinal mechanisms of *P. sidoides* raised by Kolodziez *et al*. (2003).

One other requirement by the Pelargonium industry is for tubers to have no fungal infection as these fetch a lower price (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008).Additionally, the tubers from Lesotho seem to be preferred more than tubers sourced from South Africa (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2007). This may be because there is minimal contamination from other similar species such as *P. reniforme* as *P. sidoides* occurs on its own throughout its range in Lesotho.

1.10. Wild harvest and sustainability

Although therapeutic benefits of *P. sidoides* have been known for many years, it is only since 2001 that large scale commercial harvesting commenced in South Africa and more recently in Lesotho to supply local and international market (Newton, *et al*., *in prep.*). The species is mostly harvested from the wild in the Eastern Cape Province of South Africa and in the South-eastern and North-western districts of Lesotho (Newton, *et al*., *in prep*.).

A variety of harvesting tools such as pick axes, spades or any other sharpened metallic tools are used for uprooting the plants to collect the tubers during harvest (*pers. obs*.). Because the harvesting tools used have different shapes and sizes, they tend to cause varying degrees of damage to harvested plants and the surrounding environment (*pers. obs.*). For instance a spade was observed to cause more tuber damage and more soil disturbance (*pers. obs*.).

Several studies have in the past have reported that wild populations of *P. sidoides* are harvested unsustainably (Vlok, 2003, 2005; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008; Newton *et al*., *in prep.*) and a similar observation was made during this study (*pers. obs*.). As a result, in some areas where there was previous wild harvest, local extirpations have occurred (Vlok, 2005; Newton *et al*., *in prep.*; de Castro *et al*., 2010). This is because during harvest, whole plants are uprooted and any unwanted small tubers are usually not replanted and as a result clonal rejuvenation is threatened (Lewu *et al*., 2006). In some areas, harvesting holes are not always filled with soil (closed) (Figure 1.5A) and other unwanted plant parts like stems and roots are not replanted (Lewu *et al*., 2007; *pers. obs.)*.

Additionally, Newton *et al*. (*in prep*.) observed that some harvest sites, especially those accessible by road, are harvested repeatedly, increasing the rate of plant mortality and population decline. Newton *et al*. (*in prep*.) also noted that some holes created by previous harvest did not show evidence of recovery. The assessment on the impacts of wild harvesting on *P. sidoides* populations in the Eastern Cape by Vlok (2005) also revealed that a too soon repeat harvest of the species significantly reduces plant density resulting in local extirpations. de Castro *et. al*. (2010) further confirmed that there is limited resprotuing in previously harvested sites in some parts of Lesotho and South Africa as a result of a too soon repeat harvest. Localized population declines seem to be more pronounced in communal areas especially those that are easily accessible and close to towns and commonage areas of the Eastern Cape Province (Vlok, 2005; de Castro *et al*., 2010; Newton *et. al.*, *in prep*.; *pers. obs*.).

Although there is currently lack of information on the impacts of above-mentioned harvest methods on the surrounding habit of *P. sidoides*, harvesting methods currently used have been observed to result in environmental degradation. The environmental degradation is in the form soil erosion (Figure 1.5B) and mortality of plants associated with *P. sidoides* such as *Euphorbias* and *Brachystelma* species (D. Newton, TRAFFIC East/Southern Africa [TESA], *pers. comm*., 2009; *pers. obs*.).

Figure 1.5. Unsustainable post harvest method of P. sidoides plant in the Eastern Cape that involves not filling up harvest holes with soil (A) and resultant soil erosion of surrounding habitat around a harvested P. sidoides plant in Lesotho (B).

The Pelargonium industry however insist that some form of training on harvest methods is provided to harvesters in their employ prior to harvesting operations (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008; R. Gowar, Gowar Enterprises, *in litt*., 2009; D. Newton, TRAFFIC East/Southern Africa [TESA], *pers. comm*., 2008).

In an effort to ensure sustainable harvest of *P. sidoides* wild populations, collection and bioprospecting permits are needed as per Lesotho and South African legislation. However, even with the permit system in place, there have been cases of illegal harvest which lead to arrests being made in Lesotho (2006) and South Africa (2000, 2003) (van Niekerk, 2009). No successful prosecutions were made though due to limitations of existing laws governing the use of *P. sidoides* at that time (van Niekerk, 2009).

Since it seems that harvesters are not adhering to harvest methods provided which has resulted in population declines and even legislation seems to be lacking in regulating the use of *P. sidoides*, cultivation of *P. sidodies* may be the next step to achieve sustainable use of wild populations. This alternative is possible especially because propagation of *P. sidodies* has been reported to be relatively easy using tuber cuttings, leaf petioles (Lewu *et al*., 2006; White, 2007; U. Feiter, Parceval, *pers. comm.,* 2008; White *et al*., 2008; *per. obs*.) and seeds (Afolayan and Masika, 2004; *pers. obs*.).

1.11. Rate of tuber recovery

While it was not possible to determine the rate of tuber recovery using biomass during the Non-Detriment Finding training exercise for the Lesotho CITES Scientific Authority recorded in Newton *et al*.

(*in prep*.), through interviews and field observations, it was possible to identify three approximate stages of tuber colour development as follows:

- White tuber phase: These are formed in one of three possible ways, firstly from mature tuber fragments left in the ground after harvest, secondly in the natural course of seedling development, or thirdly in undisturbed plants as part of the normal successional development of young tubers from the previous age group of tubers. This life stage remains white for an estimated one to two years.
- Pink tuber phase: This phase is a more mature form of the white tuber and is distinguished by the onset of light to dark pink colouration at which stage the tuber age is estimated to range from approximately 3 to 5 or more years.
- Red or mature tuber phase: It is generally this phase that is commercially harvested. Tubers develop the deep red colouration after about 5 to 7 or more years. It becomes difficult to estimate their age after development of red colouration.

Figure 1.6. P. sidoides hypothesized tuber colour phases and their approximate ages, (A- white tuber phase, B- pink tuber phase, C- red tuber phase).

During work by White (2007), the tuber development stages were identified for purposes of monitoring tuber regrowth although they were not associated with age estimates. Old tuber growth was separated from the new tuber growth based on tuber colour and appearance. Old tuber growth had red/brown colour as opposed to the cream white colour of new tuber growth. In terms of appearance, old tuber growth was brittle while new tuber growth was non-brittle. According to the Pelargonium industry, the white, pink and red tuber development stages may develop at different rates between sites (U. Feiter, Parceval, *pers. comm.,* 2008).

During this study, it was deduced that following harvest, *P. sidoides* tubers recover in three different ways. The first stage involves resprouting of stems from the point of cut (where the tuber was chopped off during harvest), secondly, the stem elongates and thirdly, the stem swells and matures into a tuber (*pers. obs*.).

1.12. Management and monitoring

Up until 2010, in both South Africa and Lesotho there was no form of management and monitoring carried out for the species. This may have been because prior to 2010, there was no species management plan for *P. sidoides* to give guidance on how to manage the resource. In Lesotho, DoE is invested with the responsibility of biodiversity management and conservation in the country while in South Africa DEA and the Provincial departments (e.g. Eastern Cape Provincial Department of Economic Development and Environmental Affairs [DEDEA] are responsible for biodiversity management. However, in both countries, monitoring has been left entirely to the Pelargonium industry (Newton *in prep*.; Newton *et al*., *in prep*.). The lack of an official management and monitoring framework caused several problems in managing the resource sustainably, including lack of harvested volumes, problems with permit issuance and deficient harvesting guidelines. However, with the development and submission of the species management plan to DoE in Lesotho and DEA in South Africa this situation is expected to improve.

1.13. Description of study areas

1.13.1 “Lowveld” vegetation region

1.13.1.1 Eastern Cape Province

This study was conducted in the Amatola and the Northern Ukhahlamba regions of the Eastern Cape. In the Amatola region, 7 study sites were sampled, namely Peddie, Lokwe (formerly known as Victoria Post Farm) (van Niekerk, 2009), Wesley, Stutterheim, Hogsback, Cathcart and Double-Drift Nature Reserve (Figure 1.7). The only Ukhahlamba region study site was at an agricultural holding within the town of Rhodes. All the study sites are located between 30° 47’S - 33° 19’S and 26° 49’E - 27° 57’E with altitudes ranging from 100 to 1,845 metres above sea level (masl). The Eastern Cape Province incorporates two of the former “homelands” of the Apartheid period, namely the Ciskei and Transkei as well as what was then part of the Cape Province (Dold and Cocks, 2002). The people of the Eastern Cape tend to be more traditional and rural, but also significantly poorer and less developed, than those in other South African Provinces (Cocks and Møller, 2002). Therefore reliance on natural resources for utilization and trade can become the easiest escape from poverty.

All the sites in the Eastern Cape are located in the Savanna, Grassland and to a lesser extend the Albany Thicket biomes and in particular the Sub-Escarpment Savanna, Sub-Escarpment Grassland and Drakensberg Grassland Bioregions. The Savanna Biome experiences a semi-arid to subtropical climate with wet hot summers and dry mild winters. The mean annual temperatures (MAT) range from 17°C to 18°C with mean annual precipitation (MAP) ranging between 500 and 750 mm in areas outside the Kalahari (Mucina and Rutherford, 2006). The mean daily maximum temperatures for February rarely drops below 26°C in some of the low-altitude areas in the East (Schulze, 1997), while they can drop to 18°C in higher altitudes. The mean daily minimum temperature for February can drop below 16°C in higher lying areas and can remain at 20°C in the lower “lowveld” areas. In winter, minimum temperatures are more variable with some eastern parts of the biome getting minimum daily temperatures that remain above 10°C. Only the lower-lying parts of this Biome such as the Sub-Escarpment Savanna Bioregion are considered frost-free. The Savanna Biome is dominated by the Kaapvaal Craton, a stable continental crust which contributed to deep sandy soils and shallow lithosols (Mucina and Rutherford, 2006).

The grassland biome is characterized by temperate climate with summer rainfall and cold winter droughts. The MAT ranges from 4°C to 15°C (in the Drakensberg Grassland and Sub-Escarpment Grassland Bioregions) with MAP of between 423mm and 1,234mm. The topography is mostly flat to rolling but also comprises mountains (Mucina and Rutherford, 2006). There are high lightning flash densities which raises the probability of naturally induced fires; for this reason, Grassland is a fire prone ecosystem (Mucina and Rutherford, 2006). Grazing and fire have a major influence on canopy structure and species composition. This Biome is underlain by the Karoo Supergroup rocks of the Clarens and Elliot formation which are covered by the Drakensberg group in some areas. Sweet and sour grasses are found in this Biome belonging to the subfamily Chloridoideae and Panicoideae respectively (Mucina and Rutherford, 2006).

The Albany Thicket Biome also experiences a semi-arid to sub-tropical climate with an unpredictable rainfall regime, ranging from 256 - 677mm MAP. The annual precipitation coefficient of variation (APCV) is 25-36%. The vegetation of this Biome is a dense, woody, semi-succulent and thorny vegetation type with average height of 2-3m (Acocks 1953; Everard, 1987). According to Acocks (1953, 1988), the Albany Thicket comprises small patches of other vegetation types that are embedded within the thicket, such as the Savanna Biome, which is where *P. sidoides* also occurs. Primary productivity studies have shown this biome to have slow growing species (Aucamp and Tainton, 1984). The geology of the Biome comprises folded strata of the Cape Supergroup with early Karoo Supergroup sedimentary rocks also folded in the northern margin of the Cape Fold Belt. The Biome is typified by fine and deep well-structured soils as well as shallow and coarse unstructured soils (Mucina and Rutherford, 2006). Dominant plant families are Ebenaceae, Sapindaceae and Didiereaceae (Cowling *et al*., 2005).

Poverty is severe where harvesting of *P. sidoides* occurs in the Eastern Cape (Dold and Cocks, 2002; Lewu *et al*., 2007; van Niekerk, 2009). Consequently, commercialization of medicinal plants such as *P. sidoides* is significant to people's livelihoods (Shackleton *et al*., 2002; Cocks and Wiersum, 2003).

1.13.2. "Highveld" vegetation region

1.13.2.1. Lesotho

The study was conducted at Quthing (Ha Tlhaku and Tsatsane) and Mohale's Hoek (Thoteng) districts situated in the southern part of the country, as well as Butha-Buthe (Makhunoane) which is situated in the northern part of the country. Due to the availability of the Lesotho Scientific Authority non-detriment study findings (NDF), these data (Newton *et al*. *in prep*.) were used as well. The NDF study was conducted at Quthing (Ha Tlhaku, Ha Ratema, Ha Lebelonyane), Qacha's Nek (Ha Nthunya, Ha Leteba, Likhohloaneng, Ha Mats'a, Makhoareng), Mokhotlong (Molumong I, Molumong II, Ts'epong, Mapholaneng), Thaba-Tseka (Thaba-Tseka Basotho pony garden, Machaping, Katse Ha Ramokoatsi I, Katse Ha Ramokoatsi II, Katse Ha Theko I, Katse Ha Theko II) and Butha-Buthe (Makhoakhoeng, Makhunoane) districts (Figure 1.7). The study sites are found between 28° 18'S- 30° 28'S and 27° 28'E- 29° 00'E with altitudes of between 1,595masl to 2,746masl. The study sites occupy the Grassland Biome, specifically the Drakensberg Grassland Region and to a lesser extent the Mesic Highveld Grassland Bioregion, with the predominant vegetation being the Basalt Grassland vegetation. The two vegetation regions experience temperate to sub-tropical climate regimes, characterized by MAP of between 391mm to 1,451mm. The MAT ranges from 4.0°C to 17.2°C (Mucina and Rutherford, 2006).

Lesotho is a mountainous country that is completely land-locked by the Republic of South Africa and occupies only 30,355 km^2 in size. Approximately three quarters of the country represents the Maluti range while the remaining one quarter comprises the lowlands and foothills. The majority of the population (80%) lives in rural areas and depend on subsistence agriculture for their livelihood (Mokuku *et al*., 2004). However, man-induced soil erosion has become common in Lesotho with soil loss estimated at 2,000 tons per km^2 (Chakela, 1981), and hence a great threat to agricultural production. This is aggravated by the fact that already only nine percent of Lesotho is arable land (Mokuku *et al*., 2004) and population pressures have increased landlessness. Additionally, Lesotho is considered as one of the fifty poorest countries in the world, with 56.7% of its population living below the poverty line (*Anon*., 2010b). The incidence of poverty coupled with landlessness can thus put pressure on local people to opt for commercialization of medicinal plants as they have limited means of generating income.

1.13.2.1. Free State Province

The study sites were located at Qwaqwa (Tsiame village) and Golden Gates Highland Nature Reserve with altitudes of between 1,740 and 2,360masl (Figure 1.7). The study sites are found between 28° 18'S - 28° 33'S and 28° 34'E- 28° 58'E. The whole Free-State Province including the study sites are situated in the Grassland Biome and in particular the Drakensberg Grassland Bioregions and to a limited extent within the Mesic Highveld Grassland. The Free-State Province lies in the Karoo sequence of rocks containing shales, mudstones, sandstones and the Drakensburg basalt. The area experiences a temperate climate characterized by warm to hot summers and cool winters. The areas in the east experience frequent snowfalls, especially on higher places while the west can be extremely hot. The Grassland (Mesic Highveld and Drakensberg Grassland Bioregions) areas have MAT of from 4.0°C to 16.8°C with MAP of 543 to 1451mm. The grasslands are strongly dominated by grasses of the family Poaceae (Mucina and Rutherford, 2006).

The Free State Province is one of nine provinces in South Africa and is centrally located in terms of the geographic distribution of South Africa. Prior to 1994, the Province included two small areas that made up part of the old Apartheid homelands of Bophuthatswana and the self-governing territory of Qwaqwa (Bradshaw *et al*., 2000).

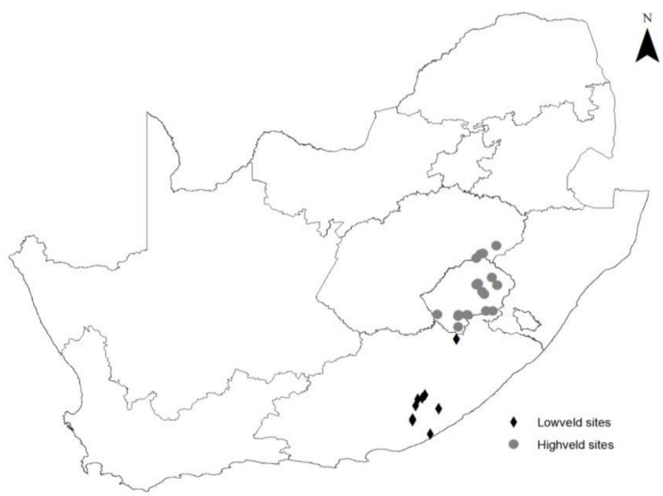

Figure 1.7. The location of study sites in the "lowveld" (diamonds) and "highveld" (circles) vegetation regions.

1.14. Rationale

The threats facing important biodiversity worldwide include invasion by alien species, ecosystems destruction, and over-exploitation through over harvesting, land conversion and habitat loss which increasingly threaten approximately 15 000 of the world's MAPs populations (Schippmann *et al.,* 2005).

A widespread disturbance to plant populations in Southern Africa and elsewhere is the harvesting of plants from the wild (Hoffman, 1997; Dzerefos and Witkowski, 2001) which is mostly driven by commercialization (Williams *et al.,* 2000). Additionally, commercial pressures are mounting, driven by a rapidly growing and urbanizing population. An estimated 80% of this population consults traditional healers, based on affordability, accessibility and acceptability of traditional medicine compared to western medicine. Furthermore, high rates of poverty, unemployment and low level of formal education has stimulated a rise in over-harvesting of most medicinal plants (Cunningham, 1988, Marshall, 1998; Ghimire *et al*., 2005). The negative effects of wild harvest are manifested by habitat loss, species extinction, and reduction in genetic variability (*Anon*., 1997).

The expanding international medicinal plant trade, over-harvest for both traditional medicine and global trade raises concerns about the impact on species for which available information on conservation status is unknown or is outdated (Cunningham, 1988; Cunningham *et al*., 1992). However, in Southern Africa, past and present research efforts on the effects of disturbance such as harvesting have focused on changes in species at a community level, essentially within a preservationist paradigm (Botha *et al*., 2004) yet changes in community and population structure often occur before major shifts in species composition or species loss (Harper, 1977) and are a useful indicator of management and disturbance impacts. Therefore, due to the rapidly growing traditional medicine and expanding local as well as international trade, intensive harvesting of popular species such as *P. sidoides* is likely to increase. Hence there is need for more studies to assess the status of the formerly abundant species and in particular to determine the impacts of large-scale harvesting on wild populations.

P. sidoides is widespread, yet its wild tubers are collected in large quantities for both international and local trade thus raising legitimate concerns about the impact of harvest on wild populations and hence a high possibility of threat in future. Even though this species is widespread, repeated harvesting can reduce its population density significantly, despite its ability to resprout (Vlok, 2005; de Castro *et al*., 2010; Newton *et al*., *in prep*.) and can thus lead to wild populations becoming threatened in the near future. This is exacerbated by poor harvest methodology such as a too regular return harvest and poor post harvest management of the harvest site (Vlok, 2003, 2005; Newton, 2004.; Newton *et al. in prep.*). Despite the current harvest pressure on *P. sidoides*, few studies in South Africa and Lesotho have investigated conservation and management options to ensure its sustainable harvest in the wild, (Vlok, 2003, 2005; Newton, 2004; Lewu *et al*., 2006, 2007; White 2007; White *et al*., 2008; Newton *et al*., *in prep*.). Furthermore, except for the work of White (2007) and White *et al*. (2008), there has been no specific attempt to investigate the rate of tuber recovery, impacts of harvesting on tuber recovery and ideal harvest and post harvest techniques that will maximize recovery of the resource post harvest. Therefore the proposed study intends to investigate the tuber recovery rate and all aspects of pre and post harvest management such as impacts of wild harvest *P. sidoides* tuber recovery as well as possible approaches to maximize tuber recovery. The findings and recommendations of this study will therefore contribute towards sustainable management of *P. sidoides* though informing the recently developed *P. sidoides* BMP which has been submitted to the Lesotho and South African Goverments.

The study also forms part of a bigger, but recently completed project called Saving Plants that Save Lives and Livelihoods which was aimed at supporting the conservation of MAPs and their habitats and establishment of sustainable use schemes (Kathe *et al*., 2010). The project was implemented through five sub-projects in six countries located in South Asia, South-east Asia, South America and Southern Africa. The International Standard for Sustainable Wild Collection of MAP (ISSC-MAP) developed by WWF, IUCN, TRAFFIC and BfN is the tool that was used to establish sustainable management programmes for MAPs for present and future generations (*Anon*., 2007). Lesotho and South Africa are the two Southern African countries which were chosen to pilot the project. The Southern African sub-project aimed to determine sustainable harvesting methods for *P. sidoides* and to develop a regional management plan to ensure the sustainable harvesting of *P. sidoides* in Lesotho and South Africa (Kathe *et al*., 2010). Thus this study has directly contributed to the overall implementation of the ISSC-MAP in Southern Africa.

1.15. Study aims

The aims of the study were:

- To research the capacity of *P. sidoides* plants to regrow from remnant tubers and the associated time frames required to regenerate commercially useful tubers.
- To investigate and analyze the sustainability of harvesting on *P. sidoides* tubers and develop harvesting recommendations that will maximize recovery of the resource post harvest.

In this context, the term remnant refers to the fragments of *P. sidoides* tubers (regardless of their size) that are left by harvesters in the ground whether deliberately (for conservation purposes) or not deliberately (due to its extensive underground system, rocky soils e.t.c.) during and after harvesting.

1.16. Study objectives

Consequently the objectives of the study were:

- To determine the time taken by tubers regrowing from previously harvested *P. sidoides* tuber fragments to develop dark-red colouration.

- To determine the time taken by previously harvested *P. sidoides* tuber fragments to regenerate commercially harvestable tubers.
- To determine the potential impacts of harvesting on *P. sidoides* tuber recovery.
- To make recommendations on harvest methodology that will lead to sustainable production of *P. sidoides* tubers.
- To recommend overall management and monitoring options for *P. sidoides.*

1.17. Hypotheses

The study tested the following hypotheses:

- Previously harvested *P. sidoides* tuber fragments require a 7 year rotation to regenerate mature harvestable tubers.
- There is an uneven distribution of tuber colour between previously harvested and unharvested sites, with pale coloured tubers being more common in previously harvested populations.

1.18. Structure of the dissertation

The dissertation is divided into five chapters.

The first chapter (1) is a general introduction into the background on use of wild plants in traditional and western medicine, their commercialization, trade and sustainability of wild harvest. The chapter also includes more specific details on *P. sidoides* and the threats it faces in the wild. Following this is the study's aims, objectives and hypotheses.

Chapters 2, 3 and 4 present research results each focusing on its specific research objective. The chapters have been written as papers for ease of publication in future. Having used this format, there is some repetition although efforts have been made to keep this to a minimum.

Chapter 2 focuses on the capacity of *P. sidoides* plants to regrow from remnant tubers and the associated time spans required to regenerate commercially useful tubers.

Chapter 3 provides an investigation into the impacts of harvesting on the recovery of *P. sidoides* tubers.

Chapter 4 discusses sustainable harvesting methods that can be applied in harvesting wild populations of *P. sidoides* and develops appropriate management and harvesting recommendations.

Chapter 5 provides a general discussion on the whole study, and lists final conclusions and recommendations for management and further research on *P. sidoides*.

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Chapter 2

Rate of post harvest tuber recovery of *Pelargonium sidoides* plants into sustainably and commercially harvestable tubers

2.1. ABSTRACT

Wild harvesting of *Pelargonium sidoides* tubers has been occurring extensively in some parts of the Eastern Cape and Lesotho for centuries. Tubers are targeted because they contain medicinal properties. The medicinal compounds in the tubers are thought to be highly correlated with colour, with their concentration increasing as the colour develops towards dark-red. Dark-red coloured tubers seem to be preferred by the Pelargonium industry and are considered to be mature. Furthermore, the industry reportedly places less value on pale coloured tubers to discourage harvesters targetting pale immature tubers and thus to promote sustainability of wild harvest. However key information relating to the time it takes for previously wild harvested *P. sidoides* plants to regenerate sustainably and commercially harvestable tubers with a dark-red colouration is lacking thus limiting conservation options. Therefore the rate of *P. sidoides* tuber recovery, measured by tuber recovery colour and biomass in previously wild harvested sites was investigated using linear and non-linear regression models. The rate of *P. sidoides* tuber regrowth in cultivated plants was also investigated in the same manner to determine prospects for cultivation. Relationships between time since last harvest and tuber colour score as well as tuber recovery biomass were investigated for "lowveld" (Eastern Cape) and "highveld" (Lesotho and Free-State) vegetation regions. Significant relationships were found between time since last harvest and tuber recovery colour in both regions (r^2= 0.63, P < 0.05, d.f = 7 and r^2= 0.55, P < 0.05, d.f = 5). Similarly, significant relationships were detected when all types of sites (wild-harvested, semi-wild and agricultural) were combined for each region (r^2 = 0.79, P < 0.001, d.f = 12 and r^2 = 0.46, p < 0.01, df= 10). Furthermore, combining wild-harvested sites from the two regions also produced a significant relationship (r^2= 0.77, P < 0.001, d.f = 13). Finally, the relationship was also significant when all types of sites from the two regions were combined (r^2= 0.77, P < 0.001, d.f = 23). When the rate of tuber recovery was investigated using tuber recovery biomass, a significant relationship was only found in the "lowveld" vegetation region (r^2= 0.72, P < 0.05, d.f = 7). In cultivated sites, significant relationships were only detected when investigations were done on the effect of time on rate of tuber regrowth using biomass when study sites from the "lowveld" and "highveld" vegetation regions were combined (r^2= 0.68, P < 0.03, d.f = 8).The study revealed that tuber recovery colour and biomass in previously wild harvested sites increased positively with time. Additionally, *P. sidoides* plants require ≥8 years for tuber recovery to develop dark-red colouration and ≥10-15 years for harvested plants to attain original pre-harvest biomass. This means that for a sustainable wild harvest, repeat harvest on sites previously harvested should not occur before at least these periods have lapsed. Should the Pelargonium industry find the 10-15 year harvest interval too long, cultivation can be considered as an alternative. This is because tuber regrowth rate of cultivated plants was found to require a shorter time at ≥9 years to develop similar biomass to that of unharvested wild populations. However, future research is recommended to determine tuber colour development in cultivated plants and what constitutes commercially harvestable tubers.

2.2. INTRODUCTION

Wild plants have been used for various purposes such as medicine and are mostly harvested from the wild (Lange and Schippmann, 1997). However, little is known about the long-term effects of harvesting on viability of wild populations (Lamont *et al*., 2001), especially how populations recover post harvest. This is more so for plants such as *Pelargonium sidoides* that are harvested for their medicinal tubers. Furthermore, it can be difficult to envisage persistence of wild populations of medicinal plants because vital rates such as mortality vary over time as they respond to varying environmental conditions (Nantel *et al*., 1996). The manner in which plants reproduce and regenerate is crucial in resource conservation as it can determine how they respond to harvesting. Although large-scale harvesting of medicinal plants for commercial use damages some species, some of these species can easily withstand the damage caused. This is because some of these plants have certain traits that they use such as growth strategy and growth form (Cunningham, 2001). For example, clonal growth is believed to give plants an advantage in stressful abiotic environment (Pennings and Callaway, 2000). According to van Groenendael *et al*. (1996), clonal growth, from for instance tubers, is the production of independent offspring through vegetative growth. Many perennial plants reproduce sexually and clonally (Schmid *et al*., 1995). *P. sidoides* can also reproduce both sexually (through seed) and vegetatively from tubers and tuber remnants (van der Walt and Vorster, 1988; Dreyer and Marais, 2000; *pers. obs*.).

Whether plants are "reseeders" or "resprouters" can also determine their response to harvest (Cunningham, 2001). For instance, some species can resprout via rhizomatous or stoloniferous growth (Pate *et al*., 1990; Luoga *et al*., 2004), and these species may have an advantage over reseeder species because vegetative growth generally occurs from an original individual, which may or may not have been damaged by harvesting. Additionally, these plants may be resilient to the impacts of harvesting because of a high resprouting/coppicing response (Cunningham, 2001). Resprouters develop a "bud bank" and respond to any form of disturbance such as harvesting or fire by producing new stems (Cunningham, 2001). Similarly, *P. sidoides* seems to possess a "bud bank" on its tubers which enables it to develop new stems following harvest (*pers. obs*). According to Harper (1977), the "bud bank" is comprised of an accumulation of dormant meristems (buds) formed on rhizomes, corms, bulbils and tubers in the soil. Through, correlative inhibition, actively growing apical buds prevent growth of axillary and adventitious buds situated below the apical meristem, a phenomenon referred to as apical dominance. Therefore these other buds remain available for vegetative regeneration until injury such as harvesting breaks the apical dominance (Tuomi, *et al*., 1994). Thus a plant's ability to resprout from buds is important for disturbance tolerance (Weiher *et al*., 1999). However, resprouting in individual plants can vary; for example, Kindscher *et al*. (2008) established that there was likely to be variation among individual *Echinacea angustifolia* plants in their ability to resprout. Hence information on factors that affect resprouting in medicinal plants and their long term implications for plant persistence is important (Kindscher *et al*., 2008). Similarly, there is lack of information on *P. sidoides* resprouting ability and consequently it becomes difficult to estimate tuber recovery rates in wild harvested populations.

Perennial plants, such as *P. sidoides,* that produce tubers or rhizomes, build up carbohydrate reserves for resprouting after a disturbance and also for spring growth (Iwasa and Kubo, 1997). This growth strategy helps these plants to persist in many habitats because among clonal strategies, rhizomatous architecture has been reported to play an important role in plant persistence and spread (Hutchings and Bradbury, 1986; Eriksson and Jerling, 1990; Orbony and Cain, 1997). Additionally, the clonal growth strategy favors colonization of a wide range of habitats but mostly in grassland (van Groenendael *et al*., 1996). For example, in fire-prone African and Australian grasslands and savannas, many resprouters possess tubers that produce new stems after fire (James, 1984; Hansen *et al*., 1991). Although resprouters may resprout after a disturbance, there should be enough assimilates available from their storage organs to support resprouting (Iwasa and Kubo, 1997). This is because if there is a limited supply of assimilates (maybe due to the relatively small size of the tubers), carbon availability can limit regeneration (Klimesova and Klimes, 2007). Thus population recovery in perennial species post harvest can depend on factors such as resource availability that stimulate or inhibit plant growth (Ticktin and Nantel, 2004). Resprouters in general however, produce relatively few viable seeds (resulting in few seedlings) and hence once the parent plant dies, re-establishment from seed is usually rare (Cunningham, 2001). Although information on sexual reproduction in *P. sidoides* is largely lacking, seed production has been observed to be low (Vlok, 2003, 2005; *pers. obs*.).

P. sidoides is reported to have a high resprouting capacity because in most areas where wild harvesting of the species occurred in Lesotho, one to several small plants could be observed resprouting from remnant tubers left in many previously harvested holes (Newton *et al*., *in prep*.; *pers. obs*.). Vlok (2003, 2005) also observed high resprouting rates in some areas in the Eastern Cape where there was extensive previous harvesting. It was observed during fieldwork for this study that *P. sidoides* responds to harvesting in three different ways. The first stage occurs some weeks (as early as 2 weeks) after harvest where the plants resprout from the point where the tuber was broken off during harvesting. The next stage is elongation of the stems, the length of which seems to be dependent on whether the tubers are covered with soil post harvest or not and how deep they were buried. The third stage is the swelling and maturation of the stem into a tuber (*pers. obs.*). Tubers that are not covered with soil after harvest often desiccate, thus limiting stem resprouting. Furthermore, tuber colour intensity seems to also increase with tuber maturity. However, the approximate time the tubers take to mature to a commercially valuable size, colour and chemical constituent levels is unknown.

Newton *et al*. (*in prep.*), estimated a return harvest period of 7 years for *P. sidoides* tubers to age sufficiently. This age appeared to be correlated with a mature dark-red/purple colouration rather than the pale cream colour associated with the youngest tubers. However, Newton *et al.* (*in prep.*) depended on field observations and interviews to obtain the 7 year period, and it is not clear if the 7 year period is an estimation of tuber biomass recovery, the minimum time required for the tubers to become this mature dark-red colour or a combination of both. Thus a thorough scientific verification into the rate of tuber recovery and tuber colour development in previously harvested plants was required.

Some researchers have investigated the response of medicinal plants harvested for their tubers to impacts of harvesting intensity, timing and frequency (Nault and Gagnon, 1993; Nantel *et al*., 1996; Rock *et al*., 2004; White, 2007; White *et al*., 2008). However, how the tubers recover, how long they take to do so and the time required for the medicinal compounds to develop to sufficient concentrations is usually ignored. White (2007) and White *et al*. (2008) used regression models to estimate tuber regeneration time for *P. sidoides* as approximately averaging 56 years under field conditions. However, using the lower and upper confidence limits, the regeneration time could range from 11.5 to 410 years (White, 2007; White *et al*., 2008). The discrepancies between tuber regeneration time established by Newton *et al*., *in prep*., White (2007) and White *et al*. (2008) may indicate that the former estimated the time using tuber colour while the latter used tuber biomass.

In other medicinal plants, Nault and Gagnon (1993) established through population projection matrices that harvest rates between 5% and 15% of *Allium tricoccum* bulbs caused population declines of the species. In another study, Rock *et al*. (2004) examined the recovery of *A. tricoccum* populations post harvest using experimental harvest of different intensities to predict the number of years required to return to pre-harvest levels. They estimated that recovery time ranged from 148 years after a 95% harvest to 2.5 years for a 5% harvest. This suggests that recovery time can depend on harvesting intensity.

There is currently a lack of information on *P. sidoides* tuber characteristics required by the Pelargonium industry, however, through informal interviews with harvesters, industry personnel and field observations; it was possible to deduce that large tubers with deep red/purple colouration are preferred (M.Letsie, area chief, Ha Tlhaku, Quthing, 2007; K. Paulsen, owner of BZH company, *pers. comm*; H. Nieuwoudt, Bophelo Natural Products, *pers. comm.,* 2007; *pers. obs*.). White (2007) and White *et al*.

(2008) also found that tubers that are large and dark-red, as opposed to small and pale coloured ones are preferred as they are assumed to be commercially mature. The harvesters are instructed to collect tubers with these characteristics as there seems to be a correlation between *P. sidoides* active compounds and colour with increasing amounts of the compounds as the tubers get to darker red (H. Nieuwoudt, Bophelo Natural Products, *pers. comm*., 2007). However, information on *P. sidoides* tuber characteristics favored by the Pelargonium industry seems to be conflicting and often changes. For instance others in the industry insist that tuber colour is not a requirement as pale coloured tubers can also have the same concentration of active compounds as dark coloured ones but rather harvesters are encouraged to harvest dark-red tubers (considered to be mature) on sustainability grounds (K. Paulsen, owner of BZH company, *pers. comm.,* 2008; H. Nieuwoudt, Bophelo Natural Products, *pers. comm.*, 2008; U. Feiter, owner of Parceval, *pers. comm*., 2008).

P. sidoides tubers have been found to contain several secondary metabolites such as coumarins and flavonoids (Kolodziej and Kinderlen, 2007). Secondary metabolites are needed for the interactions of a plant with its environment, including as a defense against predators and disease (Kutchan, 2005). Therefore harsh environmental conditions may induce an increase in the concentration of secondary metabolites. Of the secondary metabolites, flavonoids are known to comprise the most common group of polyphenolic plant secondary metabolites and function as pigments in flowers, fruits (Schijlen, 2004) and in most plant tissues such as roots and tubers (Davies, 2004). Thus the flavonoids may be responsible for pigmentation in *P. sidoides* plants, particularly in its tubers.

The information on tuber characteristics required by the Pelargonium industry and the estimated 7 year period required for *P. sidoides* tubers to recover to a commercially valuable size and dark-red tuber phase formed the hypothesis for this study. It is important to note that tuber recovery rate in *P. sidoides* can be measured by both tuber colour and tuber biomass. Therefore the aim of this study was to determine the capacity of *P. sidoides* plants to regrow from remnant tubers remaining from previous harvest events, and the time required to regenerate commercially useful tubers with a dark red/purple colouration.

The study aimed to answer the following questions:

- Does it take 7 years for *P. sidoides* tubers to develop the required dark-red tuber colouration post harvest?
- Does it take 7 years for *P. sidoides* tubers to recover to a commercially and sustainably harvestable size post harvest?

2.3. MATERIALS AND METHODS

2.3.1. Study Area

The distribution of *P. sidoides* in southern Africa occurs in high altitude regions such as Lesotho and the South African Free State Province, as well as lower altitude provinces such as the Eastern Cape. Hence the study sites were broadly divided into "lowveld" and "highveld" vegetation regions so that when comparisons on plant performance were made, these clearly different ecological sites would be considered. The Eastern Cape Province represented the "lowveld" vegetation region while Lesotho and the Free-State Province represented the "highveld" vegetation region.

Plant performance was also measured between wild-harvested and unharvested control sites, semi-wild and agricultural sites as well as across all types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites). Sites were found that had been harvested from 0.5 to 8 years previously, and were chosen from the two regions to represent wild harvested populations. Wild-harvested sites with known history of previous harvest (e.g. when they were last harvested) as well as cultivated sites (semi-wild and agricultural) were located with help from various role players in the Pelargonium industry such as middlemen and harvesters.

It must be noted that the accuracy of information on harvest history of a particular site tended to vary depending on the role player, the type of information requested and the intended use of the information. Middlemen for instance keep records of harvest sites location because they are in business hence they were able to provide accurate information on exact location of sites. On the contrary, harvesters usually have information on harvest tools and methods despite not keeping records because they carry out the actual collection. The intended use of information (e.g. setting harvest quotas, management plan or ABS guidelines) may affect its accuracy depending on how the person giving the information feels he/she maybe affected. For instance, middlemen are often reluctant to provide certain information such as information on how much they harvest per annum fearing that harvest quotas may be set too low or that release of commercial secrets may compromise their business (K. Paulsen, owner of BZH company, *pers. comm*., 2008; H. Nieuwoudt, Bophelo Natural Products, *pers. comm*., 2008; U. Feiter, owner of Parceval, *pers. comm*., 2008). Harvesters on the other hand sometimes gave inaccurate information on harvest methods (i.e. whether they fill harvest holes with soil post harvest or not) (*pers. obs*.) probably thinking that harvest may be stopped by conservation officials concerned should they be factual. It should be mentioned that some information provided such as harvest methods was not verifiable unless harvest had occurred recently like 2 years ago. In such cases, whether a harvest hole was filled up with soil (closed) or not would still visible.

Semi-wild sites were considered as those sites in which plants were originally collected from the wild, divided into propagules and placed in cultivation. These sites received minimal management, such as weeding and watering until abandoned. Agricultural sites were considered as those sites where plants were collected from the wild for their tubers, cut into propagules, and planted in established agricultural lands and sites established from seeds (e.g. some sites in Rhodes). These cultivated plants were then treated differently from semi-wild sites by receiving ongoing regular and intensive care, such as irrigation, until harvest.

For unharvested control sites, farm owners, provincial and national park managers were approached and asked for permission to conduct research on their farms and parks. Unharvested control sites comprised sites not previously harvested or those unharvested plants that were sampled from a wild-harvested site.

2.3.1.1. "Lowveld" vegetation region

2.3.1.1.1. Eastern Cape Province

This study was conducted in the Amatola and the Northern Ukhahlamba regions of the Eastern Cape. In the Amatola region, 7 study sites were sampled, namely Peddie, Lokwe (formerly known as Victoria Post Farm) (van Niekerk, 2009), Wesley, Stutterheim, Hogsback, Cathcart and Double-Drift Nature Reserve. The only Ukhahlamba region study site was at an agricultural holding within the town of Rhodes. All the study sites are located between 30° 47'S - 33° 19'S and 26° 49'E - 27° 57'E with altitudes ranging from 100 to 1,845 metres above sea level (masl). The Eastern Cape Province incorporates two of the former "homelands" of the Apartheid period, namely the Ciskei and Transkei as well as what was then part of the Cape Province (Dold and Cocks, 2002). The people of the Eastern Cape tend to be more traditional and rural, but also significantly poorer and less developed, than those in other South African Provinces (Cocks and Møller, 2002). Therefore reliance on natural resources for utilization and trade can become the easiest escape from poverty.

All the sites in the Eastern Cape are located in the Savanna, Grassland and to a lesser extend the Albany Thicket biomes and in particular the Sub-Escarpment Savanna, Sub-Escarpment Grassland and Drakensberg Grassland Bioregions. The Savanna Biome experiences a semi-arid to subtropical climate with wet hot summers and dry mild winters. The mean annual temperatures (MAT) range from 17°C to

18°C with mean annual precipitation (MAP) ranging between 500 and 750 mm in areas outside the Kalahari (Mucina and Rutherford, 2006). The mean daily maximum temperatures for February rarely drops below 26°C in some of the low-altitude areas in the East (Schulze, 1997), while they can drop to 18°C in higher altitudes. The mean daily minimum temperature for February can drop below 16°C in higher lying areas and can remain at 20°C in the lower "lowveld" areas. In winter, minimum temperatures are more variable with some eastern parts of the biome getting minimum daily temperatures that remain above 10°C. Only the lower-lying parts of this Biome such as the Sub-Escarpment Savanna Bioregion are considered frost-free. The Savanna Biome is dominated by the Kaapvaal Craton, a stable continental crust which contributed to deep sandy soils and shallow lithosols (Mucina and Rutherford, 2006).

The grassland biome is characterized by temperate climate with summer rainfall and cold winter droughts. The MAT ranges from 4°C to 15°C (in the Drakensberg Grassland and Sub-Escarpment Grassland Bioregions) with MAP of between 423mm and 1,234mm. The topography is mostly flat to rolling but also comprises mountains (Mucina and Rutherford, 2006). There are high lightning flash densities which raises the probability of naturally induced fires; for this reason, Grassland is a fire prone ecosystem (Mucina and Rutherford, 2006). Grazing and fire have a major influence on canopy structure and species composition. This Biome is underlain by the Karoo Supergroup rocks of the Clarens and Elliot formation which are covered by the Drakensberg group in some areas. Sweet and sour grasses are found in this Biome belonging to the subfamily Chloridoideae and Panicoideae respectively (Mucina and Rutherford, 2006).

The Albany Thicket Biome also experiences a semi-arid to sub-tropical climate with an unpredictable rainfall regime, ranging from 256 - 677mm MAP. The annual precipitation coefficient of variation (APCV) is 25-36%. The vegetation of this Biome is a dense, woody, semi-succulent and thorny vegetation type with average height of 2-3m (Acocks 1953; Everard, 1987). According to Acocks (1953, 1988), the Albany Thicket comprises small patches of other vegetation types that are embedded within the thicket, such as the Savanna Biome, which is where *P. sidoides* also occurs. Primary productivity studies have shown this biome to have slow growing species (Aucamp and Tainton, 1984). The geology of the Biome comprises folded strata of the Cape Supergroup with early Karoo Supergroup sedimentary rocks also folded in the northern margin of the Cape Fold Belt. The Biome is typified by fine and deep well-structured soils as well as shallow and coarse unstructured soils (Mucina and Rutherford, 2006). Dominant plant families are Ebenaceae, Sapindaceae and Didiereaceae (Cowling *et al*., 2005).

Table 2.1.: Different types of study sites and their location in the "lowveld" vegetation region

Name of site	Abbreviation	Site age (years)	Site type	Altitude (m) above sea level	GPS coordinate (degrees, minutes and seconds)
Janine Farm harvested	JFH	3	Wild-harvested	1412	S32 23 05.5 E26 57 42.4
Airstrip	ASH	3	Wild-harvested	1222	S32 16 21.8 E27 08 55.8
Peddie I	P I	4	Wild-harvested	354	S33 23 30.4 E27 03 92.2
Peddie II	P II	4	Wild-harvested	363	S33 13 03.3 E27 02 98.7
Victoria Post I	VP I	6	Wild-harvested	549	S32 54 54.5 E26 49 57.0
Victoria Post II	VP II	6	Wild-harvested	560	S32 55 15.8 E26 50 28.3
Wesley I	W I	7	Wild-harvested	139	S33 19 59.2 E27 16 73.8
Wesley II	W II	8	Wild-harvested	140	S33 18 48.9 E27 17 09.2
Bold-farm	BF	2	Semi-wild	1450	S32 33 13.2 E26 54 29.5
Stutterheim semi-wild	STS	3	Semi-wild	745	S32 38 13.8 E27 30 18.2
Rhodes I	RH I	1	Agricultural	1842	S30 47 39.2 E27 57 41.6
Rhodes II	RH II	2	Agricultural	1841	S30 47 41.7 E27 57 40.7
Stutterheim agricultural	STA	4	Agricultural	769	S32 38 0.20 E27 30 17.6

Air strip control	ASC		Unharvested control	1223	S32 16 22.6 E27 08 56.0
Janine farm control	JFC		Unharvested control	1413	S32 23 05.5 E26 57 42.5
McMaster farm	MF		Unharvested control	1360	S32 20 58.3 E27 04 57.7
Double-Drift	DD		Unharvested control	563	S32 56 59.4 E26 49 53.7

2.3.1.2. "Highveld" vegetation region

2.3.1.2.1. Lesotho

The study was conducted at Quthing (Ha Tlhaku and Tsatsane) and Mohale's Hoek (Thoteng) districts situated in the southern part of the country, as well as Butha-Buthe (Makhunoane) which is situated in the northern part of the country. Due to the availability of the Lesotho Scientific Authority non-detriment study findings (NDF), these data (Newton *et al*. *in prep*.) were used as well. The NDF study was conducted at Quthing (Ha Tlhaku, Ha Ratema, Ha Lebelonyane), Qacha's Nek (Ha Nthunya, Ha Leteba,Likhohloaneng, Ha Mats'a, Makhoareng), Mokhotlong (Molumong I, Molumong II, Ts'epong, Mapholaneng), Thaba-Tseka (Thaba-Tseka Basotho pony garden, Machaping, Katse Ha Ramokoatsi I, Katse Ha Ramokoatsi II, Katse Ha Theko I, Katse Ha Theko II) and Butha-Buthe (Makhoakhoeng, Makhunoane) districts. The study sites are found between 28° 18'S- 30° 28'S and 27° 28'E- 29° 00'E with altitudes of between 1,595masl to 2,746masl. The study sites occupy the Grassland Biome, specifically the Drakensberg Grassland Region and to a lesser extent the Mesic Highveld Grassland Bioregion, with the predominant vegetation being the Basalt Grassland vegetation. The two vegetation regions experience temperate to sub-tropical climate regimes, characterized by MAP of between 391mm to 1,451mm. The MAT ranges from 4.0°C to 17.2°C (Mucina and Rutherford, 2006).

Lesotho is a mountainous country that is completely land-locked by the Republic of South Africa and occupies only 30,355 km^2 in size. Approximately three quarters of the country represents the Maluti range while the remaining one quarter comprises the lowlands and foothills. The majority of the population (80%) lives in rural areas and depend on subsistence agriculture for their livelihood (Mokuku *et al*., 2004). However in recent years, man-induced soil erosion has become common in Lesotho with soil loss estimated at 2,000 tons per km^2 (Chakela, 1981), and hence a great threat to agricultural production. This is aggravated by the fact that already only nine percent of Lesotho is arable land (Mokuku *et al*., 2004) and population pressures have increased landlessness. Additionally, Lesotho is considered as one of the fifty poorest countries in the world, with 56.7% of its population living below the poverty line (*Anon*., 2010a).The incidence of poverty coupled with landlessness can thus put pressure on local people to opt for commercialization of medicinal plants as they have limited means of generating income.

2.3.1.2.2. Free State Province

The study sites were located at Qwaqwa (Tsiame village) and Golden Gates Highland Nature Reserve with altitudes of between 1,740 and 2,360masl. The study sites are found between 28° 18'S - 28° 33'S and 28° 34'E- 28° 58'E. The whole Free-State Province including the study sites are situated in the Grassland Biome and in particular the Drakensberg Grassland Bioregions and to a limited extent within the Mesic Highveld Grassland. The Free-State Province lies in the Karoo sequence of rocks containing shales, mudstones, sandstones and the Drakensburg basalt. The area experiences a temperate climate characterized by warm to hot summers and cool winters. The areas in the east experience frequent snowfalls, especially on higher places while the west can be extremely hot. The Grassland (Mesic Highveld and Drakensberg Grassland Bioregions) areas have MAT of from 4.0°C to 16.8°C with MAP of 543 to 1451mm. The grasslands are strongly dominated by grasses of the family Poaceae (Mucina and Rutherford, 2006).

The Free State Province is one of nine provinces in South Africa and is centrally located in terms of the geographic distribution of South Africa. Prior to 1994, the Province included two small areas that made up part of the old Apartheid homelands of Bophuthatswana and the self-governing territory of Qwaqwa (Bradshaw *et al*., 2000).

Table 2.2.: Different types of study sites and their location in the "highveld" vegetation region

Name of site	**Abbreviation**	**Site age (years)**	**Site type**	**Altitude(m) above sea level**	**GPS coordinate (degrees, minutes and seconds)**
Ha Tlhaku wild	HTW I	2	Wild-harvested	2134	S30 09 15.0 E28 14 10.7

Tsatsane	TSA	2	Wild-harvested	1880	S30 28 05.4 E28 00 11.4
Thoteng	THO	1	Wild-harvested	2109	S30 09 14.4 E28 14 11.4
Ha Nthunya	HNT	1	Wild-harvested	2190	S30 09 11.7 E 28 13 60.5
Ha Lebelonyane	HLE	3	Wild-harvested	2200	S30 11 14.0 E28 00 23.8
Makhoakhoeng	MAK	3	Wild-harvested	2182	S28 39 03.3 E28 28 03.3
Ha Tlhaku semi-wild I	HTS I	2	Semi-wild	2140	S30 09 21.0 E28 14 31.3
Ha Tlhaku semi-wild II	HTS II	1	Semi-wild	2113	S30 09 23.8 E28 14 23.6
Mohale’s Hoek white sand	MHW	0.5	Agricultural	1592	S30 08 45.6 E27 28 19.1
Mohale’s Hoek black sand	MHB	0.5	Agricultural	1594	S30 08 45.4 E27 28 19.9
Mohale’s Hoek open	MHO	1	Agricultural	1593	S30 08 46.4 E27 28 18.9
Tsiame I	TSI I	Control	Control	1740	S28 18 47.6 E28 58 50.0
Tsiame II	TSI II	Control	Control	1794	S28 19 08.4 E28 58 47.5
Likhohloaneng	LIK	Control	Control	2100	S30 03 77.3 E28 43 42.6
Ha Matsa	HMA	Control	Control	2149	S30 03 87.3 E28 43 35.4
Makhoareng	MKH	Control	Control	2146	S30 02 53.0 E28 53 35.9

Koma-koma	KOM	Control	Control	2273	S29 36 28.1 E28 40 51.0
Basotho Pony Garden	BPG	Control	Control	2230	S29 32 11.5 E28 37 45.3
Katse I	KHR I	Control	Control	2329	S29 21 27.2 E28 28 36.2
Katse II	KHR II	Control	Control	2324	S29 21 39.2 E28 28.629
Ha Theko I	KHT I	Control	Control	2312	S29 19 05.3 E28 30 50.6
Ha Theko II	KHT II	Control	Control	2355	S29 19 31.6 E28 30 73.9
Molumong I	MOL I	Control	Control	2667	S29 21 55.2 E29 00 02.5
Molumong II	MOL II	Control	Control	2736	S29 22 00.9 E29 00 08.7
Mapholaneng I	MAP I	Control	Control	2400	S29 09 51.4 E28 52 02.5
Mapholaneng II	MAP II	Control	Control	2413	S9 09 51.6 E28 51 59.8
Swaartkop	SWA	Control	Control	2353	S28 32 31.3 E28 34 19.5
Mampier I	MAI	Control	Control	2204	S28 31 37.9 E28 38 26.4
Mampier II	MAII	Control	Control	2218	S28 31 41.2 E28 38 33.6

2.3.2. Sampling of plants in the field

Plants were sampled in two periods in the Eastern Cape. The first sampling took place in February 2009 and the second one in November 2009. In Lesotho and Free-State, there was only one sampling period. Plants were sampled during March 2009 in Lesotho and during May 2009 in the Free-State. After the

Golden Gate Nature reserve was sampled, the park managers indicated that *Pelargonium reniforme* may also occur in the reserve. This species is morphologically similar to *P. sidoides* and hence sampling of the incorrect species was a distinct possibility. Since sampling occurred at the end of the growing season in May when the plants were not in flower, the two species could not be differentiated since that can only be done when they are in flower. Hence to make sure, after completion of the fieldwork, the tubers of 30 plants were excavated from the Golden Gate Nature Reserve, and then planted at Goldfields Environmental Centre shade (using 80% shade cloth) house in Johannesburg. These tubers were planted in standard potting soil and exposed to normal weather conditions. This was done so as to observe the flower colour (pink or purple for *P. reniforme* or dark-red/maroon for *P. sidoides*). At the time of publication of this dissertation, five out of the thirty planted tubers had produced the dark-red flowers of *P.sidoides*.

Four types of sites were sampled to determine *P. sidoides* plant performance: (a) wild harvested sites, (b) semi-wild sites (c) agricultural sites and (d) unharvested control sites. At each type of site ten plants (n = 10) were sampled. In wild harvested sites, plants that showed evidence of previous harvest (Figure 2.1A (i)) were individually selected and thereafter a 1m^2 quadrat was placed, with the plant at the centre and number and date card on the side to estimate canopy area and total vegetation cover (Figure 2.1A (ii)).

Evidence of previous harvest was taken as the following:

1. Harvesting holes
2. Digging marks
3. Evidence of one, two or more resprouting stems clustered around a harvesting hole

However, upon digging, an unharvested plant would still occasionally be obtained, even after following the above-mentioned selection criteria for harvested plants. Hence, from all wild harvested sites, the number of previously harvested plants obtained ranged from 4 to 8 out of the 10 excavated. This was the case with plants that were sampled in the first sampling period in the Eastern Cape (e.g. Peddie, Lokwe (formerly known as Victoria Post Farm) (van Niekerk, 2009) and Wesley) and all plants sampled in Lesotho and the Free-State. This is because during this first sampling period, there was no instantaneous repeat sampling upon encountering unharvested plants to top up the number of previously harvested plants to 10. This problem was rectified for some sites in the Eastern Cape in the next sampling period whereby repeat sampling was conducted immediately whenever an unharvested plant was found. Regardless of this it proved difficult to get the exact 10 harvested plants and hence the varying number of samples per site. On the contrary, it was not possible to supplement the sampled plants to make a total of 10 plants in the "highveld" vegetation region since there was only one sampling period.

All the other types of sites (semi-wild, agricultural and unharvested sites, except the NDF sites) were sampled by randomly selecting the plants in a given site and then placing the 1 x 1 m quadrat over the plant, together with numbered cards (with site name, plant number and date, which also aided in the taking of labeled digital photographs.

The following actions were performed on each selected plant:

1. Photographs of the plant, the quadrat and labeled cards were taken.
2. GPS coordinates were recorded for each plant.
3. Estimates of ground cover (using over-story, under-story, litter cover and rock cover) were recorded.

2.3.2. Data collection and colour delineation

After sampling of plants, various measurements were taken on the above and below ground plant parts. The following above-ground measurements and counts were made on each *P. sidoides* plant before digging it up:

1. Number of flowers, stems and resprouting shoots
2. Canopy length (W_1) and width (W_2) using a 30 cm plastic ruler
3. Ramet height using a 30 cm plastic ruler

Harvested plants were separated from unharvested ones once uprooted based upon their appearance. Harvested plants have a tuber with an obvious point of cut (where the tuber was chopped or broken off during harvesting), while unharvested plants have tubers that do not posses this feature. The following terminology was used to differentiate different tuber parts in plants sampled from different types of sites:

1. "Tuber recovery": This was only considered as new tuber formation that formed from the point of the post-harvest cut on tubers sampled from wild-harvested sites (Figure 2.1B i, ii).
2. "Mother tuber": This referred to the original tuber that possessed the point of cut (Figure 2.1B i). However, in potatoes, the term "mother" tuber refers to the initial tuber used for propagation while harvesters of Devil's claw also refer to the persistent primary from which all the rest of the tubers (secondary tubers) develop from as a "mother tuber" (Steward and Cole, 2003).
3. "Remains": It was considered as the rest of the original pre-harvest tubers, as well as the mother

tuber, remaining in the ground post-harvest (Figure 2.1B ii).

4. "Tuber": This was considered as all intact tubers from unharvested control sites without any obvious point of cut (Figure 2.1C i).
5. "Tuber regrowth": This referred to all the tubers growing from the parent tuber (tuber that was used for initial propagation) in semiwild and agricultural sites. The term was also used to refer to new tuberous formation of plants sampled from semi-wild and agricultural sites where seeds were used for initial propagation (Figure 2.1D ii).
6. "Cultivated plants": This was used as a general term when referring to plants from semi-wild and agricultural sites.

The following measurements of below-ground plant parts (listed and explained above) were carried out immediately after removal of plants (before the plants lost too much moisture) (Figure 2.1C i, ii, iii, iv).

1. Maximum tuber length (using a 30 cm plastic ruler)
2. Average tuber diameter (using vernier calipers)
3. Individual tuber mass (using an electronic weighing scale accurate to 0.001 g).
4. For tuber colour, new plastic laminated Pantone Colour Charts (PCC) for felt-tip pens were used. A finger nail was used to scrape off the tuber epidermis to expose the colour of the internal tissues for comparison against the PCC. The code for the PCC colour matching the tuber colour was recorded (Figure 2.1C iii).

Pantone colours are standardized colours owned by the company Pantone Inc., best known for its Pantone Matching System (PMS). The idea behind the PMS is to allow designers to 'color match' specific colours when a design enters the production stage, regardless of the equipment used to produce the colour. In 2001 Pantone began providing computer based simulations of their PMS colour guides using the proportional mix of red, green and blue (RGB) to create various colours (*Anon*., 2010b) on Microsoft Excel. Having mixed the colours using the Microsoft Excel colour feature and using the name of the colour allocated by the computer programme, it was possible to sort the colours into a sequence of 12 categories ranging from the whitest/cream to darkest red/purple. These sequential categories (= increasing colour intensities) made it possible to "quantify colour" and to easily determine colour frequencies.


A (i)
A (ii)
11/11/09
B (i)
1
Point of cut
Tuber recovery
Mother tuber
B (ii)
Remains
Point of cut
C (i)
UNIDATA
12/05/09
GGI 6
C (ii)
Scout
0.82

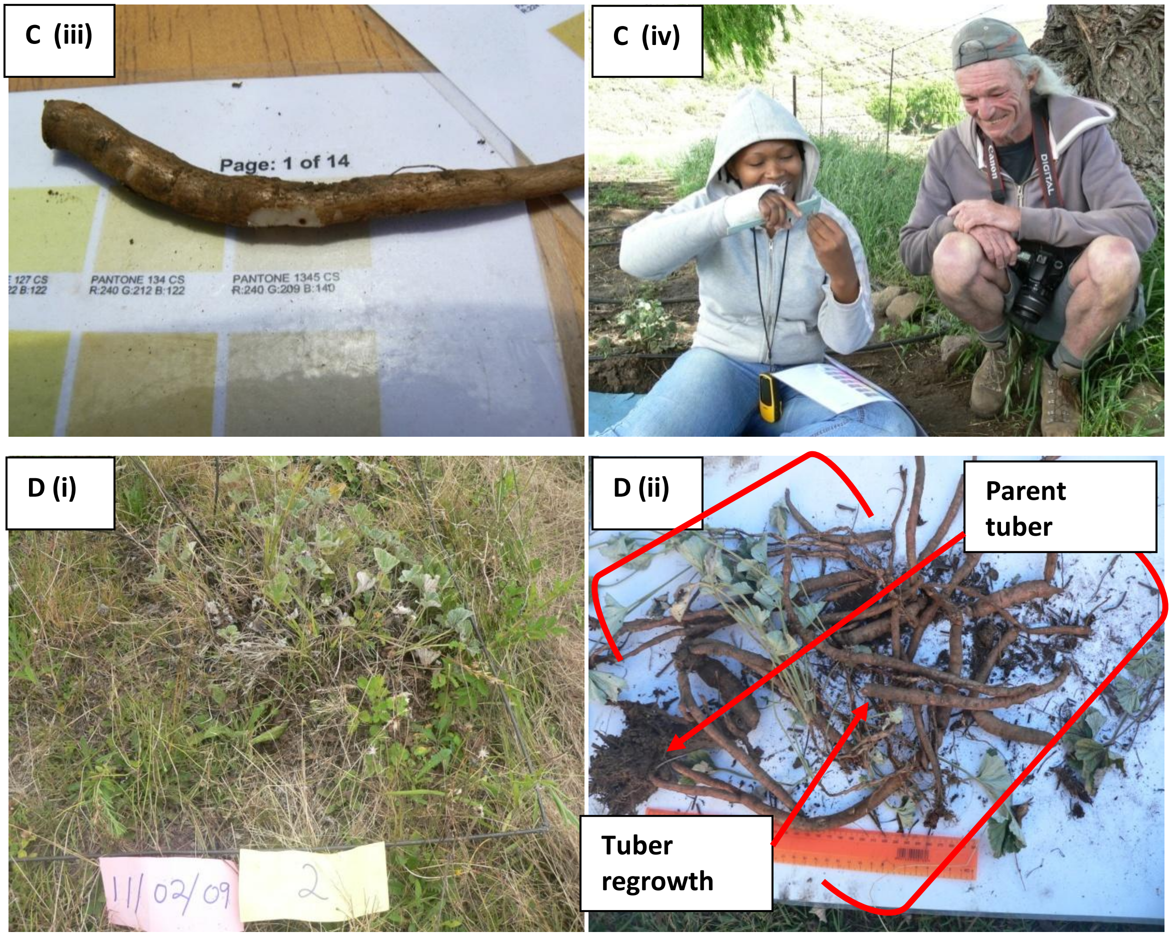

Figure 2.0. The sampling procedure used during field work for this study, terminology as well as various measurements that were taken. A(i)= evidence of previous harvest, A(ii)= sampling of wild-harvested plants, B(i) and B(ii)= wild-harvested plants with evidence of tuber damage, C(i)= photographs of uprooted tubers from unharvested "control" sites, C(ii)= measurement of tuber mass, C(iii)= comparison of tuber colour against PCC, C(iv)= measurement of tuber diameter, D(i)= sampling of semi-wild and agricultural plants, D(ii)= tuber regrowth in cultivated plants.

Tuber volume was calculated using Huber's formula as follows:

$$\text{Volume (v)} = \pi L d^2{}_m/4$$

where π= Pi, d= diameter of the tuber at mid-length; and L= tuber length (Cunningham, 2001)

Canopy area of each ramet was determined as follows (Witkowski *et al*., 1994):

$$\text{Canopy area} = 0.7854W_1W_2$$

where W_1= widest canopy width; W_2= width perpendicular to W_1

Newton *et al*. (*in prep.)* used a different sampling procedure to the one used in this study by laying out transects and measuring a limited number of variables. At each of the 20 sites that were surveyed, five transects were laid by first measuring a 100m base-line that ran perpendicular to the direction of the slope. Each of the 50m long individual transects were then laid out up the slope, i.e. perpendicular to the 100m base-line. GPS coordinates were marked at the start and finish of each transect. A 1.8m long pole was carried along each transect line (hence 0.9m on either side of the transect line) and each plant occurring within the poles breadth was counted to get plant densities. One plant would then be picked at random along each transect line and dug up. After sampling, plants were photographed. The following below-ground measurements and counts were taken:

1. Number of stems and resprouts
2. Wet tuber mass (whole plant), minimum tuber diameter, maximum tuber diameter and maximum tuber length (using a ruler and vernier caliper)

However, since the Lesotho NDF exercise was carried out to determine the impact of trade on *P. sidoides* populations, most sampled sites were unharvested control sites. Of the 20 sites that Newton *et al. (in prep*.) sampled, only three sites had a history of previous harvest. The NDF study sampled a minimum of three plants and a maximum of 6 plants per site (n = 3 and n = 6).

In order to transform the NDF data to the same format as that collected for this study, estimations and observations were made from photographs. The estimations were made possible by using the scale measure on each NDF photograph. It must be noted that estimations on NDF data were done on all different tuber parts (as listed and explained above) as was the case with plants sampled during this study. Additionally, harvested plants were separated from unharvested ones by looking at the point of cut feature.

The estimation methodology is explained below:

1. Wet tuber length (mm): The following equation used to estimate wet tuber length:

$$L_t= (L_P*L)/F_P$$

   Where L_t= actual tuber length, L_p= measured tuber length from photograph, L= actual length of scale item in photo and F_p= measured scale item length from photograph.

2. Average tuber diameter (mm): Since Newton *et al. in prep*. only measured wet maximum and minimum individual tuber diameters for each plant (meaning if one plant had four tubers, only

two had their diameters taken) therefore average individual wet tuber diameters had to be estimated from the dried NDF tubers using a conversion factor described below. Fresh average diameter for each tuber was estimated by measuring dry average maximum and minimum diameter for each tuber (oven-dried plants were kept after fieldwork and stored at Goldfields Environmental Centre in Johannesburg). Since fresh maximum and minimum diameter measurements for each plant were taken during the NDF, dry maximum and minimum tuber diameters were subtracted from the wet diameter values for each plant. The differences obtained for each tuber were added and divided by the total number of tubers whose fresh diameters were measured during NDF to get an average drying factor (shrinkage factor).

To estimate the drying (shrinkage) factor average, the following equation was used:

$$D_a = (D_f - D_d)/N_t$$

Where D_a= drying (shrinkage) factor average, D_f= fresh maximum and minimum diameters, D_d= dry maximum and minimum tuber diameters and N_t= total number of tubers whose fresh average diameters were measured during NDF.

Thus, D_a= 774/222= 3.49mm

Therefore to estimate average tuber diameter, the following equation was used:

$$D_t = D_a + D_{di}$$

Where D_t= estimated average fresh tuber diameter, D_a= drying factor average, D_{di}= dry average diameter of individual tubers whose diameters were not measured during NDF.

3. Individual tuber mass (g): Newton *et al. in prep*. did not get individual tuber masses but rather took whole plant masses. So to estimate individual tuber mass, tuber volumes had to be calculated using Huber's formula as shown above. It was possible to calculate individual tuber volumes as individual tuber lengths and average diameter measurements were calculated in 2 above. For each plant, total tuber volume was calculated by adding all tuber volumes together. Having done this, it was then possible to get the ratio of individual tuber volume to total tuber volume for each plant (individual tuber volume/total tuber volume). This ratio was then multiplied by whole plant mass and thus individual tuber mass was determined.

The following equation was used to estimate individual tuber mass:

$$M_i= (V_i/V_t)*M_w$$

where M_i= individual tuber mass, V_i= individual tuber volume, V_t= total volume/plant, M_w= whole plant mass.

4. Tuber colour and ground cover were determined by looking at the photographs. However, it was difficult to note tuber colour from photographs as some tubers were not damaged during uprooting hence tuber colour estimates were not accurate.

It was possible to estimate some variables as shown above. The sole exception was for canopy width (W_1 and W_2) which due to the two dimensional nature of photographs was difficult to estimate and hence was not determined.

2.3.3. Data analysis

Only "tuber recovery", "tuber regrowth" and "remains" biomass and tuber colour data was analysed in various ways in this chapter to determine rate of tuber recovery and rate of tuber regrowth. The other data on different tuber parts (e.g. "mother tuber" as explained in the above section) was used for analysis in subsequent chapters (e.g. Chapters 3 and 4).

In order to perform statistical analysis on "tuber recovery" and "tuber regrowth" colour data, PCC codes had to be quantified. This was done by ranking the colours from pale to dark purple with 1 being the palest and 12 the darkest colour. Since colour scores were assigned to represent colour intensities, wherever the phrase colour score is used it must be interpreted as a proxy for colour intensity.

To determine the time required for *P. sidoides* tubers to develop dark red/purple colouration, linear and non-linear regression models were used to determine relationships between variables. These were relationships between time since last harvest, time in cultivation and "tuber recovery" or "tuber regrowth" colour score.

Linear and non-linear regression models were also used to determine the time required for *P. sidoides* tubers to recover to a commercially valuable size post harvest by investigating relationships between time since last harvest, time in cultivation and "tuber recovery" or "tuber regrowth" biomass.

Micro-soft excel 2007 analysis tool package was used to conduct the analyses.

2.4. RESULTS

2.4.1. "Lowveld" vegetation region

2.4.1.1. Effect of time on colour of tuber recovery for wild harvested plants

Tuber recovery colour was expected to intensify with increasing time since harvest. Therefore the relationship between time since last harvest and tuber recovery colour score was investigated. There was a positive logarithmic relationship between the two variables ($P < 0.05$) (Figure 2.1) and thus tuber colour intensifies as time since last harvest increases.

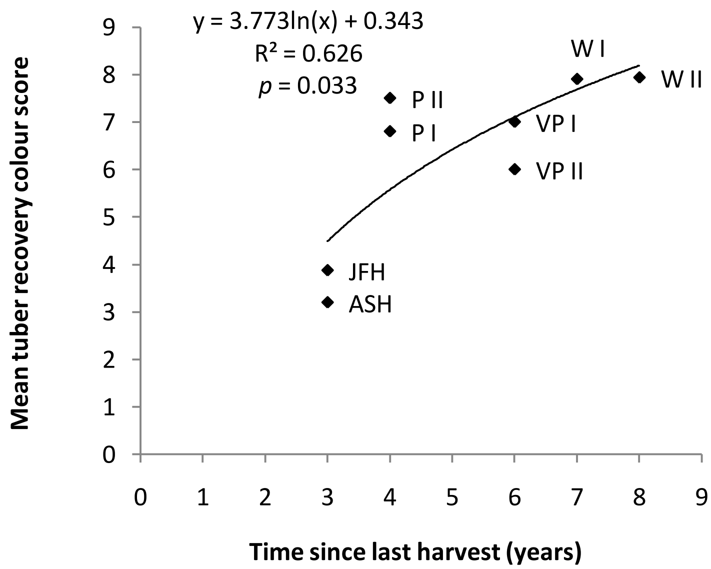

Figure 2.1. Relationship between time since last harvest (years) and colour intensity in wild-harvested sites (n = 8). ASH=Airstrip, JFH= Janine Farm, PI= PeddieI, PII= PeddieII, VPI= VictoriaPostI, VPII= VictoriaPostII, WI= WesleyI, WII= WesleyII.

2.4.1.2. Effect of time on tuber recovery biomass for wild harvested plants

Tuber recovery size was expected to increase with time since harvest. Therefore the effect of time on tuber recovery biomass mass was determined. A significant exponential relationship was found between the two variables ($P < 0.05$) (Figure 2.2). This implies that as the time since last harvest increased, tuber recovery mass also increased. Thus given time, the tubers that were damaged by harvesting recover.

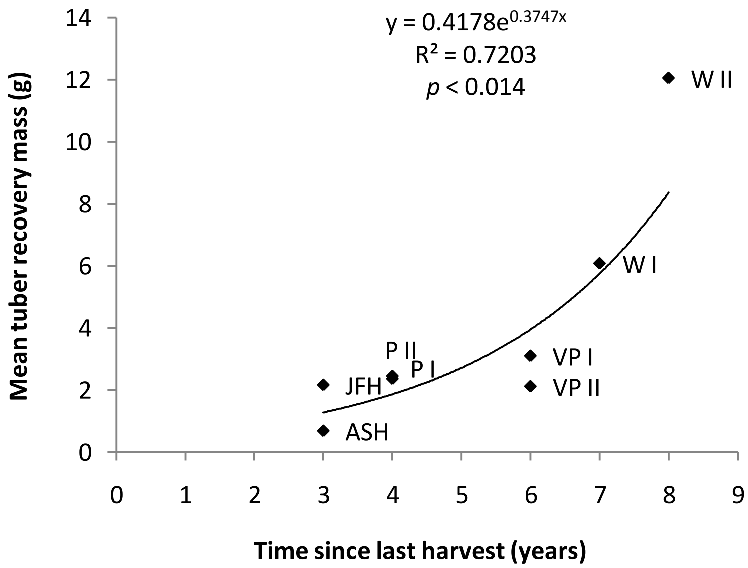

Figure 2.2. Relationship between time since last harvest and tuber recovery biomass in wild-harvested sites (n = 8). ASH= Airstrip, JFH= Janine Farm, PI= PeddieI, PII= PeddieII, VPI= VictoriaPostI, VPII= VictoriaPost II, WI= Wesley I, WII= Wesley II.

2.4.1.3. Effect of time on colour of tuber regrowth for cultivated plants (semi-wild and agricultural plants)

P. sidoides cultivation plots have been established in Lesotho and South Africa therefore information relating to when tuber regrowth colour is commercially acceptable is needed. So it was important to determine the effect of time on colour of tuber regrowth in cultivated plants. The relationship was however, not significant, although a linear and positive trend was observed, ($P > 0.05$) (Figure 2.3).

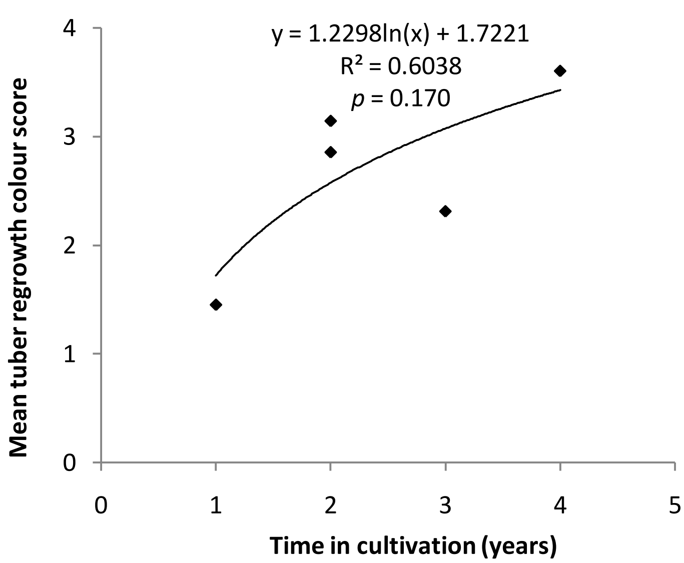

Figure 2.3. Relationship between time in cultivation (years) and colour shade in semi-wild and agricultural sites (n = 5). RHI= RhodesI (agricultural), RHII= RhodesII (agricultural), BF= Bold Farm (semiwild), STS= Stutterheim (semiwild), STA= Stutterheim (agricultural).

2.4.1.4. Effect of time on tuber regrowth biomass for cultivated plants

The Pelargonium industry not only prefers dark-coloured tubers but larger ones too. Therefore, the effect of time in cultivation on tuber regrowth biomass was investigated. A significant relationship was not found between time in cultivation and tuber regrowth biomass although a positive exponential trend was observed ($P > 0.05$) (Figure 2.4).

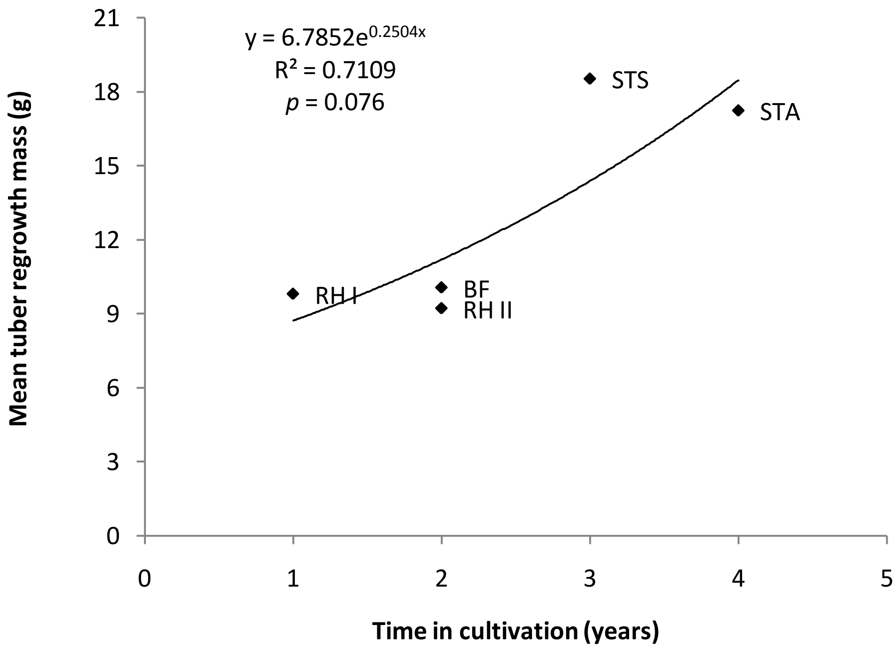

Figure 2.4. Relationship between time in cultivation (years) and tuber regrowth biomass in semi-wild and agricultural sites (n = 5). RHI= RhodesI (agricultural), RHII= RhodesII (agricultural), BF= Bold Farm (semiwild), STS= Stutterheim (semiwild), STA= Stutterheim (agricultural).

2.4.1.5. Effect of time on colour of tuber recovery or tuber regrowth when all types of sites were combined (wild-harvested, semi-wild and agricultural sites)

When all types of sites were combined to investigate the effects of time on tuber colour, a strong positive and significant relationship was obtained ($P < 0.05$) (Figure 2.5A). The highly significant relationship implies that colour intensification during tuber recovery or tuber regrowth is a function of time. This simply means that over time, tuber colour intensifies whether the plants are in the wild or in cultivation.

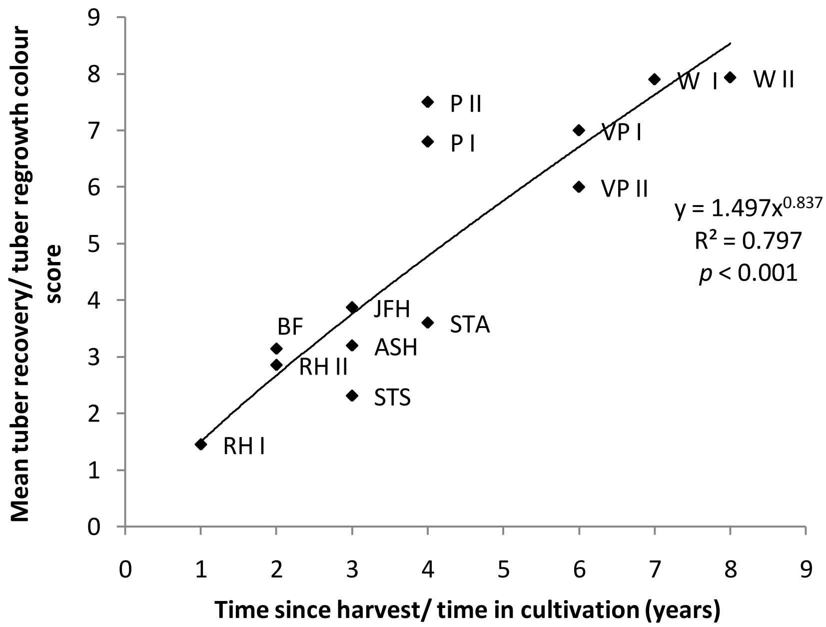

Figure 2.5A. Relationship between time since last harvest or time in cultivation and colour score in wild-harvested, semi-wild and agricultural sites (n = 13). RHI= Rhodes I (agricultural), RHII= Rhodes II (agricultural), BF= Bold Farm (semi-wild), STS= Stutterheim (semi-wild), STA =Stutterheim (agricultural), ASH=Airstrip (wild-harvested), JFH= Janine Farm (wild-harvested), PI= Peddie I (wild-harvested), PII= Peddie II (wild-harvested), VPI= Victoria Post I, (wild-harvested), VPII= Victoria Post II (wild-harvested), WI= Wesley I (wild-harvested), WII= Wesley II (wild-harvested).

The three linear trend lines for the "lowveld" vegetation region were also fitted in one graph so that differences in their slopes could be compared (Figure 2.5B). It should be noted that some of the trend lines that were fitted for the relationships on the previous graphs were non-linear but to test for significance among the slopes, a linear fit had to be used. There was no significant difference detected among the trend lines suggesting that tuber colour development is similar across different types of sites.

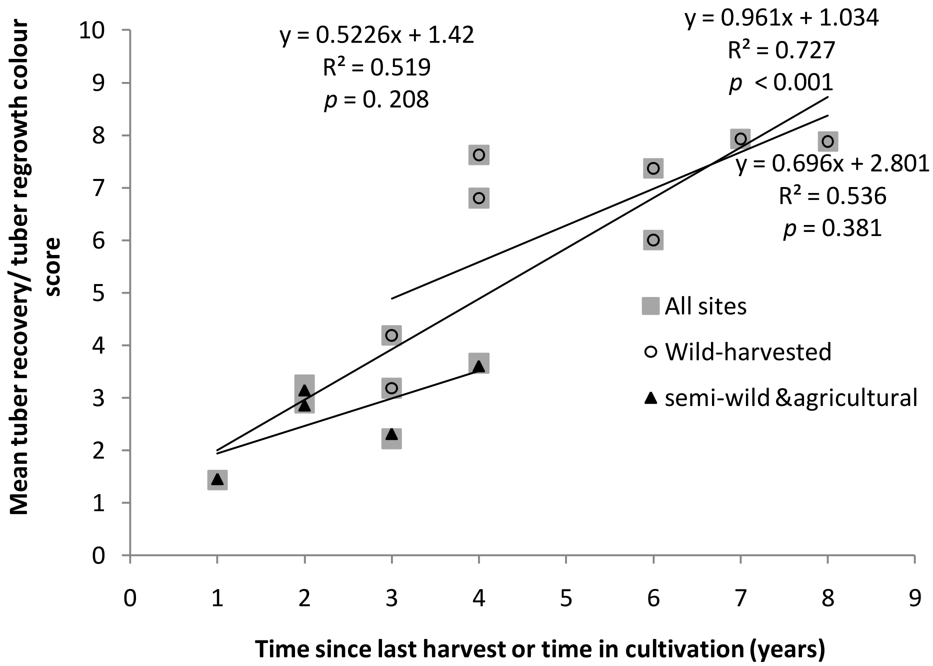

Figure 2.5B. Relationship between time since last harvest or time in cultivation and colour score in wild-harvested (n = 8), semi-wild and agricultural sites (n = 5) and all types of sites (n = 13) with the three trend lines fitted on one graph.

2.4.2. "Highveld" vegetation region

2.4.2.1. Effect of time on colour of tuber recovery for wild harvested plants

Environmental conditions vary where *P. sidoides* occurs, so how tuber colour development occurs has to be studied for various locations. Therefore, the effect of time on tuber recovery colour intensity was investigated for the "highveld" vegetation region. A significant positive relationship was found between time since last harvest and colour score ($P < 0.05$) (Figure 2.6). Thus as time since last harvest increases, tuber colour intensifies.

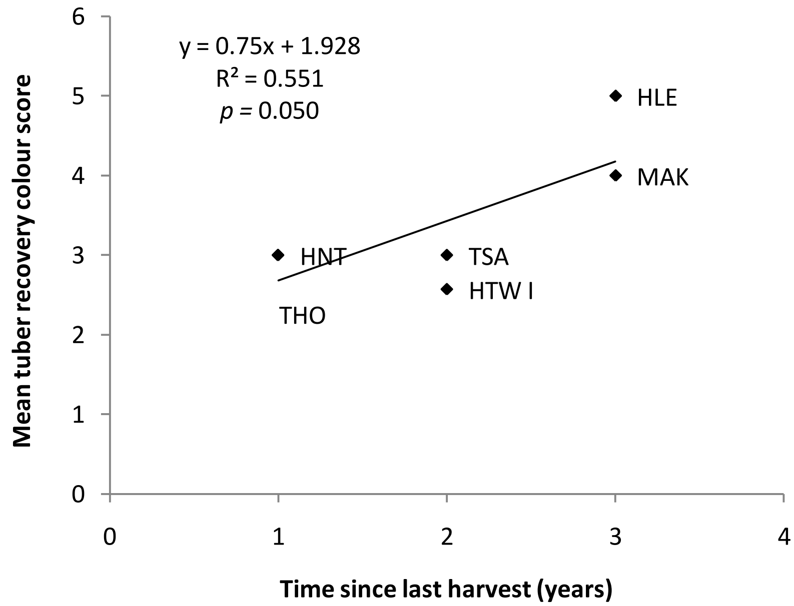

Figure 2.6. Relationship between time since last harvest (years) and colour score in wild harvested sites (n = 6). THO= Thoteng, HNT= Ha Nthunya, HTWI= Ha Tlhaku, TSA= Tsatsane, MAK= Makhoakhoeng, HLE= Ha Lebelonyane.

2.4.2.2. Effect of time on tuber recovery biomass for wild harvested plants

When investigating the effect of time on tuber recovery mass, for the "highveld" there was no significant relationship ($P > 0.05$) (Figure 2.7). The limited number of harvested sites may have contributed to this weak relationship. Furthermore, available experimental sites did not vary much (only ranging 1-3 years) in the times since they were last harvested.

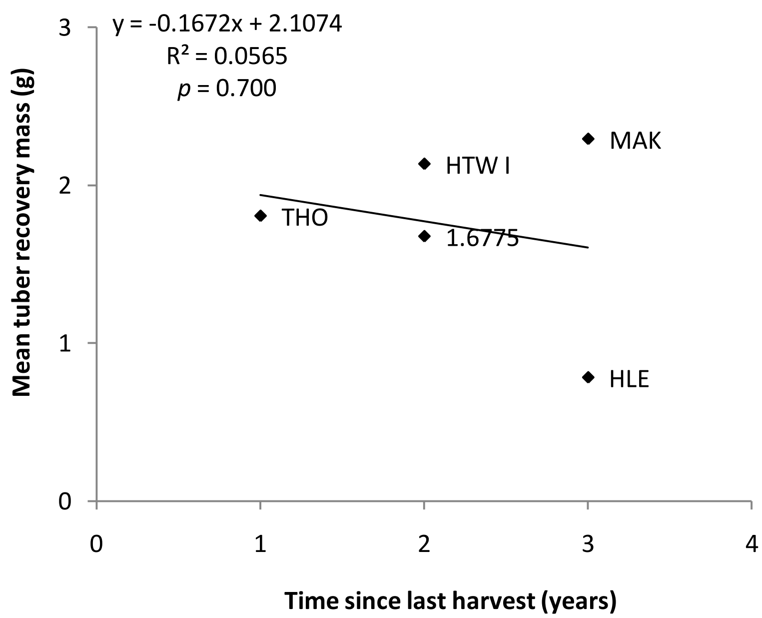

Figure 2.7. Relationship between time since last harvest (years) and tuber recovery biomass (g) in wild-harvested sites (n = 6). THO= Thoteng, HNT= Ha Nthunya, HTWI= Ha Tlhaku, TSA= Tsatsane, MAK= Makhoakhoeng, HLE= Ha Lebelonyane.

2.4.2.3. Effect of time on colour of tuber regrowth for cultivated plants (semi-wild and agricultural plants)

Similar to the "lowveld" vegetation region, the effect of time on tuber colour development was explored. However, no significant relationship was obtained ($P > 0.05$) (Figure 2.8). The unavailability of sufficient cultivated sites may have contributed to the absence of a significant relationship between the two variables. Additionally there was little variability in terms of ages of the wild-harvested sites ranging from 0.5 to 1.5 years since the last known harvest.

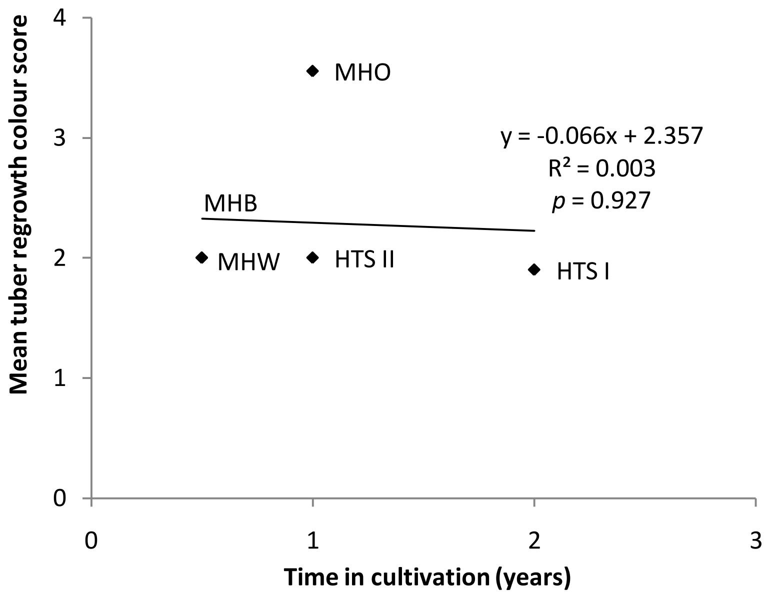

Figure 2.8. Relationship between time in cultivation (years) and colour score in semi-wild and agricultural sites (n = 5). MHW= Mohale's Hoek (agricultural), MHB= Mohale's Hoek (agricultural), MHO= Mohale's Hoek (agricultural) HTSII= Ha Tlhaku (semi-wild), HTSI= HA Tlhaku (semi-wild).

2.4.2.4. Effect of time on tuber regrowth biomass for cultivated plants

Cultivation can be a conservation option for medicinal plants in trade. Therefore information is needed on tuber regrowth rate for *P. sidoides* especially across different vegetation regions. To generate such information, the effect of time on tuber regrowth biomass was investigated in the "highveld" vegetation region. No significant relationship was however found between the two variables (Figure 2.9).

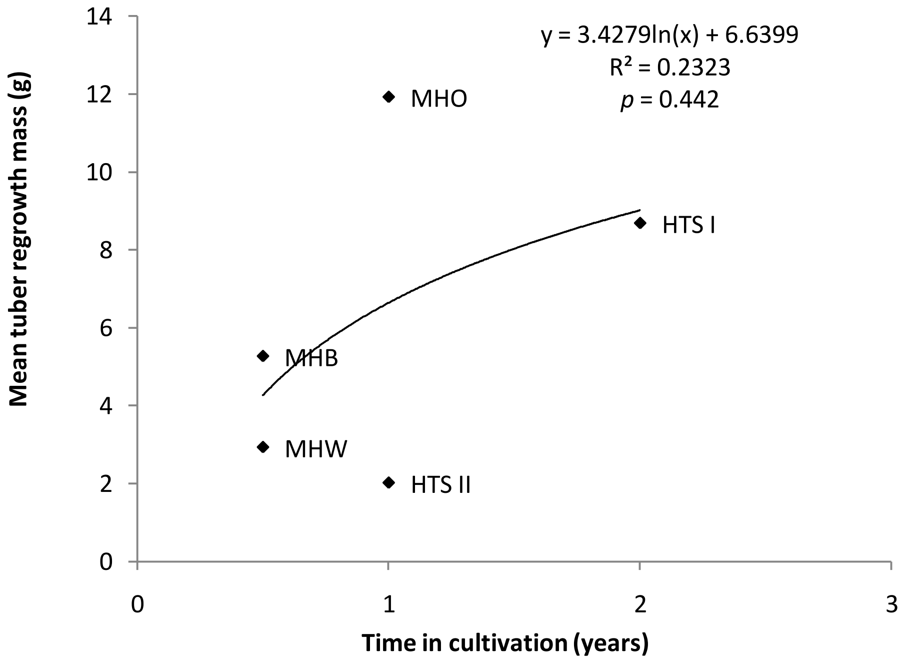

Figure 2.9. Relationship between time in cultivation (years) and tuber regrowth in semi-wild and agricultural sites (n = 5). MHW= Mohale's Hoek (agricultural), MHB= Mohale's Hoek (agricultural), MHO= Mohale's Hoek (agricultural) HTSII= Ha Tlhaku (semi-wild), HTSI= HA Tlhaku (semi-wild).

2.4.2.3. Effect of time on colour of tuber recovery or tuber regrowth when all types of "highveld" sites were combined (wild-harvested, semi-wild and agricultural sites)

All types of sites in the "highveld" vegetation region were merged to explore how tuber colour develops over time. A weak but significant relationship was found between time since last harvest/ time in cultivation and colour score ($P < 0.05$) (Figure 2.10A). Combining all types of sites increased the number of data points and thus the relationship was significant despite including cultivated sites. This result is similar to the positive linear trend detected in the "lowveld" vegetation region.

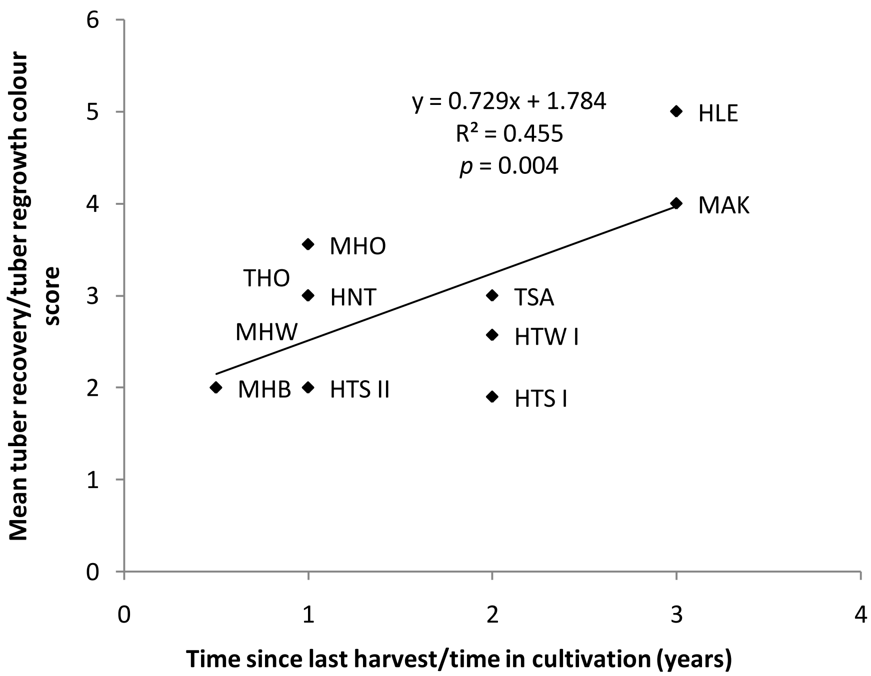

Figure 2.10A. Relationship between time since last harvest or time in cultivation (years) and colour score in wild-harvested, semi-wild and agricultural sites (n = 11). MHB= Mohale's Hoek (agricultural), MHW= Mohale's Hoek (agricultural), THO= Thoteng (wild-harvested), HTSII= Ha Tlhaku (semi-wild), HNT= Ha Nthunya (wild-harvested), MHO= Mohale's Hoek (agricultural), HTSI=Ha Tlhaku (agricultural), HTWI= Ha Tlhaku (wild-harvested), TSA= Tsatsane (wild-harvested), MAK= Makhoakhoeng (wild-harvested), HLE= Ha Lebelonyane (wild-harvested).

Similar to the lowveld region, the three trend-lines were constructed on a single graph so that differences in their slopes could be compared (Figure 2.10B). The trend lines for wild-harvested sites and all types of sites were not significantly different implying that tuber colour development is similar. However, a significant difference was observed between wild-harvested sites and cultivated sites.

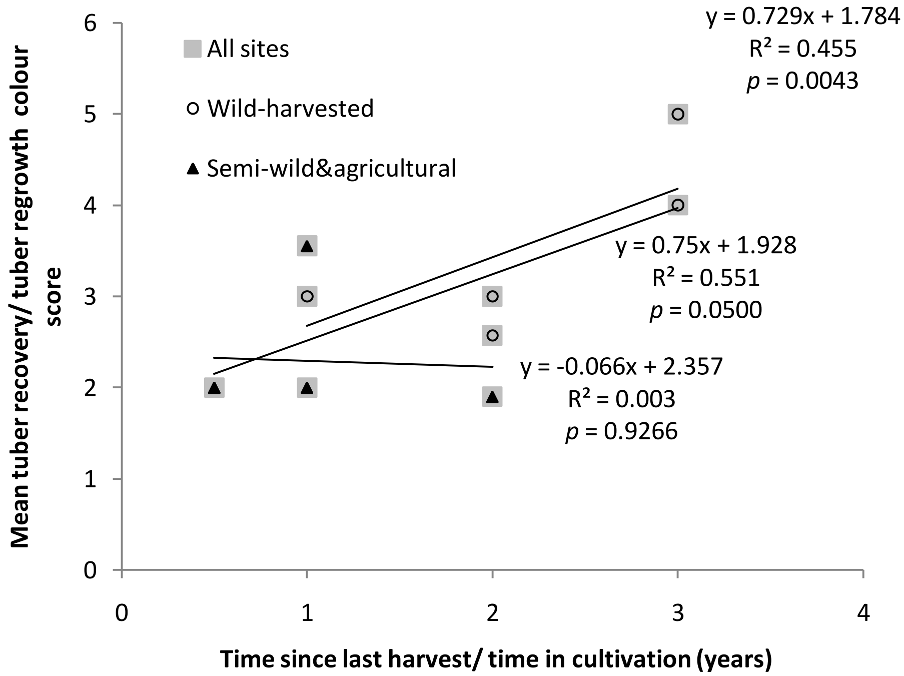

Figure 2.10B. Relationship between time since last harvest or time in cultivation and colour score for all sites (n = 11), wild-harvested (n = 6) and semi-wild and agricultural sites (n = 5) with the three trend lines fitted on one graph.

2.4.3. "Lowveld" and "highveld" vegetation regions combined

2.4.3.1. Effect of time on colour of tuber recovery for wild harvested plants

When data from wild-harvested sites from the two regions was combined to investigate the effect of time on tuber recovery colour, a highly significant relationship resulted ($P < 0.05$) (Figure 2.11A). These results imply that irrespective of the different environmental conditions where *P. sidoides* occurs, the colour of recovering tubers intensifies with time.

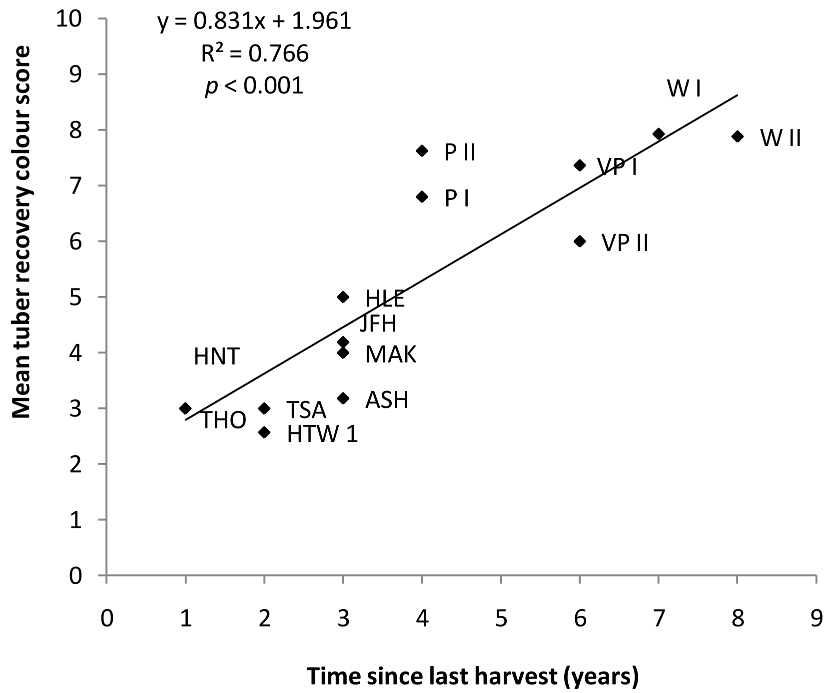

Figure 2.11A. Relationship between time since last harvest (years) and colour score in wild-harvested sites in the two regions (n = 14). THO= Thoteng (wild-harvested), Ha Nthunya (wild-harvested), HTWI= Ha Tlhaku (wild-harvested), TSA= Tsatsane (wild-harvested), MAK= Makhoakhoeng (wild-harvested), HLE= Ha Lebelonyane (wild-harvested), ASH= Airstrip (wild-harvested), JFH= Janine Farm (wild-harvested), PI= Peddie I (wild-harvested), PII= Peddie II (wild-harvested), VPI=Victoria PostI, (wild-harvested), VPII= Victoria Post II (wild-harvested), WI= Wesley I (wild-harvested), WII= Wesley II (wild-harvested).

The two regression trend lines for relationships between these variables in wild-harvested sites for the two regions were also fitted on one graph in order to compare the slopes and therefore determine significant differences between the two lines (Figure 2.11B). There was however no significant difference between the two trend lines suggesting that tuber recovery colour development between the two regions occurs at the same rate.

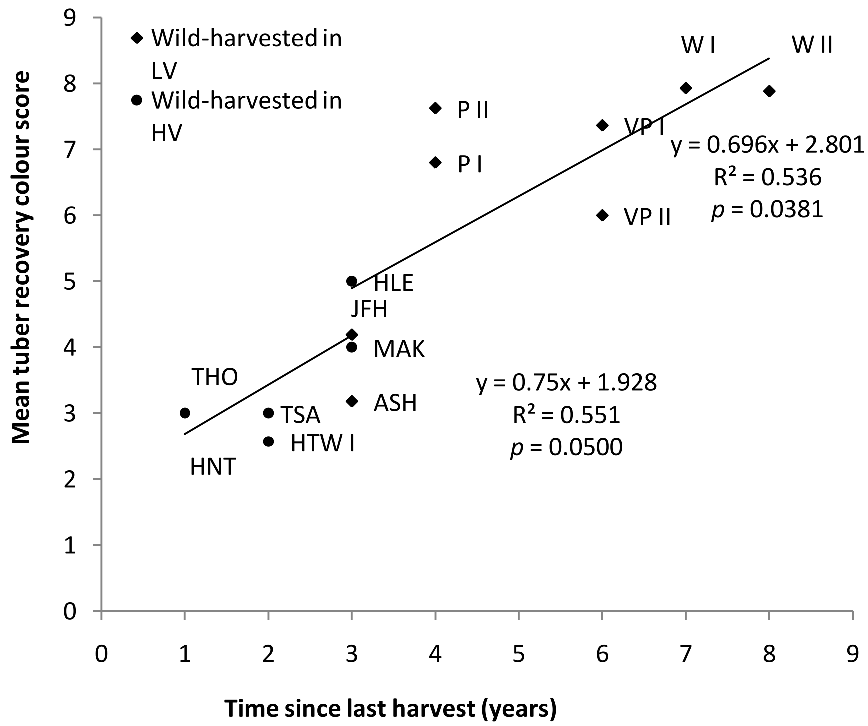

Figure 2.11B. Relationship between time since last harvest (years) and colour score for wild-harvested sites from "lowveld" (ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI= VictoriaPost I, VPII= VictoriaPost II, WI= Wesley I, WII= Wesley II) (n = 8) and "highveld" (THO= Thoteng, HNT= Ha Nthunya, HTWI= Ha Tlhaku, TSA= Tsatsane, MAK= Makhoakhoeng, HLE= Ha Lebelonyane) (n = 6) vegetation regions with the two trend lines fitted on one graph.

2.4.3.2. Effect of time on tuber recovery biomass for wild harvested plants

A too soon repeat harvest in previously harvested *P. sidoides* plants has been reported to cause population declines. As such the effect of time on tuber recovery biomass was investigated. A positive exponential relationship was found between the two variables ($P < 0.05$) (Figure 2.12). This implies that an increase in the time since last harvest resulted in an increase in tuber recovery biomass.

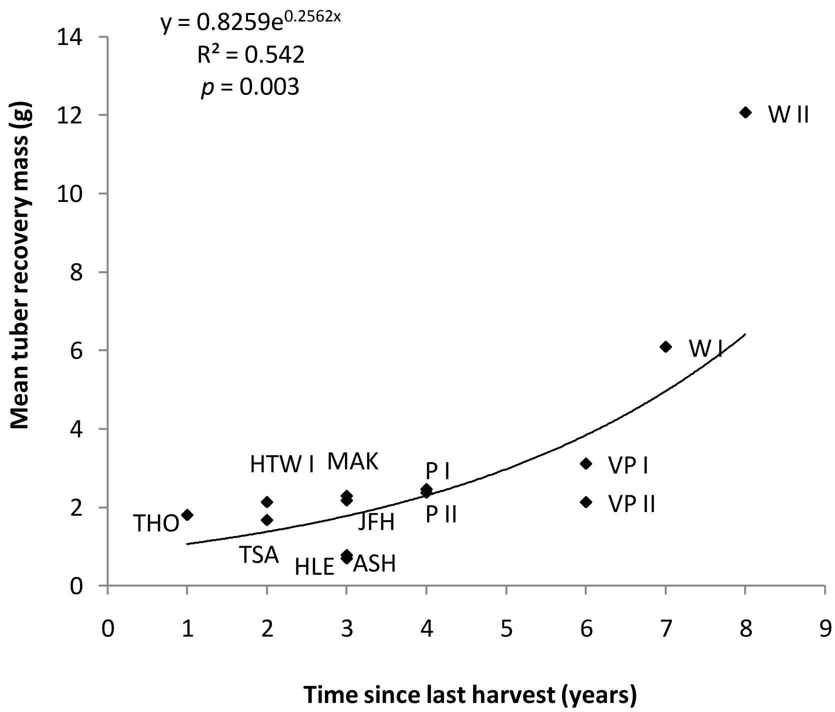

Figure 2.12. Relationship between time since last harvest (years) and tuber recovery biomass in wild-harvested sites from the two regions (n = 13). THO= Thoteng (wild-harvested), HTWI= Ha Tlhaku (wild-harvested), TSA= Tsatsane (wild-harvested), MAK= Makhoakhoeng (wild-harvested), HLE= Ha Lebelonyane (wild-harvested), ASH= Airstrip (wild-harvested), JFH= Janine Farm (wild-harvested), PI= Peddie I (wild-harvested), PII= Peddie II (wild-harvested), VPI=Victoria PostI, (wild-harvested), VPII= Victoria Post II (wild-harvested), WI=Wesley I (wild-harvested), WII= Wesley II (wild-harvested).

2.4.3.3. Effect of time on colour of tuber regrowth for cultivated plants (semi-wild and agricultural plants)

Cultivation of *P. sidoides* is essential to take pressure off wild populations. Therefore, an understanding on tuber regrowth colour development in cultivated plants is needed. There was no significant relationship between time in cultivation and tuber regrowth colour score ($P > 0.05$) (Figure 2.13A). However, the trend observed followed a linear pattern.

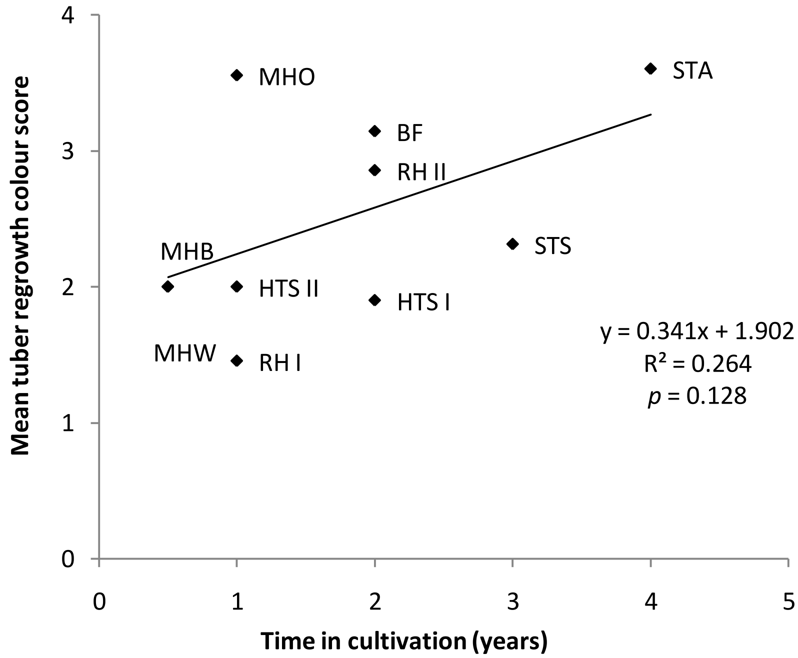

Figure 2.13A. Relationship between time in cultivation and colour score in semi-wild and agricultural sites from the two regions (n = 9). MHW=Mohale's Hoek (agricultural), MHB=Mohale's Hoek (agricultural), MHO= Mohale's Hoek (agricultural) HTSII= Ha Tlhaku (semi-wild), HTSI=HA Tlhaku (semi-wild). RHI= Rhodes I (agricultural), RHII=Rhodes II (agricultural), BF= Bold Farm (semiwild), STS= Stutterheim (semiwild), STA= Stutterheim (agricultural).

The two trend lines for each region were fitted in one graph (Figure 2.13B) to illustrate each regions contribution to the non-significant relationship.

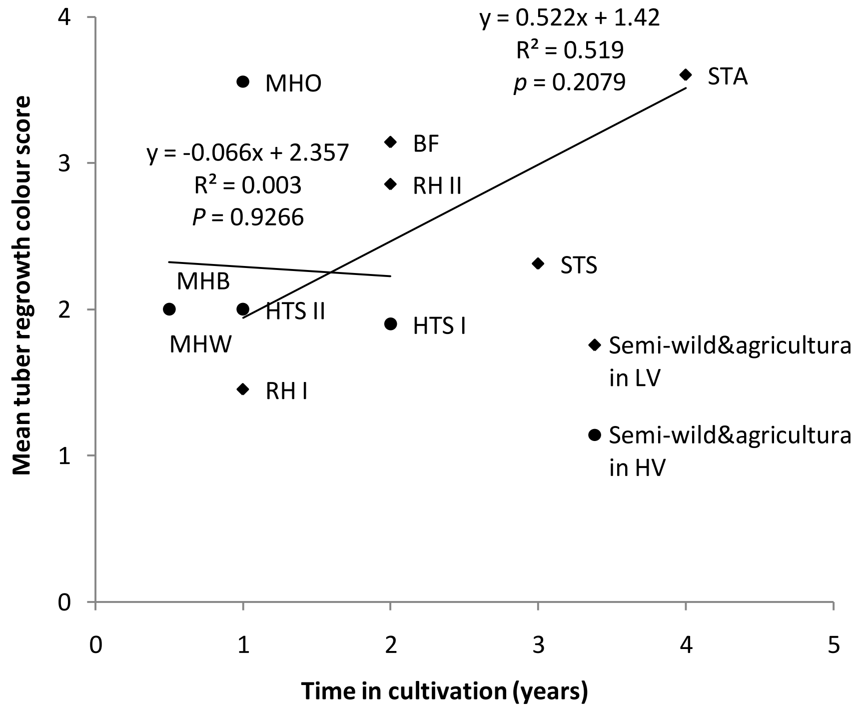

Figure 2.13B. Relationship between time in cultivation (years) and colour score for semi-wild and agricultural sites from the "lowveld"(LV) (RHI= Rhodes I (agricultural), RHII= Rhodes II (agricultural), BF=Bold Farm (semiwild), STS= Stutterheim (semiwild), STA= Stutterheim (agricultural) (n = 5) and "highveld"(HV) (MHW= Mohale's Hoek (agricultural), MHB= Mohale's Hoek (agricultural), MHO= Mohale's Hoek (agricultural) HTSII= Ha Tlhaku (semi-wild), HTSI= HA Tlhaku (semi-wild)) (n = 5) vegetation regions with the two trend lines fitted on one graph.

2.4.3.4. Effect of time on tuber regrowth biomass for cultivated plants

Cultivation can be an alternative to alleviate pressure of wild collection on *P. sidoides* populations. As such the rate of tuber regrowth in cultivated plants needs to be known. In this regard, the effect of time on tuber regrowth biomass was determined. There was a significant linear relationship between the two variables (Figure2.14) suggesting that given time, cultivated *P. sidoides* plants can produce the required biomass.

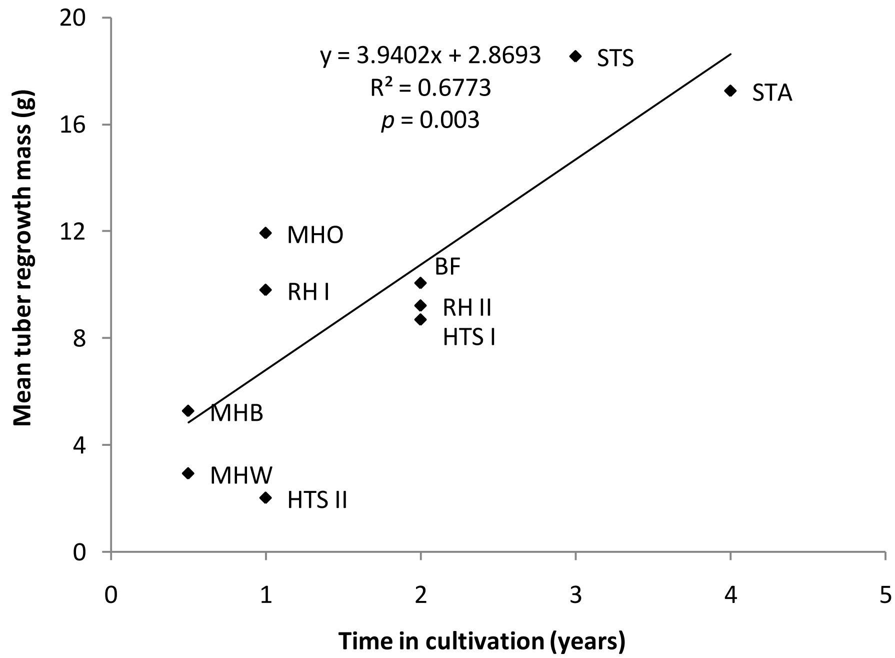

Figure 2.14. Relationship between time in cultivation (years) and tuber regrowth biomass in semi-wild and agricultural sites from the two regions (n = 9). MHW=Mohale's Hoek (agricultural), MHB=Mohale's Hoek (agricultural), MHO= Mohale's Hoek (agricultural) HTSII= Ha Tlhaku (semi-wild), HTSI=HA Tlhaku (semi-wild). RHI= Rhodes I (agricultural), RHII=Rhodes II (agricultural), BF= Bold Farm (semiwild), STS= Stutterheim (semiwild), STA= Stutterheim (agricultural).

2.4.3.4. Effect of time on colour of tuber regrowth for semi-wild plants

There was no significant relationship between time in cultivation and tuber regrowth colour score when all semi-wild sites were combined ($P > 0.05$) (Figure 2.15). Furthermore, no obvious trend was detected, probably due to limited data points.

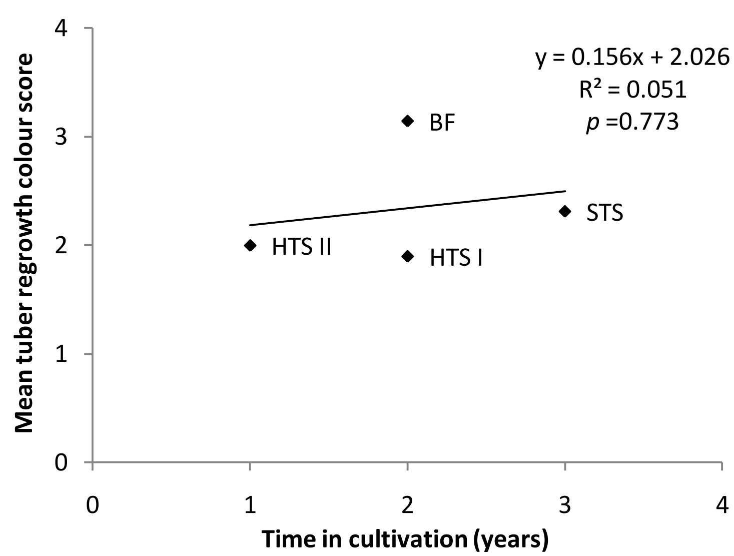

Figure 2.15. Relationship between time in cultivation and colour score in semi-wild sites from the two regions (n = 4). HTSII= Ha Tlhaku (semi-wild), HTSI= HA Tlhaku (semi-wild), BF= Bold Farm (semiwild), STS= Stutterheim (semiwild).

2.4.3.5. Effect of time on colour of tuber regrowth for agricultural plants

Combining all agricultural sites together from both regions did not produce any significant relationship between time in cultivation and tuber regrowth colour score ($P > 0.05$) (Figure 2.16). However, although there was no significant relationship, a linear trend was observed.

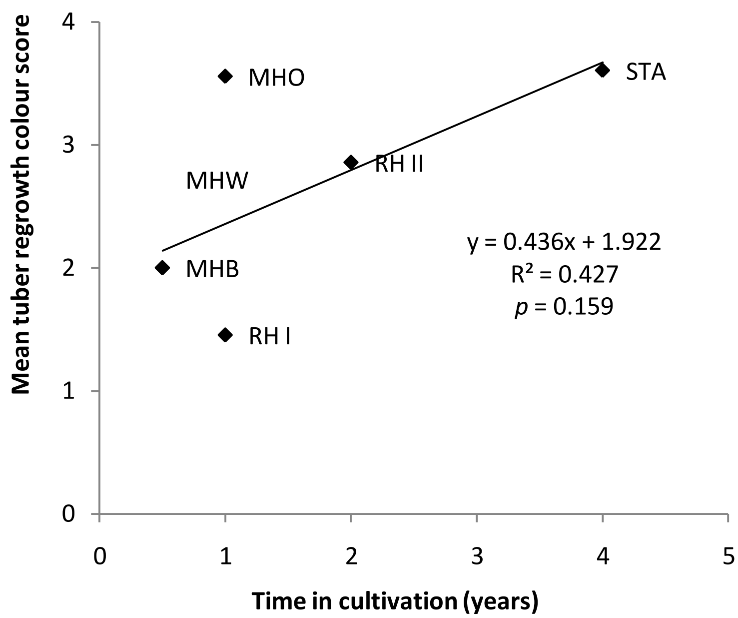

Figure 2.16. Relationship between time in cultivation (years) and colour score in combined agricultural sites from the two regions (n = 6). MHW= Mohale's Hoek, MHB= Mohale's Hoek, MHO= Mohale's Hoek, RHI= Rhodes I, RHII= Rhodes II, STA= Stutterheim.

2.4.3.6. Effect of time on colour of tuber recovery or tuber regrowth when all types of "lowveld" and "Highveld" sites were combined (wild-harvested, semi-wild and agricultural sites)

When all types of sites regardless of the region were combined, a highly significant relationship between time and tuber colour was obtained ($P < 0.05$) (Figure 2.17A). These results imply that tuber colour development is a linear function of time. Thus, as time increased, colour intensity of the recovered or regrowing tubers intensified.

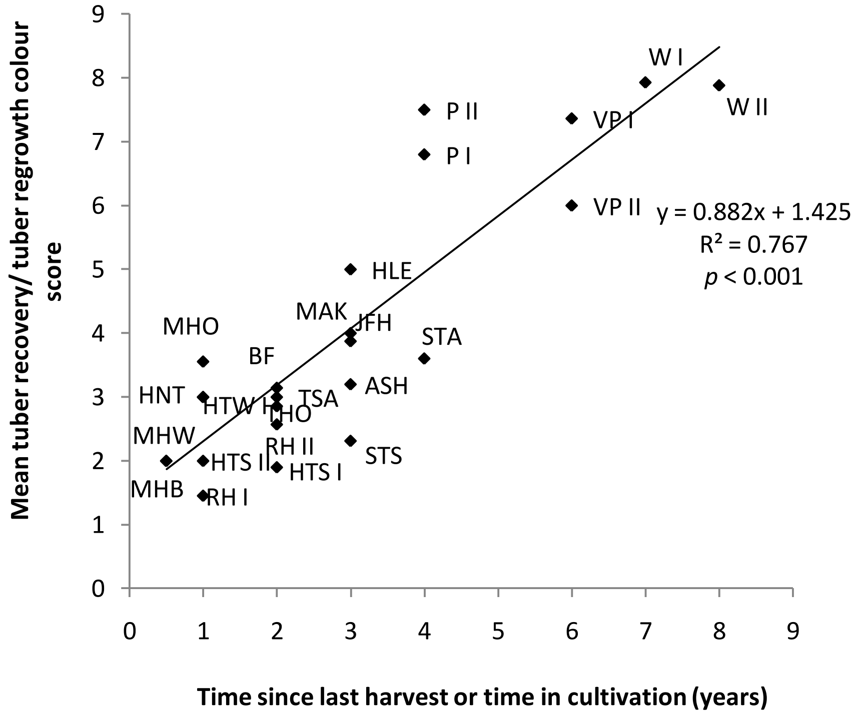

Figure 2.17A. Relationship between time since last harvest/time in cultivation (years) and colour score for all types of sites combined regardless of their type or region (n = 24). MHW= Mohale's Hoek (agricultural), MHB= Mohale's Hoek (agricultural), MHO= Mohale's Hoek (agricultural), RHI= RhodesI (agricultural), RHII= RhodesII (agricultural), STA= Stutterheim (agricultural), HTSII= Ha Tlhaku (semi-wild), HTSI= HA Tlhaku (semi-wild), BF= Bold Farm (semiwild), STS= Stutterheim (semiwild), THO= Thoteng (wild-harvested), HNT= Ha Nthunya (wild-harvested), HTWI= Ha Tlhaku (wild-harvested), TSA= Tsatsane (wild-harvested), MAK= Makhoakhoeng (wild-harvested), HLE= Ha Lebelonyane (wild-harvested), ASH= Airstrip (wild-harvested), JFH= Janine Farm (wild-harvested), PI= Peddie I (wild-harvested), PII= Peddie II (wild-harvested), VPI= Victoria Post I, (wild-harvested), VPII= Victoria Post II (wild-harvested), WI= Wesley I (wild-harvested), WII= Wesley II (wild-harvested).

The all types of sites trend lines for the two regions were fitted in one graph in order to assess significant differences in their slope (Figure 2.17B). There was no significant difference between the three trend lines implying that tuber colour development between the regions occurs at similar rate.

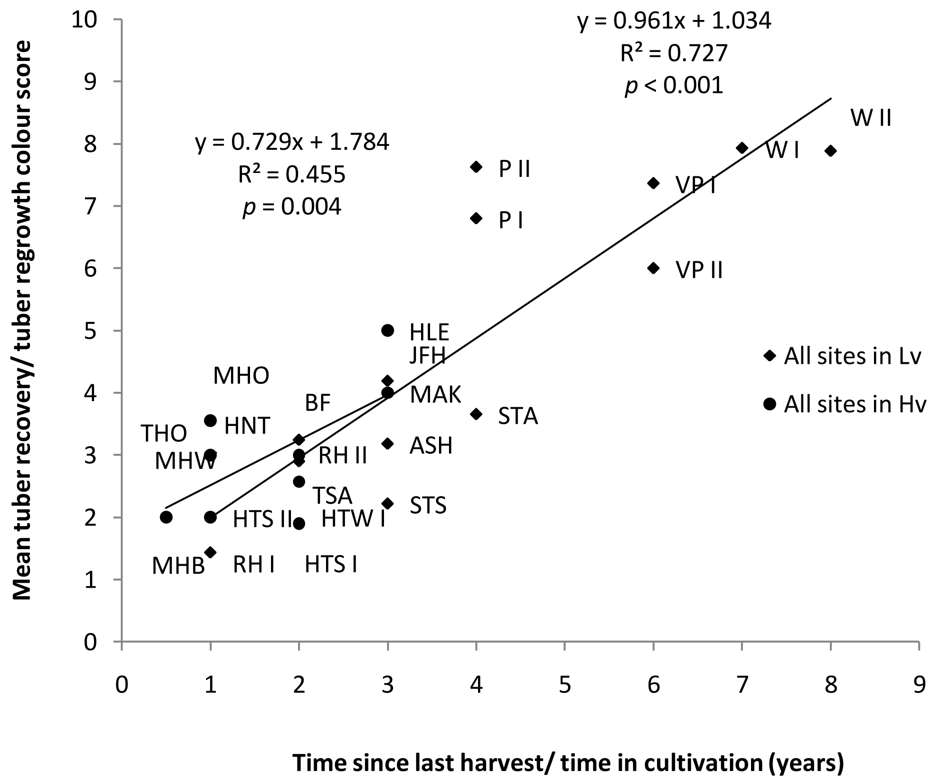

Figure 2.17B. Relationship between time since last harvest or time in cultivation (years) and colour score for all types of sites from "lowveld" (RHI= RhodesI (agricultural), RHII= RhodesII (agricultural), BF= Bold Farm (semi-wild), STS= Stutterheim (semi-wild), STA =Stutterheim (agricultural), ASH= Airstrip (wild-harvested), JFH= Janine Farm (wild-harvested), PI= Peddie I (wild-harvested), PII= Peddie II (wild-harvested), VPI= Victoria PostI, (wild-harvested), VPII= Victoria Post II (wild-harvested), WI= Wesley I (wild-harvested), WII= Wesley II (wild-harvested) (n = 13) and "highveld" (n = 11) vegetation regions (MHB= Mohale's Hoek (agricultural), MHW= Mohale's Hoek (agricultural), THO= Thoteng (wild-harvested), HTSII=Ha Tlhaku (semi-wild), HNT= Ha Nthunya (wild-harvested), MHO= Mohale's Hoek (agricultural), HTSI=Ha Tlhaku (agricultural), HTWI= Ha Tlhaku (wild-harvested), TSA= Tsatsane (wild-harvested), MAK= Makhoakhoeng (wild-harvested), HLE= Ha Lebelonyane (wild-harvested) with the two trend lines fitted on one graph.

2.4.4. Determination of rate of tuber recovery or tuber regrowth

2.4.4.1. "Lowveld" and "highveld" vegetation regions rate of tuber recovery using tuber colour and tuber biomass

The linear and non-linear regression models that were fitted to investigate the effect of time on tuber recovery colour in wild-harvested and cultivated plants (semi-wild and agricultural sites) as well as on tuber recovery biomass were used to estimate return harvest intervals. This was done by using the available mean tuber colour score for unharvested plants (y-value, Table 2.3) in the equation to solve for the x-value (minimum time taken for tubers of unharvested plants to be dark-red). It was possible to do this because (1) time was found to have a significant positive effect on tuber recovery colour and tuber recovery biomass in wild-harvested plants and (2) estimations on tuber colour for unharvested plants were done during the sampling period. The logic was that having solved for the x-value for unharvested plants, it would make sense to deduce that wild-harvested plants would take a minimum of that x-value (time) to get to the pre-harvest tuber colour.

To estimate rate of tuber recovery using tuber recovery biomass, linear and non-linear regression models that were fitted to determine the effect of time on tuber recovery biomass were used. In order to do this, the y-value had to be estimated as explained below. The assumption was that previously wild harvested plants would need that tuber biomass size (y-value) to get to pre-harvest size.

The following equation was used to calculate the y-value:

$$Y = U_{tb} - R_{tb}$$

Where Y= pre-harvest mean tuber biomass of wild-harvested plants, U_{tb}= mean tuber biomass of unharvested plants, R_{tb}= mean tuber biomass of "remains".

The calculated y-value was then used in the regression model (table, 2.3) to solve for the x-value (time required for wild-harvested plants to reach pre-harvest tuber size).

2.4.4.2. "Lowveld" and "highveld" vegetation regions rate of tuber regrowth using tuber colour and tuber biomass

The effect of time on tuber regrowth colour was not significant therefore estimations on how long it takes for tuber regrowth to be dark-red in cultivated plants were not done. But since trendlines fitted followed a similar trend to that fitted for wild-harvested sites, it was inferred that cultivated plants may take a similar time to be dark-red.

It was not possible during this study to sample from previously harvested cultivated sites. Thus it proved difficult to estimate the y-value (pre-harvest mean tuber regrowth biomass) for cultivated plants. However, for argument's sake and the fact that time was found to have a significant positive relationship on tuber regrowth biomass, the y-value estimated above for wild harvested plants was used. It must be noted though that inaccuracies were inevitable when time to maturity (x-value) for cultivated plants was determined with the y-value that was calculated this way.

The y-value estimated above was used in the regression model fitted to investigate the effect of time on tuber regrowth biomass (when sites from the two regions were combined) to solve for the x-value (time, Table 2.3).

Table 2.3.: Return harvest intervals for P. sidoides plants in the "Lowveld" and "highveld" vegetation regions estimated using tuber recovery colour (tuber recovery$_C$) and tuber recovery biomass (tuber recovery$_B$)

Region	**Site type**	**Equation**	**Y-value [mean tuber colour score or mean tuber biomass (grams)]**	**X-value [time (years)]**
"Lowveld"	Wild-harvested (tuber recovery$_C$)	Y= 3.773ln(x)+0.343 (Figure 2.1)	8.604754	9
"Lowveld"	*All types of sites (tuber recovery$_c$/tuber regrowth$_c$)	Y= $1.497X^{0.837}$ (Figure 2.5A)	8.604754	8
"Lowveld"	Wild-harvested (tuber recovery$_B$)	Y= $0.4178^{e0.3747x}$ (Figure 2.2)	16g	10
"Highveld"	Wild-harvested	Y= 0.75x+1.928 (Figure 2.6)	7.983526	8
"Highveld"	*All types of sites(tuber recovery$_c$/tuber regrowth$_c$)	Y= 0.729x+1.784 (Figure 2.10A)	7.983526	9
"Lowveld" & "highveld"	Wild-harvested (tuber recovery$_C$)	Y= 0.831x+1.961 (Figure 2.11A)	8.480508	8
"Lowveld" & "highveld"	*All types of sites (tuber recovery & tuber regrowth)	Y= 0.882x+1.425 (Figure 2.17A)	8.480508	8

"Lowveld" & "highveld"	Wild-harvested (tuber recovery$_B$)	Y= $0.8259e^{0.2562x}$ (Figure 2.12)	36.7g	15
"Lowveld" & "highveld"	*Cultivated sites (tuber regrowth$_B$)	Y= 3.9402x+2.8693 (Figure 2.14)	36.7g	9

***All type of sites (wild-harvested, semi-wild and agricultural sites), *Cultivated sites (semi-wild and agricultural sites)**

2.5. DISCUSSION

This study has revealed important information central to sustainable use of *P. sidoides*. This information will be relevant especially because use and commercialization of medicinal plants is central to people's livelihoods, particularly the rural poor. However, in most cases, this is at odds with conservation objectives (Shackleton *et al*, 2009). Currently open harvesting permits have been issued by the Lesotho and South African governments to *P. sidoides* traders. The open permits simply mean that the traders are not guided on how much to collect per year and the frequency of harvest per site. The reason for issuance of these kinds of permits is probably lack of critical information such as the return harvest interval to base management decisions on. Furthermore, in 2007, DEDEA imposed a moratorium on wild harvesting of *P. sidoides* in the Eastern Cape suspecting that the resource was under threat (N. Bam, DEDEA, *pers. comm*., 2009).

2.5.1. The effect of time on tuber recovery colour intensity

Pigmentation (caused by presence of secondary metabolites such as flavonoids) in plants is affected by many factors such as light and drought (Davies, 2004). Furthermore, ecological, climatic, ages of the plant, season, microbial attack, grazing, competition and nutritional status have been reported to modify concentrations of secondary metabolites in plants (Harbone, 1982). Thus the older the plants are, the more time they are exposed to environmental conditions that might contribute to varying pigmentation or colour in their tissues. Hence tuber recovery colour was expected to intensify with time. In all wild-harvested sites regardless of the region, linear and non- linear regression models that were fitted to investigate the effect of time on tuber recovery colour intensity yielded significant relationships. The significant results made it possible to estimate the rate of colour development in tuber recovery. In the lowveld vegetation region, the harvest interval for wild-harvested sites was predicted to be 9 yrs years while in the highveld it was 8 years. Combining all types of sites in the “lowveld” vegetation region yielded the rate of colour development of 8 years and 9 years in the “highveld” vegetation region. When all wild-harvested sites from the two regions were combined, the tuber recovery colour development rate was predicted to be 8 years and 8 years when all types of sites from the two regions were combined. The expectation would be that in wild harvested sites from the “lowveld” vegetation region, the time (9 years) required for the tubers to develop the dark-red colouration would be less than that in the “highveld” vegetation region (8 years). This is because, pigments such as flavonoids are known to increase with drought conditions (Davies, 2004) and the “lowveld” vegetation region is drier than the “highveld” vegetation region, especially where the study sites were located. On the other hand, solar radiation (Wilson *et al*., 1998; Wulff *et al*., 1999) and low temperatures (Bilger *et al*., 2007) are known to increase flavonoid concentration in plants more than drought which would suggest that tuber colour development would be quicker in the “highveld” vegetation region. For the same reasons, it was thought that when all types of sites were combined irrespective of the region, the tuber recovery colour development rate would increase, however it decreased.

Furthermore the variation in *P. sidoides* tuber recovery rates obtained in this study may be attributed to other factors such as the number of available wild-harvested sites and unharvested control sites. The variation could be explained to have been caused by the unequal number of sites for the two regions. For instance the effect of time on tuber colour became more pronounced in the “lowveld” vegetation region (n = 8) probably due to more wild-harvested sites that were used as opposed to the “highveld” vegetation region (n = 5). Furthermore, it was possible to obtain wild-harvested sites that varied much in when they were last harvested. For example wild-harvested sites from the “lowveld” varied in age from 3 to 8 years and were also replicated. However, in the “highveld”, it was impossible to find sites that were last harvested 8 years ago but rather the available sites used for this study were only harvested 1 year to 4 years ago. The variation at regional level on how long the tubers take to become dark-red may have been due to lack of significant relationships between time in cultivation and tuber colour intensity in semi-wild and agricultural sites. Varying colour scores for the unharvested controls from the two regions may also have contributed to different rates.

The absence of significant relationships between time and colour of tuber regrowth in cultivated plants has negative implications for the commercial cultivation of *P. sidoides*. This is because the time required for the tuber regrowth to attain the dark-red colour could not be estimated in cultivated plants. This is more so because cultivation of *P. sidoides* has been suggested as one way to achieve sustainability of the resource. (Vlok, 2003, 2005; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008; Newton *et al*., *in prep*). On the other hand, since the trend lines followed a positive linear trend, the rate of tuber regrowth colour development when all types of sites were combined could be employed when conservation decisions are made. Several factors may have contributed to absence of significant relationships in semi-wild and agricultural sites. Some of these factors may be attributed to unavailability of sufficient cultivated sites from both regions and regular management that these sites receive such as irrigation. This is because secondary metabolites such as coumarins (to which umckalin belongs) are known to be produced when plants experience water stress (Ojala, 2001) thus it can be expected that the higher the availability of water for plants the lower the amount of umckalin concentration. Therefore it makes sense that tubers from cultivated plants that receive water regularly showed no significant relationships with time. Another contributing factor could have been that coumarins are produced by plants as an allelopathic response (Uritani *et al*., 1999); meaning plants that are in cultivation cannot produce a lot of the coumarins as there is no competition from other plants due to regular weeding. However, although coumarins may be thought of as marker compounds for efficacy of *P. sidoides*, high pharmacological activity of this plant may be attributed to a combination of a number of chemical constituents (White, 2007; Kolodziej and Kiderlen, 2007).

2.5.2. The effect of time on tuber recovery biomass

The Pelargonium industry does not only require dark-red tubers, but also mature and large ones. Therefore rate of tuber recovery using biomass for *P. sidoides* was also estimated. The relationships between time and tuber recovery biomass resulted in significant relationships in the "lowveld" vegetation region but not in the "highveld" vegetation region. However, when wild-harvested sites from the two regions were merged, significant relationships were revealed. The rate of tuber recovery biomass in wild-harvested plants was estimated to be 10 years in the "lowveld" vegetation region. However, when wild-harvested data from the two regions was used, the regression models predicted it to be 15 years. The different return harvest interval values obtained may be attributed to unequal number of sites that were used to run the regression analyses. For example, only few wild-harvested sites (n = 8) were used in the "lowveld" vegetation region while when wild-harvested sites from the two regions were combined the number of sites increased (n = 14).

The results of this study concur with findings of other authors on the long harvest intervals experienced by medicinal plants harvested for their tubers. White (2007) and White *et al.* (2008) estimated the return harvest interval for *P. sidoides* as approximately 56 years under field conditions. Furthermore the same authors established that the return harvest interval could range from 11.5 years to 410 years when the regression equations for the lower and upper confidence limits were used. In another study, Rock *et al*. (2004) estimated recovery time for *A. tricoccum* that ranged from 2.5 years for 5 % harvest to 148 years for 95% harvests.

2.5.3 The effect of time on tuber regrowth biomass

Medicinal plants play a pivotal role in sustaining people's livelihoods and this can be through their use in traditional medicine and as trade commodities (Schippmann *et al*., 2006). Extensive wild harvest of *P. sidoides* to meet the trade demand can thus be detrimental to its populations and to people who depend on it. Cultivation has therefore been recommended for medicinal plants to reduce pressure from wild populations (Lambert *et al*., 1997). For *P. sidoides*, few cultivation plots have been set-up in Lesotho and South Africa. However, it is not clear to what extent tubers have been sourced from cultivated stocks to supplement wild-harvested ones in meeting trade demands. This maybe due to lack of information on tuber regrowth rate in cultivated plants across different vegetation regions. Investigations on the effect of time in cultivation on tuber regrowth biomass did not produce significant relationships in the "lowveld" and "highveld" vegetation regions. Despite this, positive trends were seen indicating that maybe given more study sites (hence data points) per region, relationships would have been more pronounced. Indeed when study sites from the two regions were combined, significant relationships were found. Tuber regrowth rate in cultivated plants was found to take 9 years when compared against the tuber biomass size required by previously wild-harvested plants to reach pre-harvest size. This period is not thought to be viable for commercial production but nevertheless shorter than the 10-15 year tuber recovery period determined for wild-harvested plants. However, since the 9 year period was determined using tuber biomass data for wild-harvested plants, it might be inflated suggesting that cultivated plants might require a shorter time to reach harvestable size. This period may also prove inpractical particularly because cultivation of medicinal plants requires high input costs (U. Feiter, Parceval*, pers. comm*., 2008).

2.6. CONCLUSION

The results of this study revealed that tuber recovery or tuber regrowth colour intensity (quantified as colour scores) as well as tuber recovery or tuber regrowth biomass is dependent on time. Both colour development from pale to dark-red or dark-purple colouration and tuber recovery or tuber regrowth biomass increased with time. Previously wild-harvested *P. sidoides* tubers were found to require at least

8 years for their tuber recovery to develop the dark-red colouration. However, the 8 year period required for the tubers to develop the dark-red colouration is not enough on its own to base sustainability decisions on since the Pelargonium industry seems to also require large tubers. Consequently the study further established that tuber recovery biomass of previously wild-harvested *P. sidoides* plants may require at least 10 to 15 years to reach the pre-harvest tuber biomass. Conversely, tuber regrowth in cultivated plants may require 9 years to attain similar biomass to that of unharvested wild populations. Since it is unclear what the Pelargonium industry considers as commercially acceptable for *P. sidoides* tubers, the tuber regrowth rate of 9 years in cultivation can be flexible to suit the trade requirements. Hence this period may be shorter. Further investigations in to what constitutes commercially acceptable *P. sidoides* tubers is thus needed.

It must be noted though that there are factors that may contribute to increasing or decreasing rate of tuber recovery or tuber regrowth (measured in colour and biomass) in *P. sidoides*. Some of these factors are dealt with in subsequent chapters (e.g. Chapter 4).

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Chapter 3

The impacts of harvesting on the tuber recovery of *Pelargonium sidoides* plants

3.1. ABSTRACT

Pelargonium sidoides tubers have been wild-harvested in some parts of the Eastern Cape and Lesotho for centuries. Harvesting of *P. sidoides* plants has been reported to be impacting negatively on its wild populations.This is exacerbated by harvesting methods currently used which involve entire removal of the plant and not filling up harvest holes. However key information is lacking on the impacts of harvest on *P. sidoides* tuber recovery and hence has implications for conservation. Therefore ANOVA was used to compare tuber size (tuber mass, tuber diameter, tuber length and tuber volume) and above-ground plant size (canopy area and number of stems/plant) across different types of sites (wild-harvested, semi-wild, agricultural and unharvested sites). Comparisons were done for "lowveld" and "highveld" vegetation regions. A significant difference was found in tuber recovery mass across wild-harvested sites for each vegetation region (lowveld- $F_{7,59}$= 11.0219, P < 0.001, highveld- $F_{5,15}$= 3.7634, P < 0.028). Similarly, significant differences were observed for both regions when comparisons on tuber mass between wild-harvested and unharvested control sites were done (lowveld- $F_{11,95}$= 9.7226, P < 0.001, highveld- $F_{23,99}$= 7.0519, P < 0.001). Comparing tuber mass across all types of sites also produced significant differences for each region (lowveld- $F_{16,140}$= 9.542, P < 0.001, highveld- $F_{28,138}$= 7.9993, P < 0.001). All the other tuber size variables were also significantly different across all sites whether comparisons were done in wild-harvested, semi-wild, agricultural and unharvested sites as well as across all types of sites. In the "lowveld" vegetation region, above-ground plant size was larger in sites last harvested 8 years ago compared to those harvested 4 to 7 years ago (canopy area- $F_{7,59}$= 5.0054, P < 0.001, number of stems/plant- $F_{7,59}$= 3.9956, P = 0.0012). Similarly, above-ground plant size was larger in sites harvested 8 years ago than unharvested sites (canopy area- $F_{11,95}$= 5.9258, P < 0.001, number of stems/plant- $F_{11,95}$= 3.5084, P < 0.001). However, when all types of sites were compared, semi-wild and agricultural sites had larger above-ground plant size compared to all the other sites (canopy area- $F_{11,140}$= 11.6244, P < 0.001, number of stems/plant-($F_{16,140}$= 9.5121, P < 0.001). In the "highveld" vegetation region, although unharvested sites tended to have larger above-ground plant size (canopy area- ($F_{6,51}$= 3.9058, P < 0.003, number of stems/plant-$F_{23,98}$= 2.092, P = 0.007) than wild-harvested sites, no obvious trend was detected for canopy area. Furthermore, semi-wild and agricultural sites in the "highveld" also had larger canopies when all types of sites were compared ($F_{11,91}$= 7.8019, P = 0.0001). However, semi-wild and unharvested sites had more stems/plant than the rest of the agricultural and wild-harvested sites ($F_{28,138}$= 2.917, P < 0.001). The results show that tuber recovery size in previously harvested sites is smaller compared to unharvested sites even at 8 years since last harvest, suggesting that tuber recovery size has not reached pre-harvest size even after this period. Hence this confirms that to sustainably harvest *P.sidoides* plants from the wild, repeat harvest should only occur after 10-15 years (Chapter 2).Therefore, despite training on sustainable harvest, such as harvest methods provided by the Pelargonium industry, tuber recovery of *P. sidoides* plants can be negatively affected by harvesting if there is a too soon repeat harvest.

3.2. INTRODUCTION

Many medicinal plants that have been utilized for subsistence use are now also used commercially in traditional and western medicine. These plants are mostly collected from the wild (Lange and Schippmann, 1997) despite that a widespread disturbance to plant populations in southern Africa and elsewhere has been reported to be caused by wild harvesting (Hoffman, 1997) which is mostly driven by commercialization (Williams *et al*., 2000). However, the impacts of harvesting on medicinal plants are rarely quantified and this is more so for plants harvested for their below-ground parts. Thus, the ability to manage the affected populations becomes limited (Botha *et al*., 2004). The shift in use patterns towards commercialization has major implications for conservation of medicinal plants hence the need to understand the impacts of harvest on wild populations. This is more so because harvesting of medicinal plants can result in negative impacts on survival rates, growth, reproduction and associated impacts on population structure and dynamics (Ticktin, 2004a).

When determining the impacts of harvesting on plants, it is important to obtain information on their abundance, distribution and how plants respond to harvesting (Cunningham, 2001). Efforts to understand how plants respond to harvesting should be aimed at individual, species, plant population, ecosystem, as well as landscape level as harvesting may change ecological process at all these levels (Hall and Bawa, 1993; Ticktin, 2004b). Understanding how individual plants respond to harvesting is however the most important aspect.

The response of plants to harvest depends on several factors. These are factors such as growth strategy and growth form, plant part harvested, harvesting methods, frequency and intensity as well as environmental factors (Cunningham, 2001; Ticktin, 2004b). Plants have different growth forms and strategies that can determine how they respond to unfavourable growth conditions. For example, some authors have suggested that shade intolerant species usually maximize dry matter production by increasing leaf area and shoot/root ratio (Grime, 1966; Loach, 1970; Mygren and Kellomaki, 1983). In the same manner, plants devise various growth strategies which enable them to counteract the effects of harvest. For instance, other than reproducing sexually through seed, perennial plants can also undergo clonal reproduction. *P. sidoides* undergoes both sexual and asexual (vegetative or clonal) reproduction (van der Walt and Vorster, 1988; Dreyer and Marais, 2000) the latter being achieved through its tubers. In most plants, clonal reproduction is a survival strategy for when growth conditions are unfavorable (Werger and Huber, 2006) such as after a disturbance in the form of harvesting. Some species can resprout from dormant buds which are located on stems after disturbances such as those caused by hurricanes (Zimmerman *et al*., 1994) or fires. In fire-prone grasslands, savanna and woodland systems of South Africa, and Australia, woody plants resprout and produce new stems from lignotubers (James 1984; Hansen *et al*., 1991; Bell and Ojeda, 1999). *P. sidoides* can also resprout from its tubers (Vlok, 2003, 2005; Newton, *et al., in prep.*) after harvest and produce new stems which ultimately develop into tubers (*pers. obs*.). Thus, using this growth strategy, *P. sidoides* plants are able to minimize the impacts of harvest. For successful resprouting, there has to be enough post-harvest tuber biomass left to provide assimilates to the developing stems (Huhta *et al*., 2003). Tuber harvesting has negative implications for "resprouters" as they mostly produce few viable seeds and this can lead to population declines once the parent plant dies (Cunningham, 2001). For *P. sidoides*, clonal reproduction is more established than sexual reproduction hence due to the limited seed bank in the soil its populations may go into decline should there be over-harvest of clonal material.

Clonal plants can also spread horizontally from where they occur using their rhizomes or stolons, and establish themselves in areas of differing resource supply (Eriksson, 1986). Through a process of clonal integration, resource translocation occurs between ramets (Marshall, 1990) especially for plant species occurring across heterogenous environments (Hutchings and de Kroon, 1994). Consequently, plant survival is improved in situations where resources are limiting as there will be resource translocation from source sites to sink sites (Pitelka and Ashmun, 1985). This becomes particularly true for clonal plants in resource poor and stressful environments (Jonsdottir and Watson, 1997). Similarly, following harvest, there may be resource translocation from one ramet to another in *P. sidoides* plants and this might ensure persistence after a disturbance. No studies have been conducted however on the degree of clonal integration in *P. sidoides* to determine the degree to which it can minimize harvesting impacts on the species. On the other hand, in disturbed habitats, clonal integration may be reduced due to increased risk of spacer breakage by disturbances (Birch and Hutchings, 1999; Dietz and Steinlein, 2001). Although resource translocation may occur between ramets in *P. sidoides*, ramets maybe disconnected if harvesting is severe. Furthermore, in many species ramets are not physically integrated (Eriksson, 1993).

The impacts of harvest can also be determined by the plant part harvested. For instance, harvesting of leaves, seeds or fruits is less harmful to plants' survival than harvest of roots, tubers, or the whole plant (Cunningham, 2001). For example, harvest of roots before a plant has produced seeds can end the chances of future growth and regeneration (Sheldon *et al*., 1997). Additionally, damage caused by root harvest reduces the efficiency of water uptake by plants and susceptibility to fungal infections (Williams *et al*., 2000). On the other hand, harvesting of plant parts such as leaves can seldom lead to mortality as they are regarded as renewable (Sheldon *et al*., 1997). Furthermore, although harvesting of tubers usually means that the whole plant is removed, the impact of destructive harvesting at a plant population level also depends upon tuber size class selection (Cunningham, 2001). Harvest of tubers from the smaller size-classes can be more harmful than that from larger size-classes. This is because plants from smaller size-classes are often immature and if they are harvested cannot contribute to the reproductive pool (Ghimire *et al*., 2005). According to Condit *et al*. (1998) and Miller (1998), a healthy and growing population is considered as the one with abundant juveniles relative to adults. Thus changes in demographic profile of species may alert conservation officials to declining populations (Walker *et al*., 1986; Shackleton *et al*., 1994; Wiegand *et al*., 2000; Wilson and Witkowski, 2003). However, no population structure studies have been carried out on *P. sidoides* yet to establish the tuber size classes that are mostly harvested.

Harvesting techniques can also have adverse impacts on the wild populations of medicinal plants and this can depend on whether medicinal plants are harvested for subsistence or commercial use. In most cases, commercial harvesters harvest in large quantities without being selective on whether a plant is mature or immature. For example, Ghimire *et al*. (2005) working on two Himilayan medicinal plants, found that harvest of *Nardostachys grandiflora* and *Neopicrorhiza scropulariiflora* by commercial harvesters was detrimental when compared to that by the "Amchi" (traditional doctors trained in Tibetan medicine) who use the plants only for local health care. This was the case because other than harvesting in large quantities, commercial harvesters were not selective and did not restrict their harvest to any specific season or plant size-classes. Furthermore, mature plants were found to have higher survival rates as compared to younger ones.

Other than selective harvesting, harvest methods can have dramatic effects on the well being of plants in the wild. Harvest methods that include non replacement of plants and non-closure of harvest holes can negatively impact plant populations. It has been observed that following harvest, *P. sidoides* plant parts such as stems, roots and younger tubers are rarely replanted and that harvest holes are not closed (Lewu *et al.,* 2006, 2007; Newton *et al*. *in prep*; *pers. obs*.). Wild harvesting coupled with these harvest methods have contributed to localized declines of *P. sidoides* by negatively affecting survival of remanant tubers and rate of tuber recovery which has been found to take up to between 10 and 15 years (Chapter 2).

Only limited research has been conducted on the impacts of wild harvesting on *P. sidoides* populations (Vlok, 2003, 2005; Lewu *et al*., 2007; White, 2007; White *et al*., 2008; Newton *et al*., *in prep*.). All these studies have concluded that the wild populations of *P. sidoides* are harvested unsustainably and may be facing a future threat of decreased populations and even local extirpations. Although these studies have attempted to investigate the impacts of wild harvesting on *P. sidoides*, they have some limitations. For example, they only focused on measurements of above-ground plant biomass, counts of reproductive structures and estimation of plant densities but not on how harvesting impacts on tuber recovery. With the few that managed to investigate harvesting impacts such as White (2007) and White *et al*. (2008), the methodology used was unclear. White (2007) and White *et al*. (2008) depended on novel harvest simulation methods for their study which included removal of varying proportions of different portions of the plant. Since these were novel harvest methods, inaccuracies could have occurred as they simulated how the harvesters carry out the actual harvest. Secondly, the plants which were collected were unharvested plants hence why the authors had to carry out harvest simulation methods. Thirdly, the plants that were used for their experiments were uprooted and replanted which could have decreased plant regrowth as they were initially disturbed. Lastly, it is not clear which part of the below-ground part of *P. sidoides* plant was removed for the study. For instance, White (2007) and White *et al*. (2008) throughout their study referred to root which is not the commercially harvestable part. In this study, it was understood that what they were actually referring to was tubers.

This called for a more thorough investigation into the impacts of harvesting on *P. sidoides* tuber recovery, which involved measuring tuber recovery in previously wild-harvested sites. The aim of this study was therefore to determine the impacts of current harvesting methods on *P. sidoides* tuber recovery.

To achieve the above-mentioned aim, the study addressed the following objectives:

- To compare tuber size between previously harvested and unharvested control sites
- To compare tuber size across wild-harvested, semi-wild, agricultural and unharvested control sites
- To compare population structure of previously harvested and unharvested control populations
- To compare tuber colour intensity across wild-harvested, semi-wild, agricultural and unharvested control sites
- To compare tuber colour intensity distribution across wild-harvested, semi-wild, agricultural and unharvested control sites
- To compare above-ground plant size (canopy area and number of stems/plant) across wild-harvested, semi-wild, agricultural and unharvested control sites

3.3. MATERIALS AND METHODS

Refer to Chapter 2, section 2.3.1, 2.3.2 and 2.3.3.

While the term “tuber” was used to refer to tubers from unharvested control sites, in this chapter it was also used when comparisons on tuber size were made across wild-harvested, semi-wild, agricultural and unharvested control sites. Thus it was sometimes used as a collective term to avoid always having to say tuber recovery (wild-harvested sites), tuber regrowth (semi-wild and agricultural) and tuber (unharvested control sites).

3.3.3. Data analysis

Above and below ground plant data was analyzed in various ways to compare plant performance across different types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites) and across regions (“lowveld and “highveld” vegetation regions). To perform statistical analysis, tuber colour PCC codes were quantified as explained in chapter 2.

To determine the impacts of harvest on tuber recovery of *P. sidoides* plants, “tuber recovery”, “tuber regrowth” and “tuber” biomass and tuber colour data was compared across different sites and at various levels (e.g carrying out analysis per site type and across site type).

One way analysis of variance (ANOVA) was used to compare tuber size, canopy area, number of stems/plant and tuber colour intensity across different types of sites. Tuber size was measured as tuber mass, tuber diameter, tuber length and tuber volume. Where significant differences were detected, Fisher’s Least Significant Difference post-hoc test (LSD, $P < 0.05$) was performed to establish where the differences lay (Zar, 1996). Both mean of mean and mean of total tuber recovery, tuber regrowth and tuber size values were used in the analysis.

Student t-tests were also used to compare between wild-harvested, semi-wild, agricultural and unharvested control sites from the “lowveld” and “highveld” vegetation regions.

Additionally, to allow for visual comparions, tuber mass size-class distributions (SCDs) and tuber colour frequencies were displayed graphically. Tuber colour frequencies/colour score/site were also constructed. Kolmogorov-Smirnov tests were used to compare mass size-class distributions and tuber colour frequencies.

Statistica 6 and 8 was used to analyse tuber size, canopy area and number of stems/plant comparisons.

Microsoft excel 2003 and 2007 was also used to construct colour frequency distributions, tuber mass and tuber diameter size-classes.

3.4. RESULTS

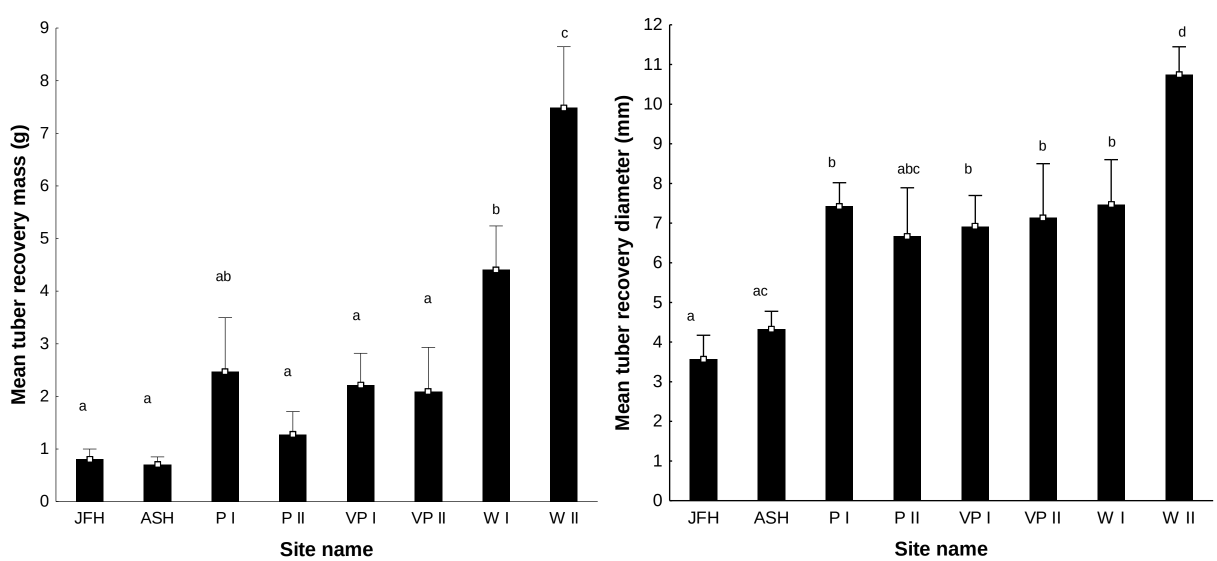
3.4.1. "Lowveld" vegetation region

3.4.1.1. Below-ground plant growth across sites

3.4.1.1.1. Comparisons on tuber recovery size in wild-harvested sites

To compare tuber recovery size (mass, diameter, length, volume) across wild-harvested sites, mean tuber recovery mass of plants which were previously harvested (harvested 3 to 8 years ago) was compared. There was a significant difference in tuber recovery mass across the eight wild-harvested sites that were compared ($F_{7,59}$= 11.0219, P < 0.001) (Figure 3.1A). Plants from W II (Wesley II) had more tuber recovery mass than plants from all the other sites. Similarly, a significant difference was detected when mean tuber recovery diameter was compared across wild-harvested sites ($F_{7,59}$= 6891, P < 0.001) (Figure 3.1B). Of all the compared sites, W II was found to have plants with larger tuber recovery diameter than all the other sites. On the contrary, mean tuber recovery length was not significantly different across wild-harvested sites ($F_{7,59}$= 1.2061, P = 0.314) (Figure 3.1C). However, there was a significant difference found when tuber recovery volume was compared across wild-harvested sites ($F_{7,59}$= 3.6755, P = 0.002) (Figure 3.1D). Although tuber recovery volume of plants from W II was higher than that of plants from other sites, it was not significantly higher than that of plants from VP II (Victoria Post I) and W I (Wesley I).

(A) **(B)**



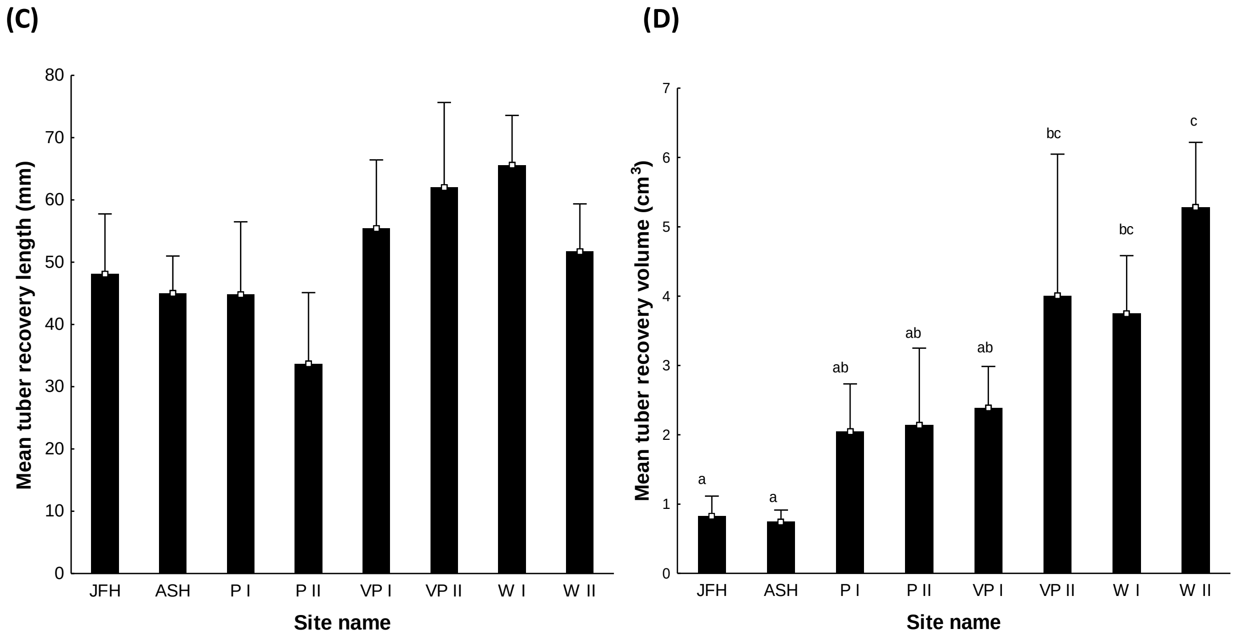


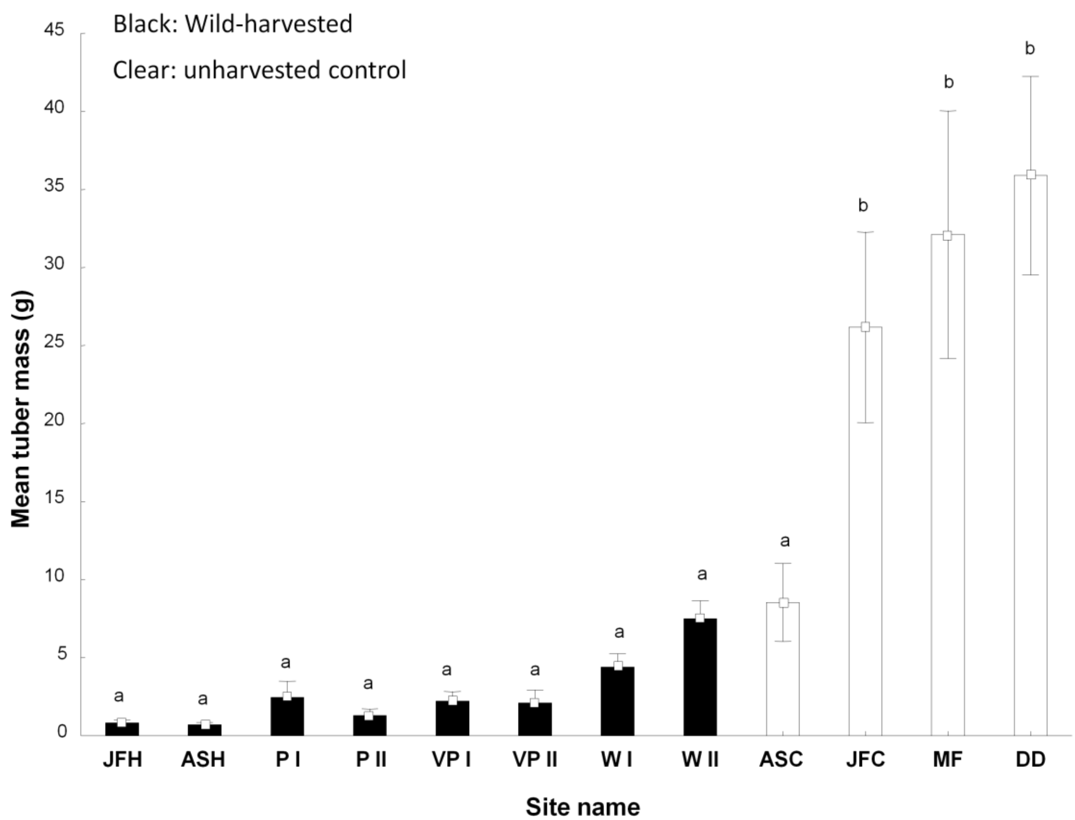
Figure 3.1. Comparisons of post-harvest tuber recovery size (A= tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in wild-harvested sites of differing ages in the "lowveld" vegetation region (JFH= Janine farm harvested (3 years), ASH= Airstrip harvested (3 years), P I= Peddie I (4 years), P II= Peddie II (4 years), VP I= Victoria Post I (5 years), VP II= Victoria Post II (5 years), W I= Wesley I (7 years) and W II= Wesley II (8 years)). Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

Similarly, when total tuber recovery values for mass, diameter, length and volume were used, the same results as those obtained above when mean tuber size values were used for each variable were found (Appendix 1, Figure 3.1).

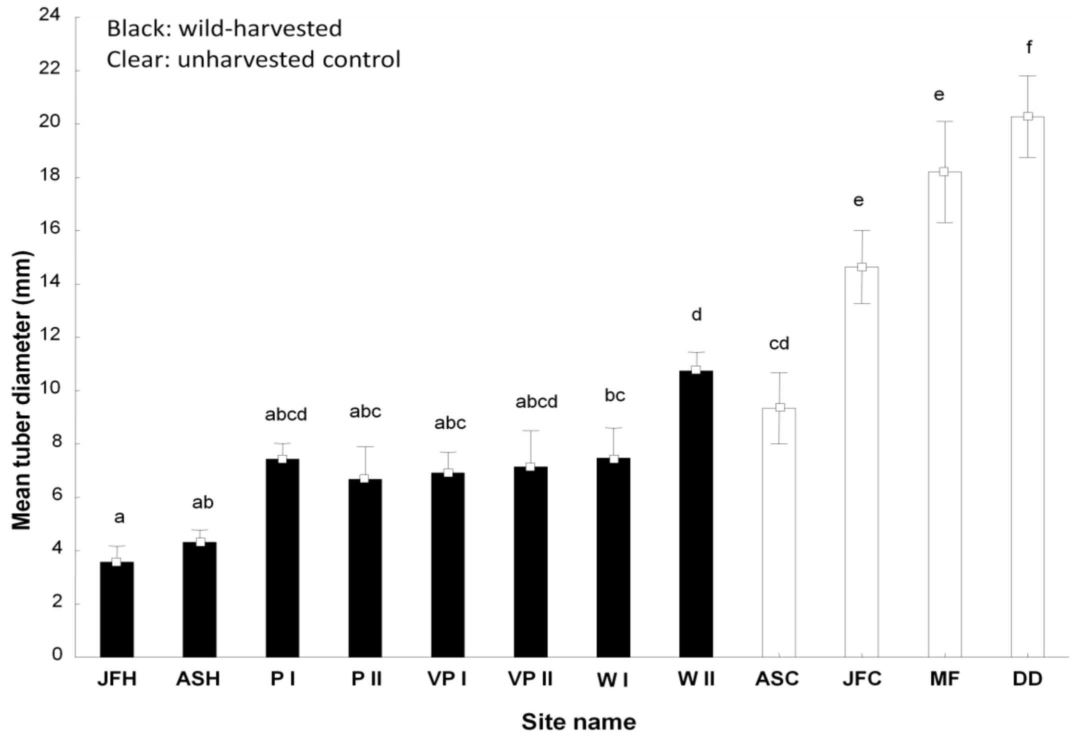
3.4.1.1.2. Comparisons on tuber size in wild-harvested and unharvested control sites

Tuber size (mass, diameter, length and volume) was compared between wild-harvested and unharvested control sites. There was a highly significant difference found when mean tuber mass was compared between wild-harvested and unharvested control sites ($F_{11,95}$= 9.7226, P < 0.001) (Figure 3.2A). Plants from unharvested control sites had significantly larger tuber mass than plants from wild-harvested sites. Likewise, a highly significant difference in mean tuber diameter was found between wild-harvested and unharvested control sites ($F_{11,95}$= 19. 7951, P < 0.001) (Figure 3.2B). Unharvested control sites had plants with significantly larger tuber diameter than plants from wild-harvested sites. Furthermore, when mean tuber length was compared, a highly significant difference between wild-harvested and unharvested control sites was found ($F_{11,95}$= 10.2224, P < 0.001) (Figure 3.2C). Plants from unharvested control sites were found to have significantly longer tubers than plants from wild-harvested sites. JFC (Janine farm harvested) had plants with the longest tubers although these were not significantly longer than tubers from ASC (Airstrip control). As expected, mean tuber volume was significantly higher in unharvested control sites than wild-harvested sites ($F_{11,95}$= 10.3868, P < 0.001) (Figure 3.2D).

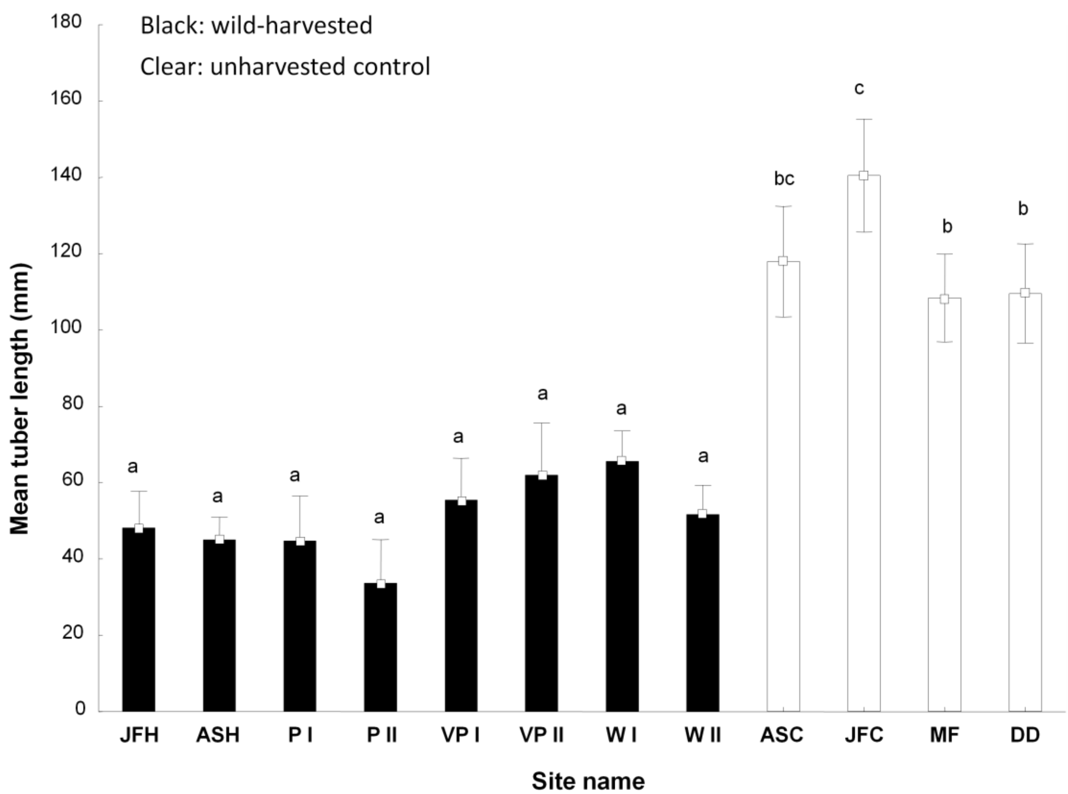
(A)



(B)


Black: wild-harvested
Clear: unharvested control
Mean tuber diameter (mm)
0
2
4
6
8
10
12
14
16
18
20
22
24
a
ab
abcd
abc
abc
abcd
bc
d
cd
e
e
f
JFH
ASH
P I
P II
VP I
VP II
W I
W II
ASC
JFC
MF
DD
Site name

(C)


Black: wild-harvested
Clear: unharvested control
Mean tuber length (mm)
0
20
40
60
80
100
120
140
160
180
a
a
a
a
a
a
a
a
bc
c
b
b
JFH
ASH
P I
P II
VP I
VP II
W I
W II
ASC
JFC
MF
DD
Site name

(D)

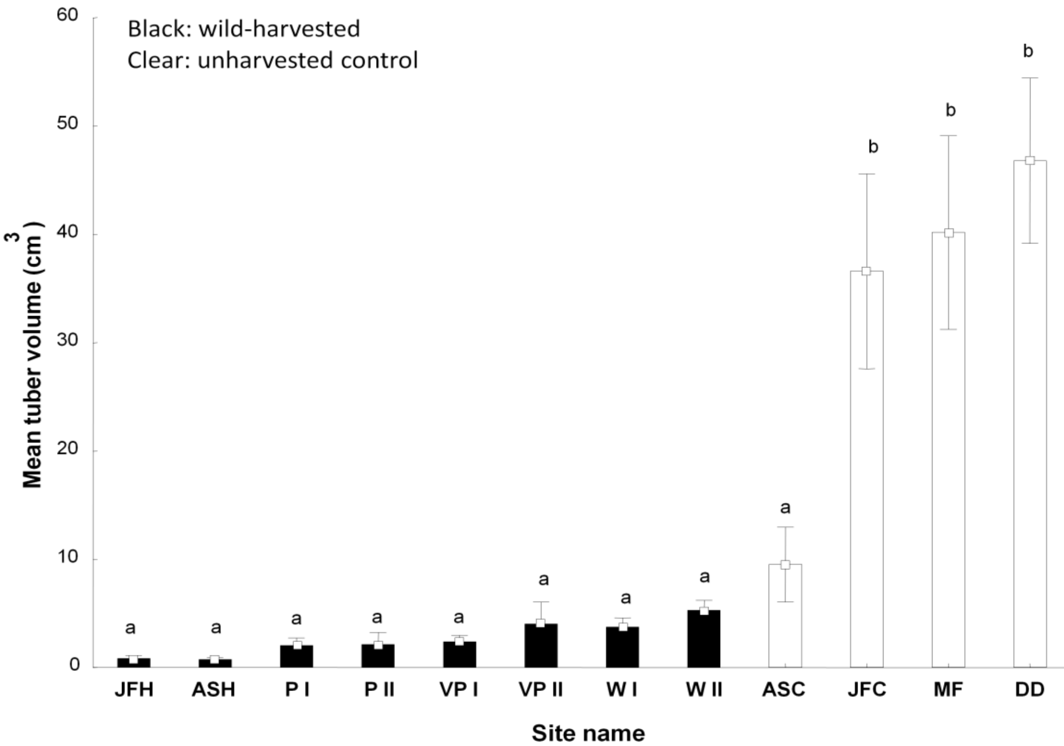


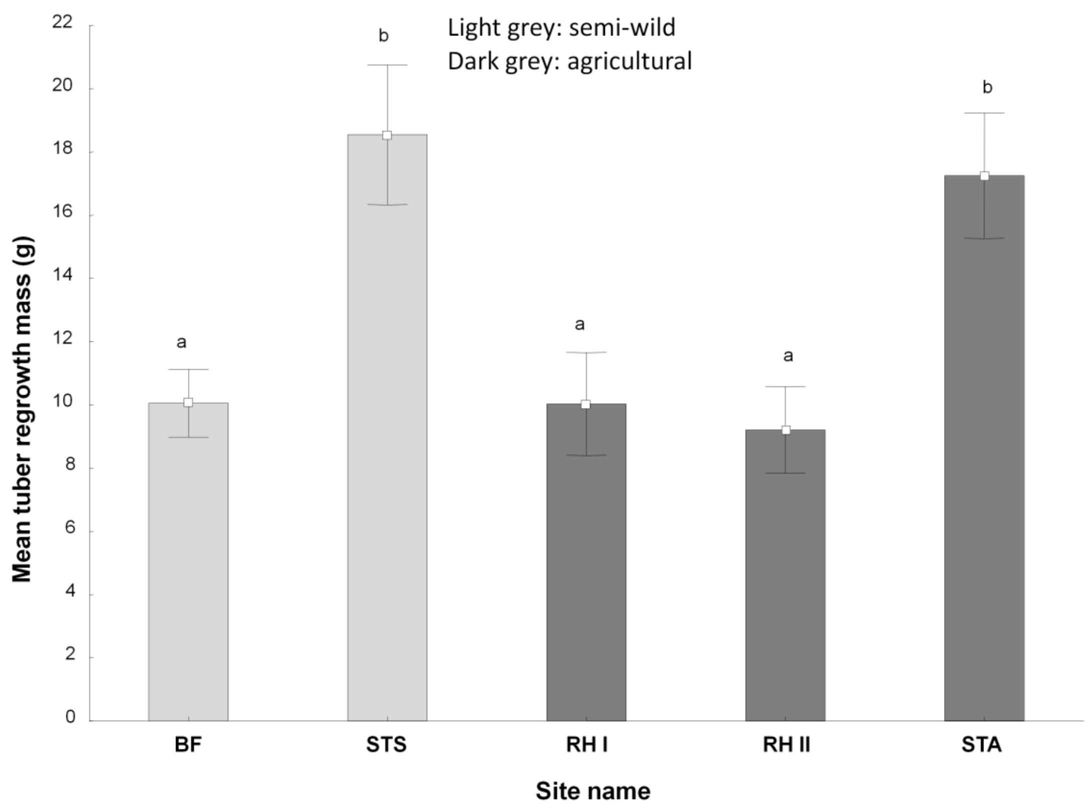
Figure 3.2. Comparisons of tuber recovery and tuber size (A= tuber recovery and tuber mass, B= tuber recovery and tuber diameter, C= tuber recovery and tuber length, D= tuber recovery and tuber volume) of Pelargonium sidoides plants in wild-harvested (JFH=Janine farm harvested, ASH= Airstrip harvested, P I= Peddie I, P II= Peddie II, VP I= Victoria Post I, VP II= Victoria Post II, W I= Wesley I and W II= Wesley II and unharvested control plants (ASC= Airstrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift) in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.1 for site ages (Chapter 2, Section 2.3.1.1.).

Comparisons were also made using total tuber mass, tuber diameter, tuber length and tuber volume values and same results as above were obtained when mean tuber size values were used (Appendix 1, Figure 3.2).

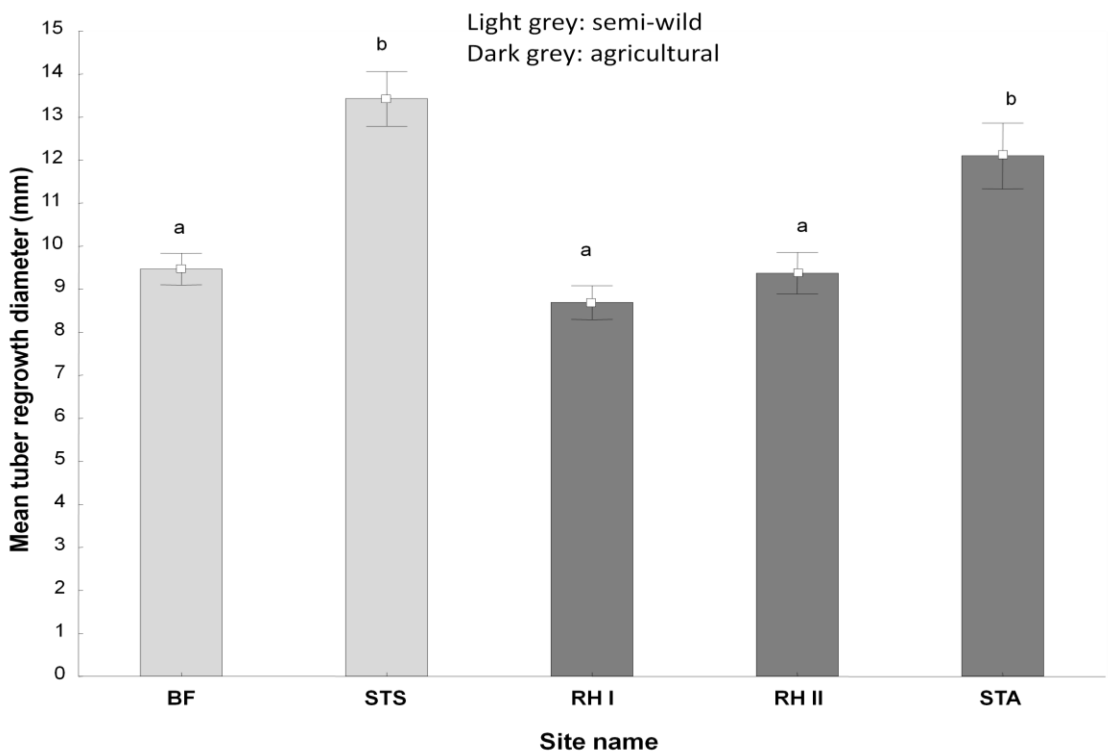
3.4.1.1.3. Comparisons on tuber regrowth size in semi-wild and agricultural sites

Plants from cultivated sites (semi-wild and agricultural sites) were expected to have large tubers and agricultural sites were expected to have larger tubers. Therefore, comparison on tuber regrowth mass was made between semi-wild and agricultural sites. There was a highly significant difference in tuber regrowth mass between semi-wild and agricultural sites ($F_{4,45}$= 6.9455, P < 0.001) (Figure 3.3A). Plants from STS (Stutterheim semi-wild) and STA (Stutterheim agricultural) had larger tuber regrowth mass than plants from the other sites. Similarly, STS and STA had plants with significantly larger tuber regrowth diameter than plants from the other sites ($F_{4,45}$= 13.8546, P < 0.001) (Figure 3.3B). However, STS tended to have larger tuber regrowth mass and diameter. Conversely, when mean tuber regrowth length was compared, STA had more tuber regrowth length than STS although this was not significantly different from that of plants from other agricultural sites (RH I- Rhodes I) and semi-wild sites (BF- Bold farm and STS) ($F_{4,45}$= 4.6347, P = 0.003) (Figure 3.3C). When mean tuber regrowth volume was compared, STS was found to have plants that had significantly larger tuber regrowth volume than plants from all the other sites ($F_{4,45}$= 10.0906, P < 0.001) (Figure 3.3D).

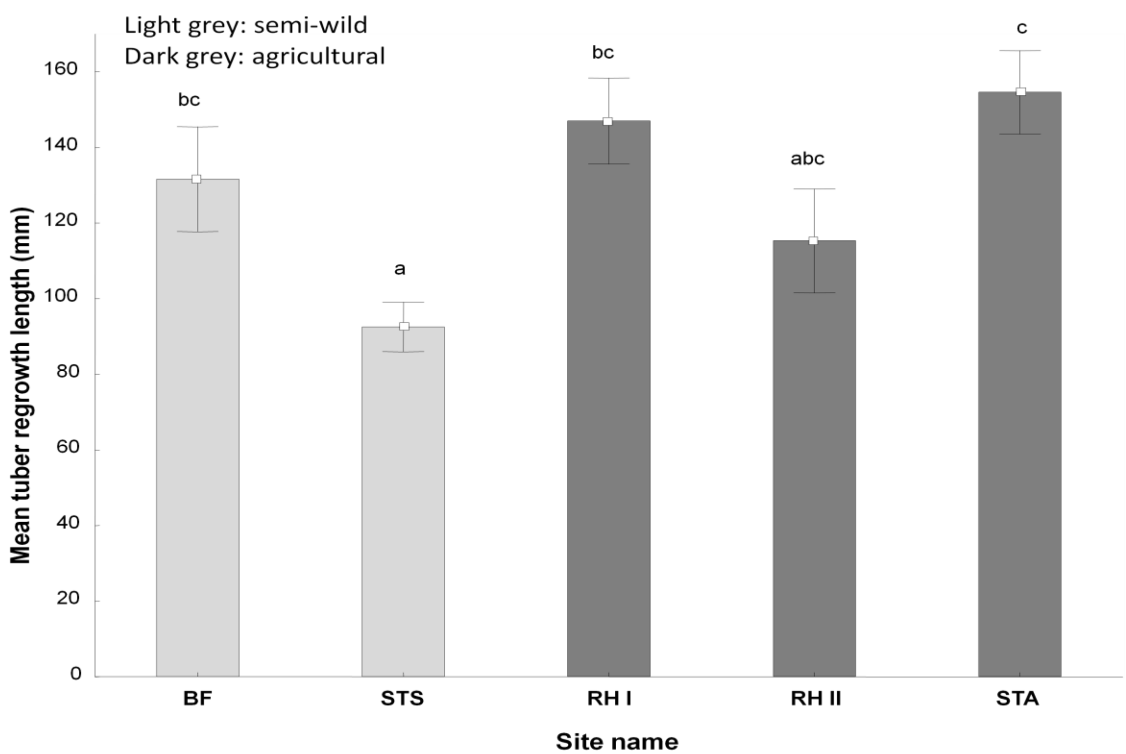
(A)



(B)


Light grey: semi-wild
Dark grey: agricultural
Mean tuber regrowth diameter (mm)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
a
b
a
a
b
BF
STS
RH I
RH II
STA
Site name

(C)


Light grey: semi-wild
Dark grey: agricultural
Mean tuber regrowth length (mm)
160
140
120
100
80
60
40
20
0
bc
a
bc
abc
c
BF
STS
RH I
RH II
STA
Site name

(D)

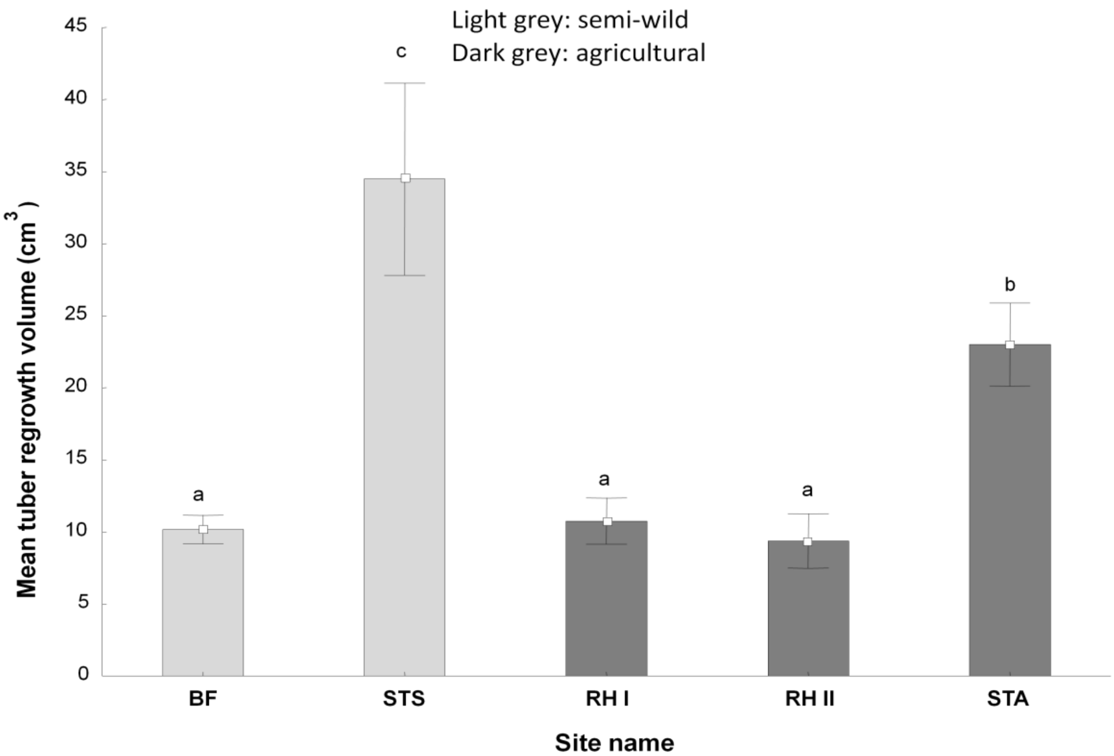


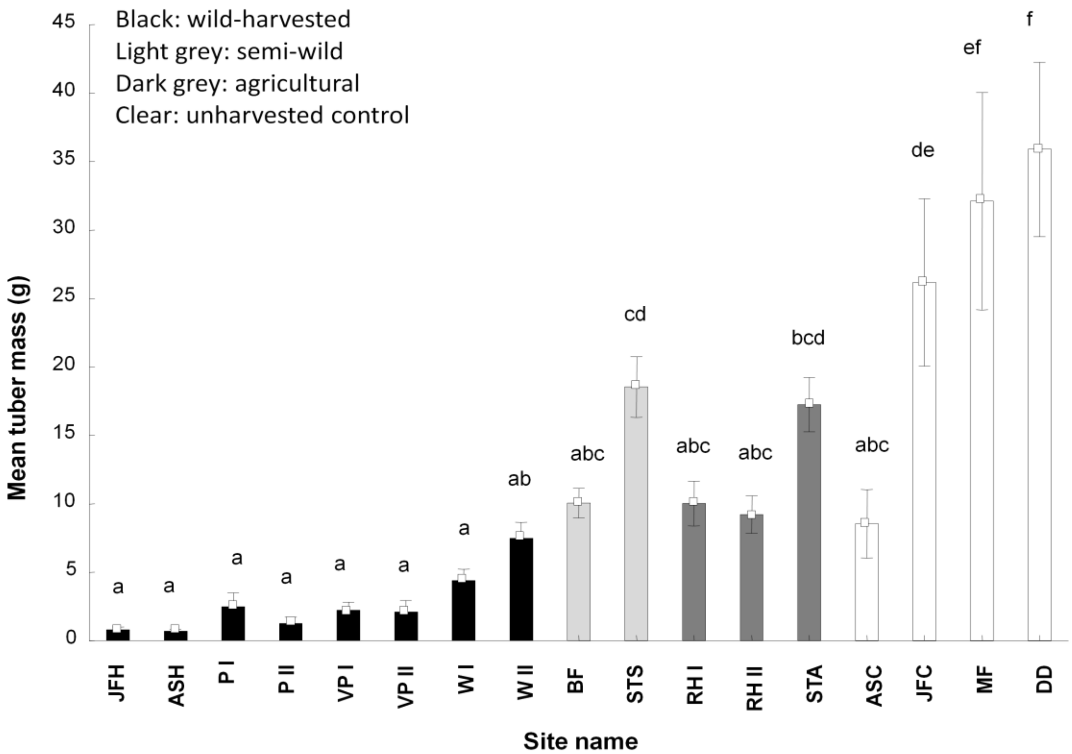
Figure 3.3. Comparisons of tuber regrowth size (A= tuber regrowth mass, B= tuber regrowth diameter, C= tuber regrowth length, D= tuber regrowth volume) of Pelargonium sidoides plants in semi-wild (BF= Bold farm (2 years), STS= Stutterheim semi-wild (3 years)) and agricultural sites (RH I= Rhodes I (1 year), RH II= Rhodes II (2 years) and Stutterheim agricultural (4 years) of differing ages in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

Tuber regrowth size was also compared using total tuber regrowth size (mass, diameter, length and volume) values and similar results to those found when mean values were used as above were obtained (Appendix 1, Figure 3.3). However, tuber regrowth volume results were slightly different. For example, STA was found to have larger tuber regrowth mass than all the rest of the sites when total values were used whereas when mean values were used STS had larger tuber regrowth volume. This was probably because STA had more tubers/plant than STS and hence using total tuber regrowth size values produced a biased result.

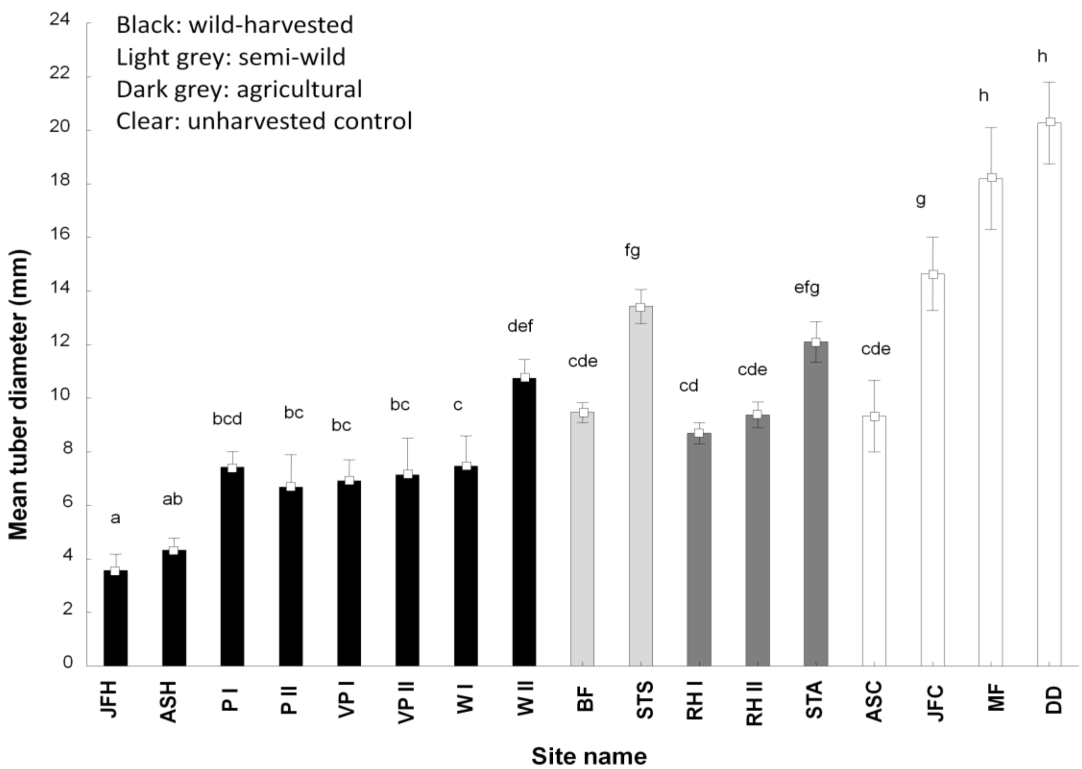
3.4.1.1.4. Comparisons on tuber recovery, tuber regrowth and tuber size across all types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

Comparison on tuber recovery, tuber regrowth and tuber size was also made across all types of sites. There was a highly significant difference in tuber recovery, tuber regrowth and tuber mass detected across sites ($F_{16,140}$= 9.542, $P < 0.001$) (Figure 3.4A). Plants from unharvested control sites had significantly larger tuber mass than plants from all the other types of sites. DD was found to have largest tuber mass than all the other sites although this was not significantly different from tubers obtained from MF (McMaster farm). In the same manner, a highly significant difference was found across sites when tuber diameter was compared ($F_{16,140}$= 19.2302, $P < 0.001$) (Figure 3.4B). Similarly, unharvested control sites had plants with larger tuber diameter than plants from the other types of sites. Of the unharvested control sites, plants from DD and MF had larger tuber diameter than plants from the rest of the other sites. Furthermore, comparisons on mean tuber length produced a significant difference across sites ($F_{16,140}$= 12.4004, $P < 0.001$) (Figure 3.4C). Plants from agricultural sites (STA) had tubers that were longer than those from the other types of sites. On the other hand, the tubers were not significantly longer than the tubers from some semi-wild (BF- Bold farm) and unharvested control (JFC-Janine farm control) sites. When tuber volume was compared across sites, a highly significant difference was found ($F_{16,140}$= 10.1436, $P < 0.001$) (Figure 3.4D). The unharvested control sites had plants with larger tuber volume than plants from the other sites. However, this was not significantly different from tuber regrowth volume of plants from STS.

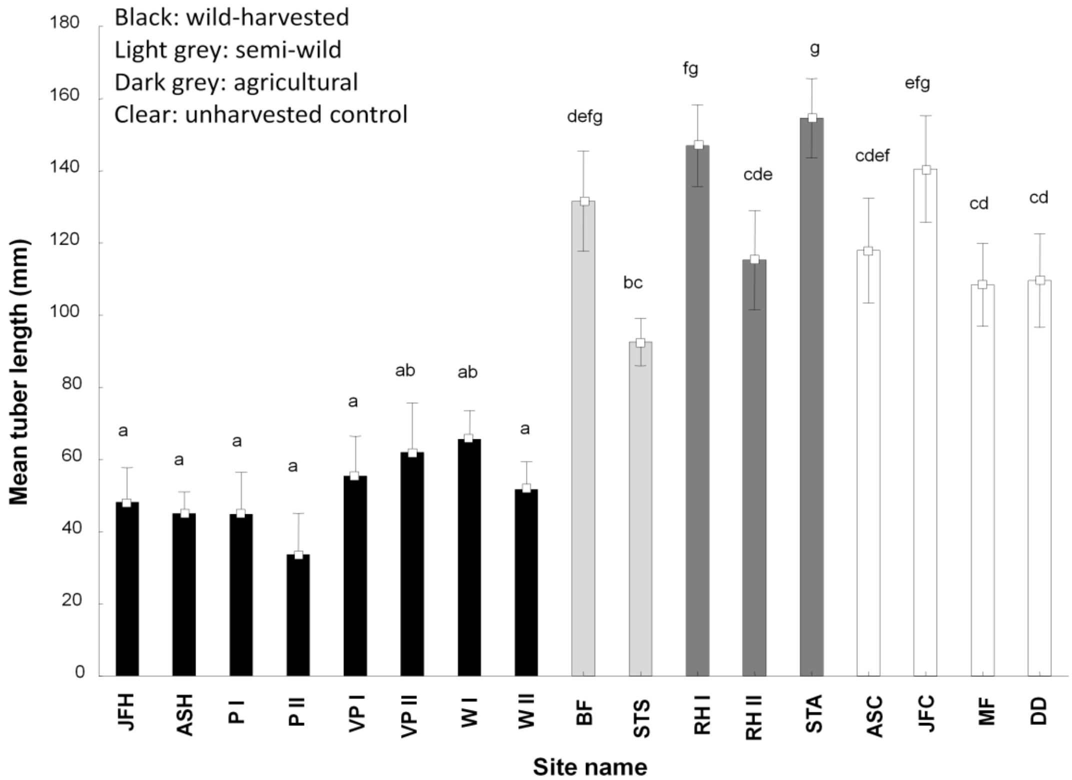
(A)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber mass (g)
45
40
35
30
25
20
15
10
5
0
a
a
a
a
a
a
a
ab
abc
cd
abc
abc
bcd
abc
de
ef
f
JFH
ASH
P I
P II
VP I
VP II
W I
W II
BF
STS
RH I
RH II
STA
ASC
JFC
MF
DD
Site name

(B)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber diameter (mm)
24
22
20
18
16
14
12
10
8
6
4
2
0
a
ab
bcd
bc
bc
bc
c
def
cde
fg
cd
cde
efg
cde
g
h
h
JFH
ASH
P I
P II
VP I
VP II
W I
W II
BF
STS
RH I
RH II
STA
ASC
JFC
MF
DD
Site name

(C)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber length (mm)
0
20
40
60
80
100
120
140
160
180
a
a
a
a
a
ab
ab
a
defg
bc
fg
cde
g
cdef
efg
cd
cd
JFH
ASH
P I
P II
VP I
VP II
W I
W II
BF
STS
RH I
RH II
STA
ASC
JFC
MF
DD
Site name

(D)

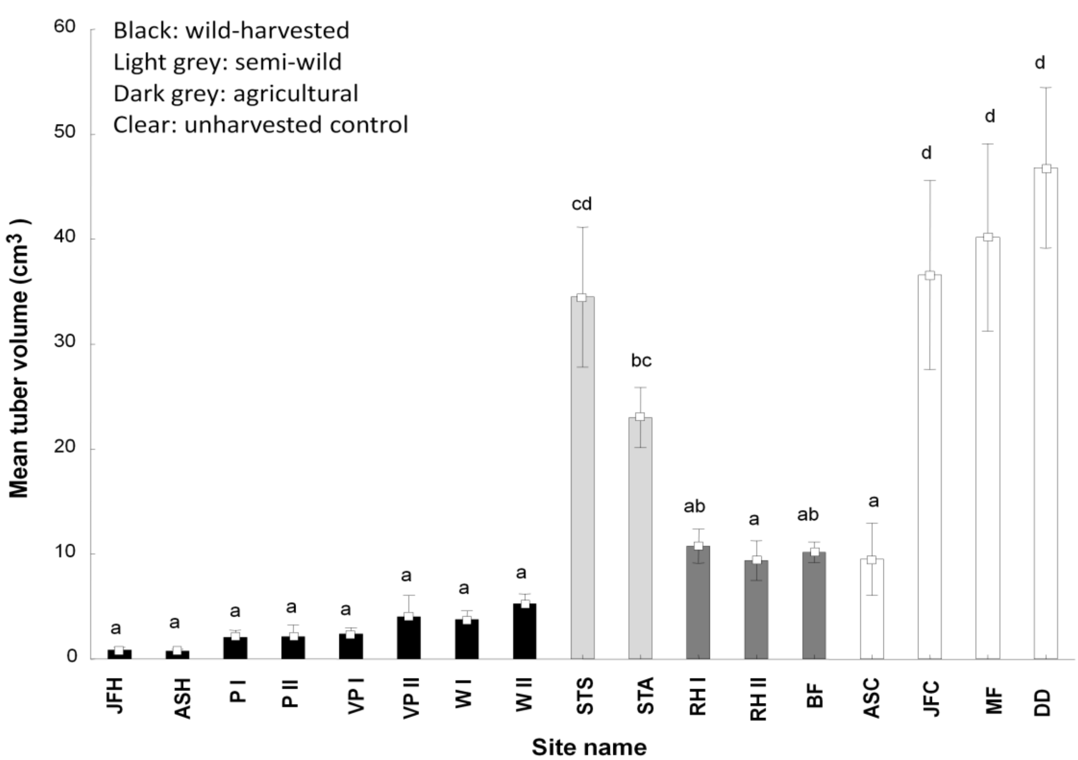

Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber volume (cm^3)
0
10
20
30
40
50
60
a
a
a
a
a
a
a
a
cd
bc
ab
a
ab
a
d
d
d
JFH
ASH
P I
P II
VP I
VP II
W I
W II
STS
STA
RH I
RH II
BF
ASC
JFC
MF
DD
Site name

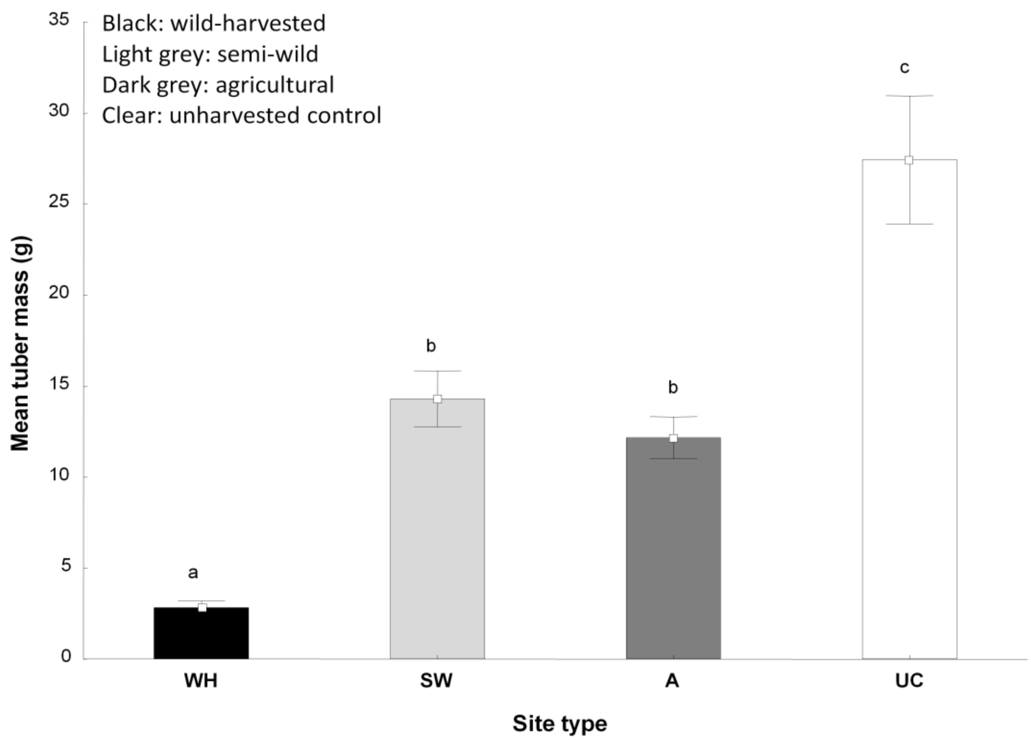
Figure 3.4. Comparisons of tuber recovery, tuber regrowth and tuber size (A= tuber recovery, tuber regrowth and tuber mass, tuber recovery, tuber regrowth and tuber diameter, C= tuber recovery, tuber regrowth and tuber length, D= tuber recovery, tuber regrowth and tuber volume) of Pelargonium sidoides plants in wild-harvested (JFH=Janine farm harvested, ASH= Airstrip harvested, P I= Peddie I, P II= Peddie II, VP I= Victoria Post I, VP II= Victoria Post II, W I= Wesley I and W II= Wesley II), semi-wild (BF= Bold farm, STS= Stutterheim semi-wild) and agricultural sites (RH I= Rhodes I, RH II= Rhodes II and Stutterheim agricultural) and unharvested control sites (ASC= Airstrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift) in the 'lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.1 for site ages (Chapter 2, Section 2.3.1.1.).

The results obtained when total tuber size values were used differed from above-mentioned results from using mean tuber size values (Appendix 1, Figure 3.4). The varying number of tubers/plant may have caused this. For instance, plants from semi-wild and agricultural sites had more tubers/plant than plants from other site types, therefore basing a comparison on total tuber size values would have favoured these more than the other sites.

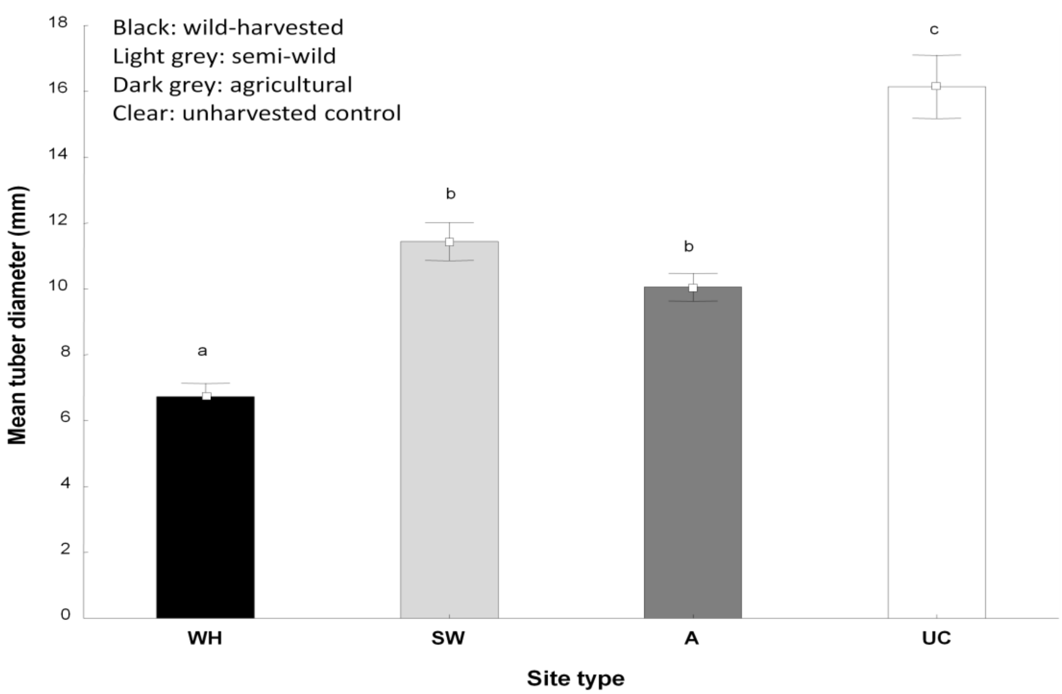
3.4.1.1.5. Comparisons on tuber size when sites are grouped according to site type (wild-harvested- WH, semi-wild- SW, agricultural- A and unharvested control- UC sites)

To investigate tuber size of plants growing under different management regimes, comparisons on tuber size was done across wild-harvested, semi-wild, agricultural and unharvested control sites. There was a highly significant difference in mean tuber mass across sites ($F_{3,153}$= 35.2965, $P < 0.001$) (Figure 3.5A). Unharvested control sites were found to have plants that had significantly larger tubers than plants from the other types of sites. Similarly, when comparing tuber size across sites using mean tuber diameter, significant differences were detected ($F_{3,153}$= 46.5085, $P < 0.001$) (Figure 3.5B). Plants from unharvested control sites had larger tubers than plants from the other sites. However, when comparisons were made across sites using mean tuber length, agricultural sites had plants with longer tubers than plants from the other types of sites but the tubers were not significantly longer tubers from unharvested control sites ($F_{3,153}$= 54.0368, $P < 0.001$) (Figure 3.5C). Comparisons of tuber volume also produced significant differences across site types ($F_{3,153}$= 34.0645, $P < 0.001$) (Figure 3.5D). Unharvested control sites had plants with significantly more tuber volume than plants from other types of sites.

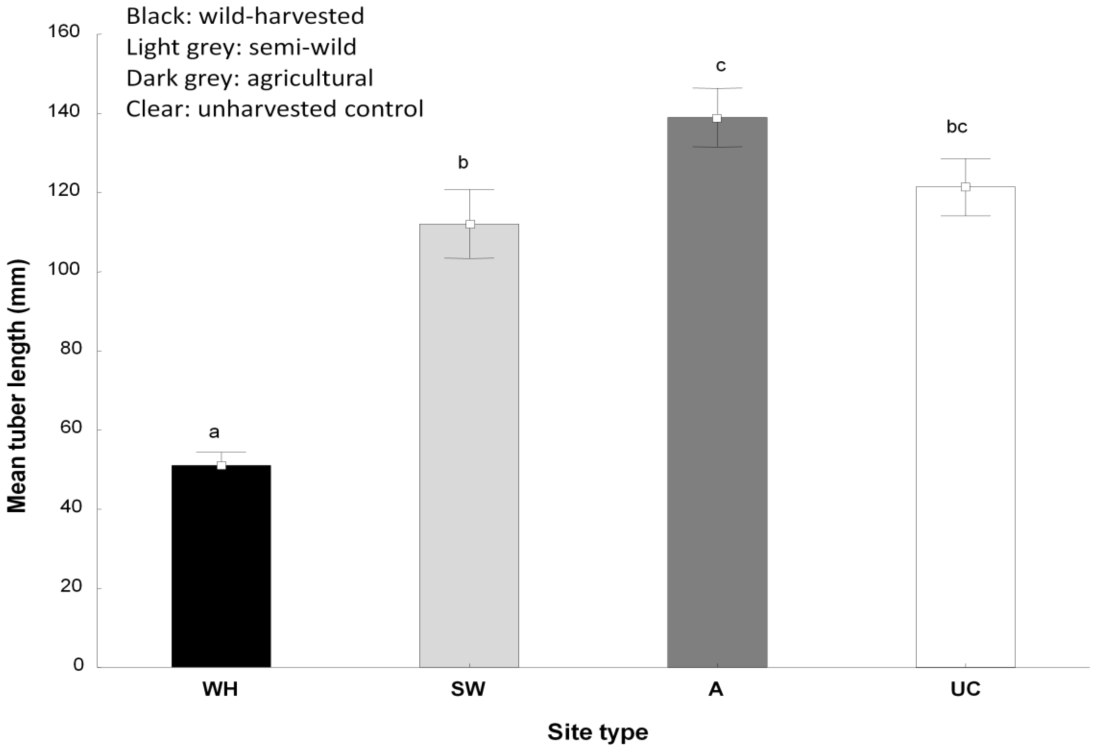
(A)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber mass (g)
0
5
10
15
20
25
30
35
a
b
b
c
WH
SW
A
UC
Site type

(B)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber diameter (mm)
0
2
4
6
8
10
12
14
16
18
a
b
b
c
WH
SW
A
UC
Site type

(C)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber length (mm)
160
140
120
100
80
60
40
20
0
a
b
c
bc
WH
SW
A
UC
Site type

(D)

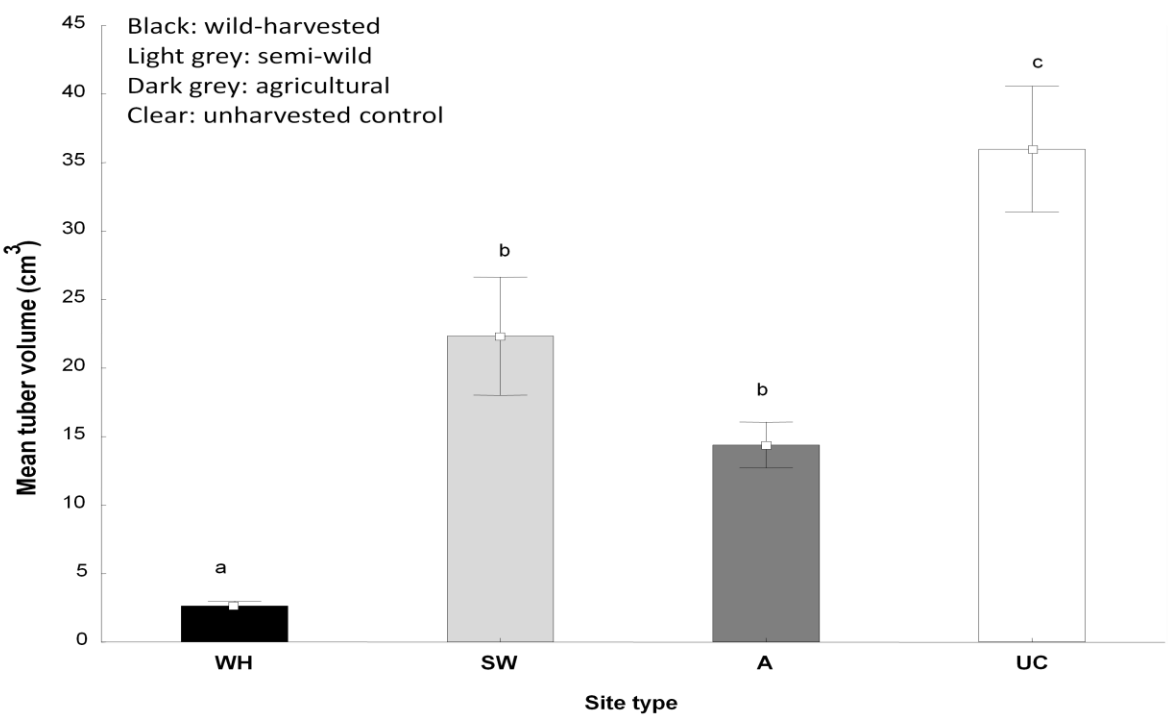

Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber volume (cm3)
45
40
35
30
25
20
15
10
5
0
a
b
b
c
WH
SW
A
UC
Site type

Figure 3.5. Comparisons of tuber recovery, tuber regrowth and tuber size (A= tuber recovery, tuber regrowth and tuber mass, B= tuber recovery, tuber regrowth, and tuber diameter, C= tuber recovery, tuber regrowth and tuber length, D= tuber recovery, tuber regrowth and tuber volume) of Pelargonium sidoides plants in wild-harvested (WH), semi-wild (SW), agricultural (A) and unharvested control (UC) sites in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

Other than making comparisons using mean tuber size values, total tuber size values were also used. However, the results that were obtained varied (Appendix 1, Figure 3.5). For example, plants from agricultural sites were significantly larger (in tuber mass, tuber diameter, tuber length and tuber volume) than plants from the other site types. The discrepancy may be a result of unequal number of tubers/plant across types of sites. Agricultural sites had more tubers/plant than other site types.

3.4.1.2. Above-ground plant growth across sites

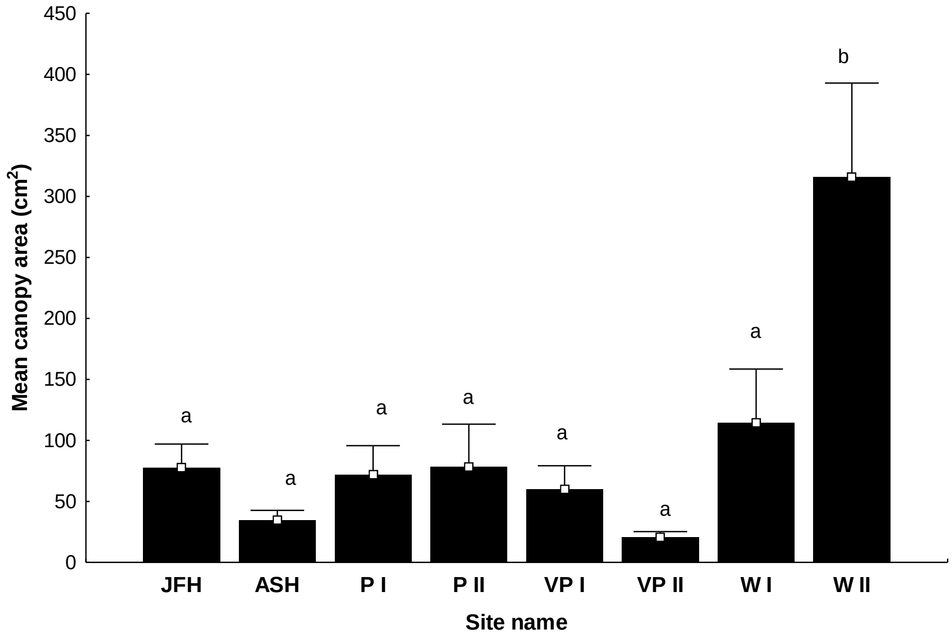
3.4.1.2.1. Comparisons of canopy area across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

There was a significant difference in canopy area across the wild-harvested sites that were compared. Plants from W II (Wesley II, harvested 7 years ago) were found to have bigger canopies than all the other plants ($F_{7,59}$= 5.0054, $P <$ 0.001) (Figure 3.6A). This was probably the case because this site had been last harvested 8 years ago meaning disturbance from harvest happened a long time ago compared to the other sites. On the other hand, canopy area of plants from all the rest of the wild-harvested sites was not significantly different. Similarly, when wild-harvested and unharvested control sites were compared, a highly significant difference was observed ($F_{11,95}$= 5.9258, P < 0.001) (Figure 3.6B). Of all the sites, W II (wild-harvested) and MF (unharvested control) had plants with bigger canopies.

Canopy area was also found to be significantly different among semi-wild and agricultural sites ($F_{4,45}$= 4.9580, P < 0.001) (Figure 3.6C). Plants from STS (Stutterheim semi-wild) had bigger canopies than plants from the other sites. However, canopy area of plants from this site was not significantly from STA. Furthermore, canopy area of plants from the other 3 sites (BF- Bold farm, RH II- Rhodes II) was not significantly different.

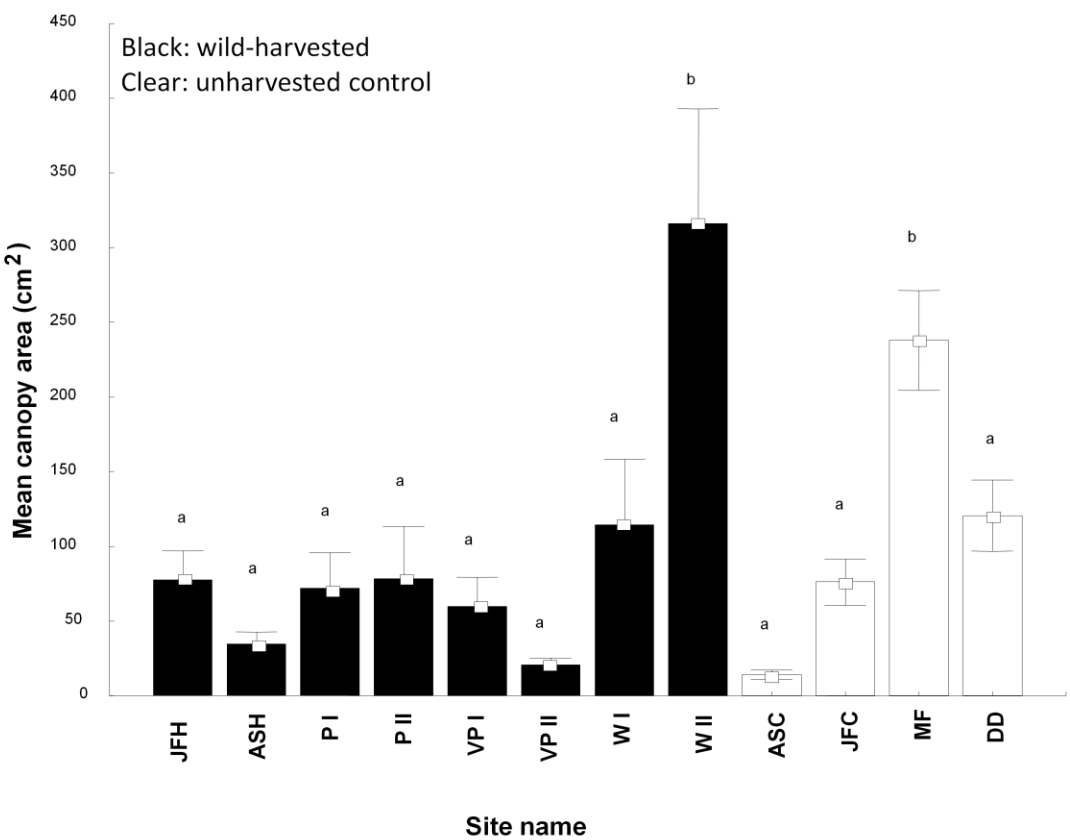
To also check if canopy area varied across all sites, comparisons were made. Canopy area was found to vary significantly across sites ($F_{11,140}$= 11.6244, P < 0.001) (Figure 3.6D). STS site was found to have plants with bigger canopies than all the rest of the sites.

(A)



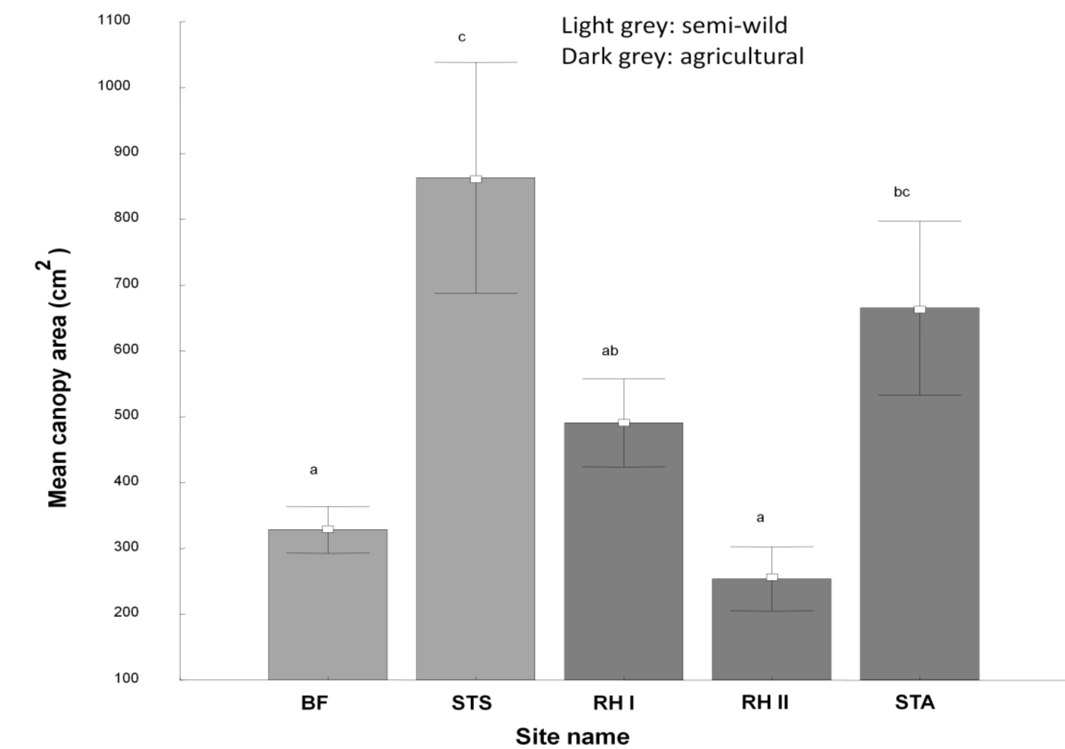
Mean canopy area (cm^2)
450
400
350
300
250
200
150
100
50
0
a
a
a
a
a
a
a
b
JFH
ASH
P I
P II
VP I
VP II
W I
W II
Site name

(B)



Black: wild-harvested
Clear: unharvested control
Mean canopy area (cm^2)
450
400
350
300
250
200
150
100
50
0
a
a
a
a
a
a
a
b
a
a
b
a
JFH
ASH
P I
P II
VP I
VP II
W I
W II
ASC
JFC
MF
DD
Site name

(C)


Light grey: semi-wild
Dark grey: agricultural
Mean canopy area (cm^2)
1100
1000
900
800
700
600
500
400
300
200
100
c
bc
ab
a
a
BF
STS
RH I
RH II
STA
Site name

(D)

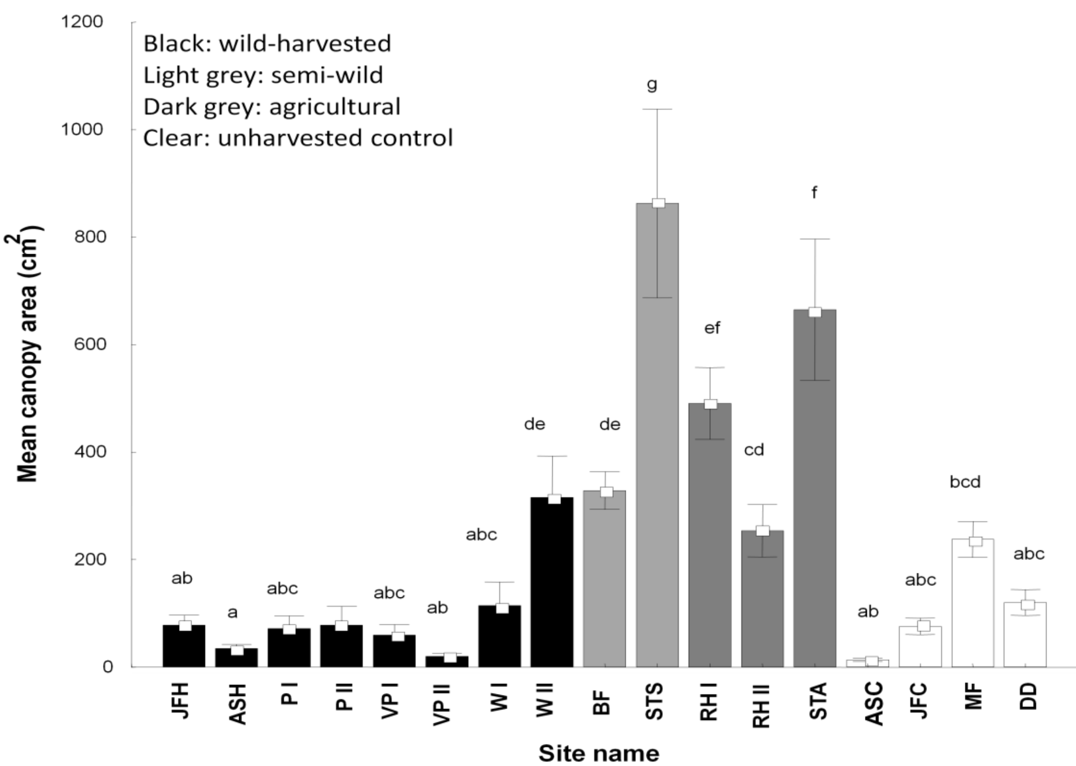

Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean canopy area (cm^2)
1200
1000
800
600
400
200
0
g
f
ef
de
de
cd
bcd
abc
ab
a
abc
abc
ab
abc
ab
abc
abc
JFH
ASH
P I
P II
VP I
VP II
W I
W II
BF
STS
RH I
RH II
STA
ASC
JFC
MF
DD
Site name

Figure 3.6. Comparisons of canopy area (cm^2) of Pelargonium sidoides plants in wild-harvested sites (A) (ASH, P I= Peddie I, P II= Peddie II, VP I= Victoria Post I, VP II= Victoria Post II, W I= Wesley I and W II= Wesley II and unharvested control sites (B) (ASC= Airstrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift), semi-wild and agricultural sites (C) (Semi-wild - BF= Bold farm, STS= Stutterheim semi-wild and agricultural- RH I= Rhodes I, RH II= Rhodes II and Stutterheim agricultural) and all types of sites in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.1 for site ages (Chapter 2, Section 2.3.1.1.).

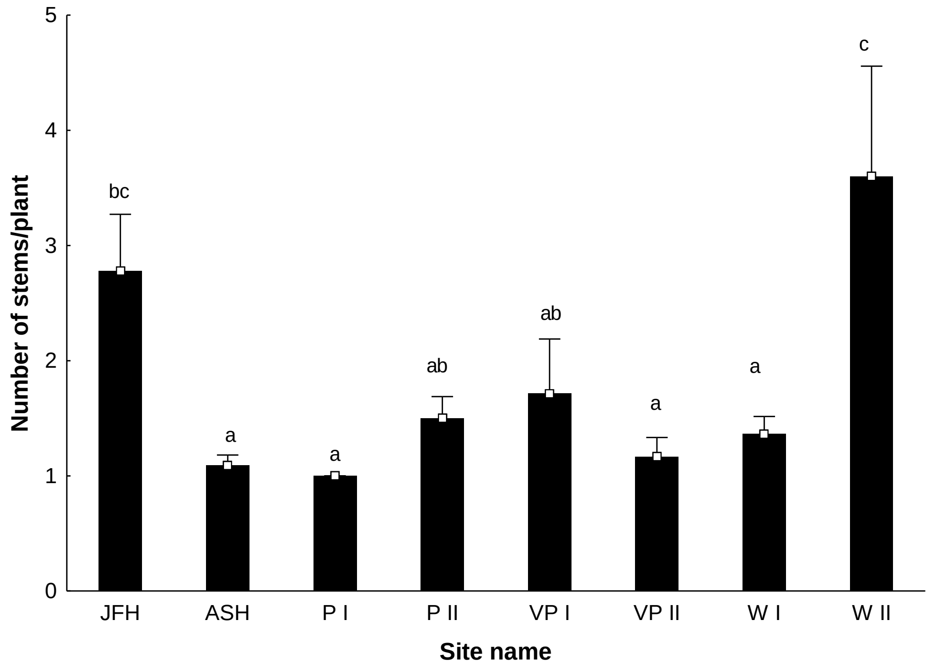
3.4.1.2.2. Comparisons on the number of stems/plant across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

To determine *P. sidoides* above-ground plant growth in wild-harvested sites, the number of stems/plant was compared. There was a significant difference in the number of stems/plant across wild harvested sites ($F_{7,59}$= 3.9956, P= 0.0012) (Figure 3.7A). Plants from W II tended to have significantly more stems/plant than plants from all the other sites although these were not significantly different from stems/plant from JFH (Janine farm harvested). When wild harvested and unharvested control sites were compared, plants from wild-harvested sites were found to posses significantly more stems/plant than plants from unharvested control sites ($F_{11,95}$= 3.5084, P < 0.001) (Figure 3.7B). Similarly, W II was found to have plants with significantly more stems/plant than all the other sites.

Above-ground plant performance using the number of stems/plant was also determined between semi-wild and agricultural sites. There was a significant difference in the number of stems/plant between semi-wild and agricultural sites ($F_{4,45}$= 16.1665, P < 0.001) (Figure 3.7C). Plants from RH I (Rhodes I) had significantly more stems than plants from the rest of the other sites.

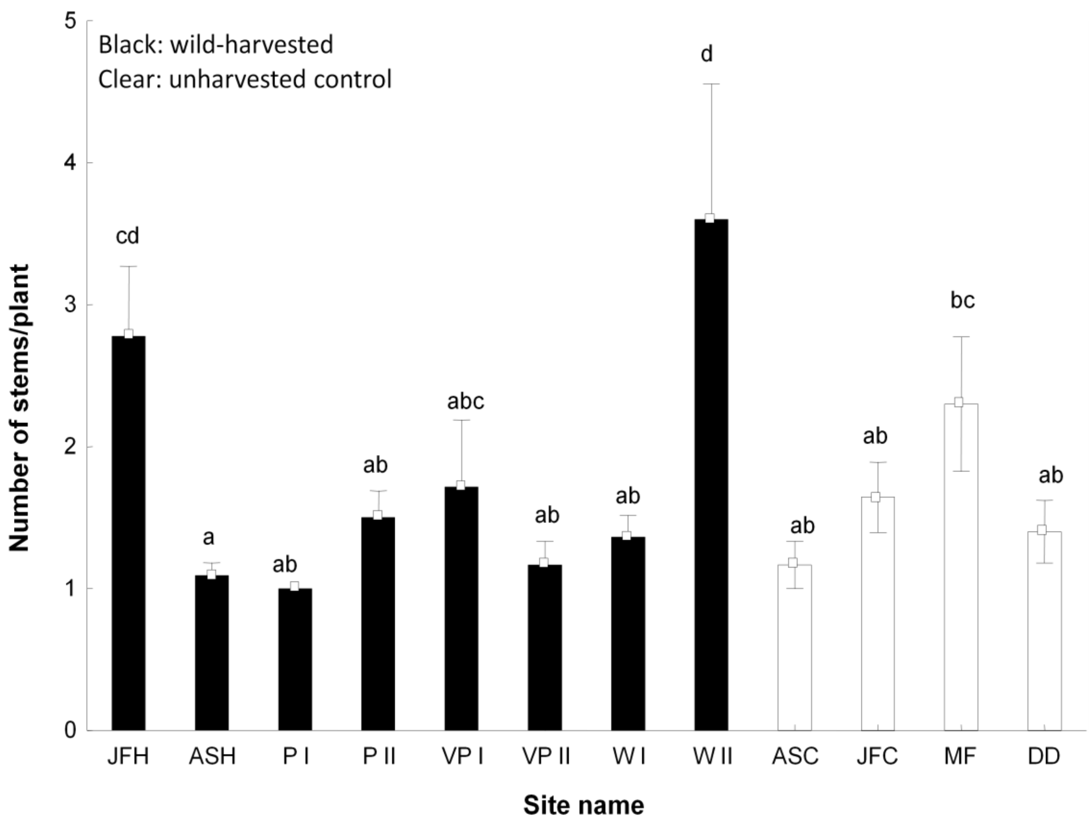
Additionally, comparisons on the number of stems/plant across all types of sites yielded significant relationships ($F_{16,140}$= 9.5121, P < 0.001) (Figure 3.7D). Semi-wild and agricultural sites had plants with significantly more stems/plant than the other types of sites. Furthermore, RH I was found to have significantly more stems/plant than all the other sites. The number of stems/plant was not significantly different across all the wild-harvested and unharvested control sites.

(A)



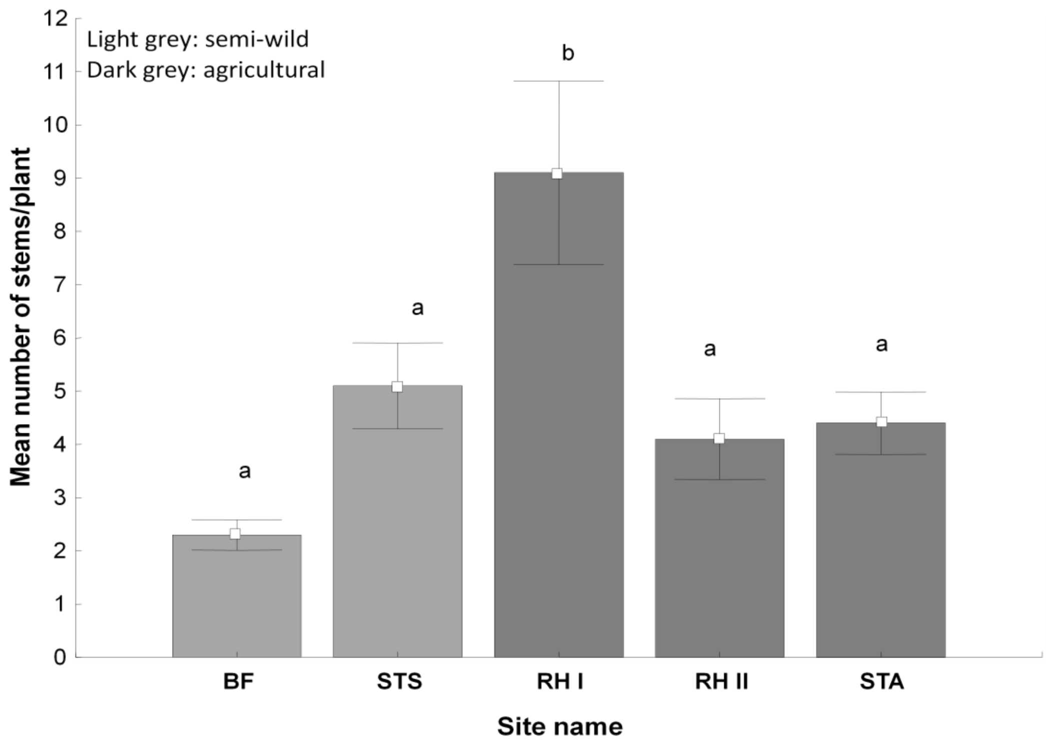
Number of stems/plant
0
1
2
3
4
5
bc
a
a
ab
ab
a
a
c
JFH
ASH
P I
P II
VP I
VP II
W I
W II
Site name

(B)



Black: wild-harvested
Clear: unharvested control
Number of stems/plant
0
1
2
3
4
5
cd
a
ab
ab
abc
ab
ab
d
ab
ab
bc
ab
JFH
ASH
P I
P II
VP I
VP II
W I
W II
ASC
JFC
MF
DD
Site name

(C)


Light grey: semi-wild
Dark grey: agricultural
Mean number of stems/plant
0
1
2
3
4
5
6
7
8
9
10
11
12
a
a
b
a
a
BF
STS
RH I
RH II
STA
Site name

(D)

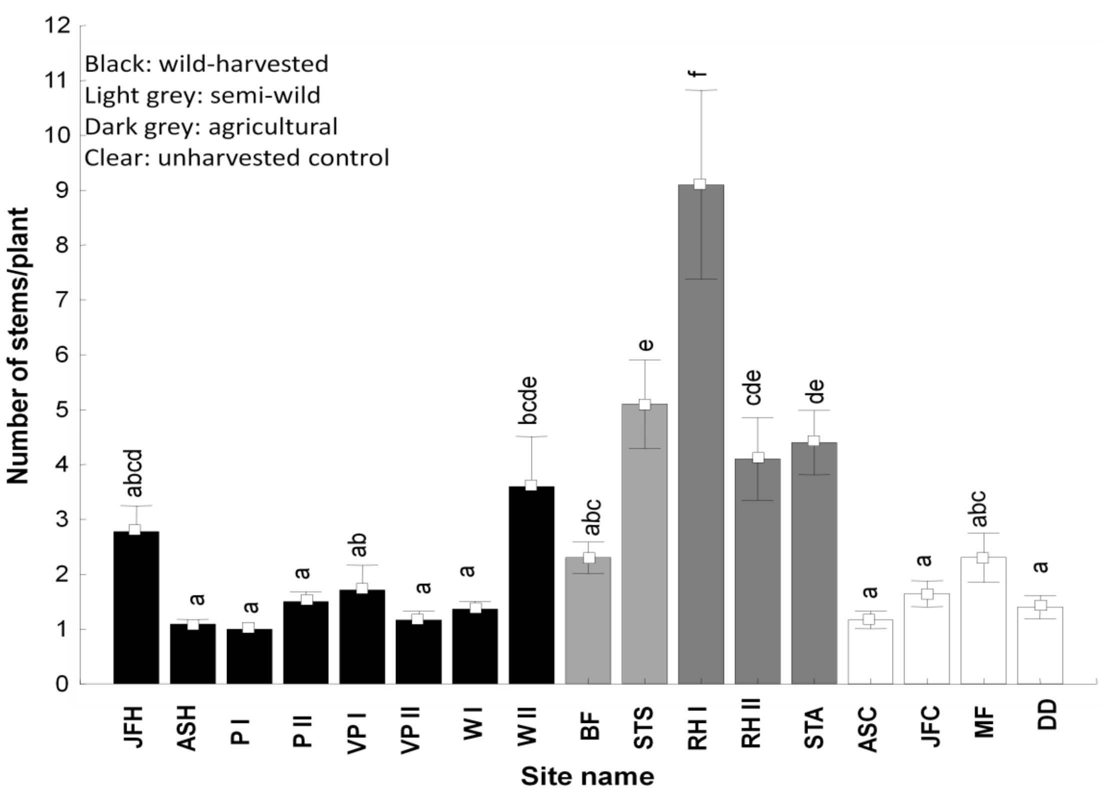

Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Number of stems/plant
0
1
2
3
4
5
6
7
8
9
10
11
12
abcd
a
a
a
ab
a
a
bcde
abc
e
f
cde
de
a
a
abc
a
JFH
ASH
P I
P II
VP I
VP II
W I
W II
BF
STS
RH I
RH II
STA
ASC
JFC
MF
DD
Site name

Figure 3.7. Comparisons on the number of stems/plant of Pelargonium sidoides plants in wild-harvested sites (A= ASH, P I= Peddie I, P II= Peddie II, VP I= Victoria Post I, VP II= Victoria Post II, W I= Wesley I and W II= Wesley II), unharvested control sites (B= ASC= Airstrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift), semi-wild and agricultural sites (C= Semi-wild - BF= Bold farm, STS= Stutterheim semi-wild and agricultural- RH I= Rhodes I, RH II= Rhodes II and Stutterheim agricultural) in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.1 for site ages (Chapter 2, Section 2.3.1.1.).

3.4.1.2.3. Comparisons on the number of stems/plant when sites are grouped according to site type (wild-harvested- WH, semi-wild- SW, agricultural- A and unharvested control- UC sites)

When various types of sites were grouped according to site type, a highly significant difference in the number of stems/ plant was found ($F_{3,153}$= 23.9684, P = 0.0001) (Figure 3.8). Plants from agricultural sites had significantly more stems/plant than plants from the other site types. This was the case even though sites were grouped according to different site types irrespective of the times since last harvest/cultivation.

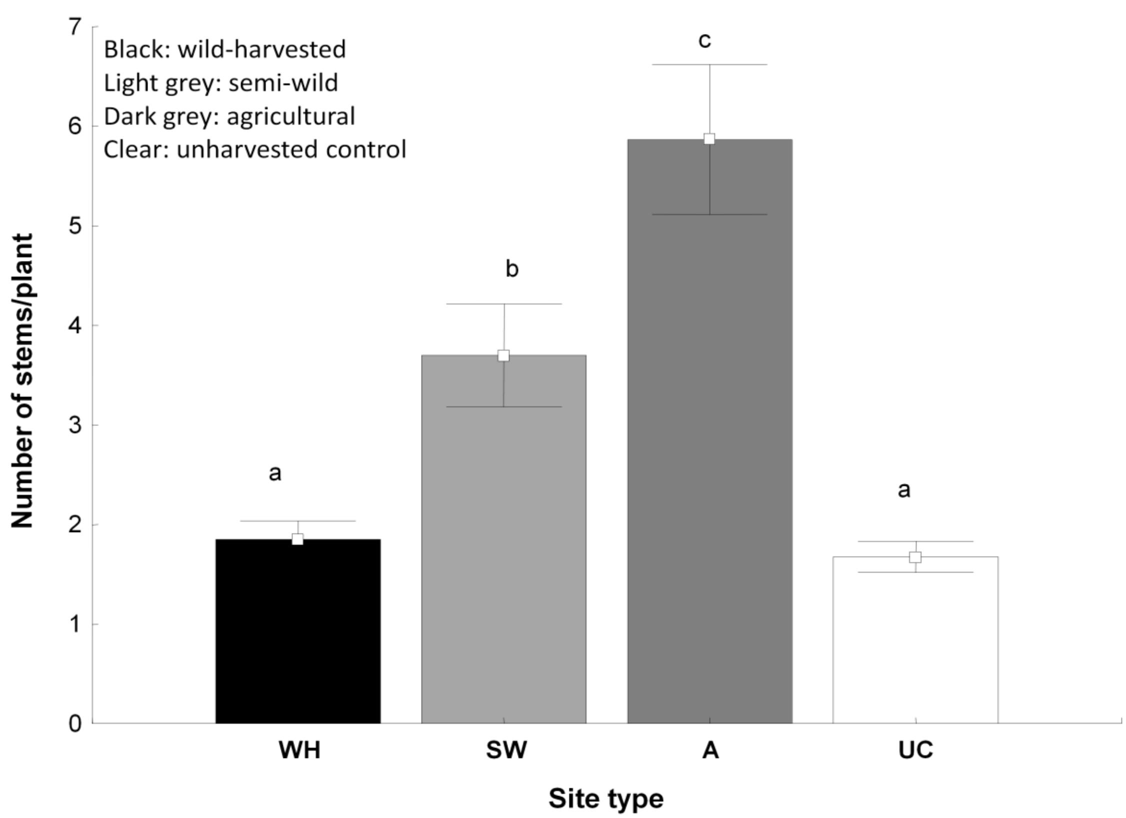


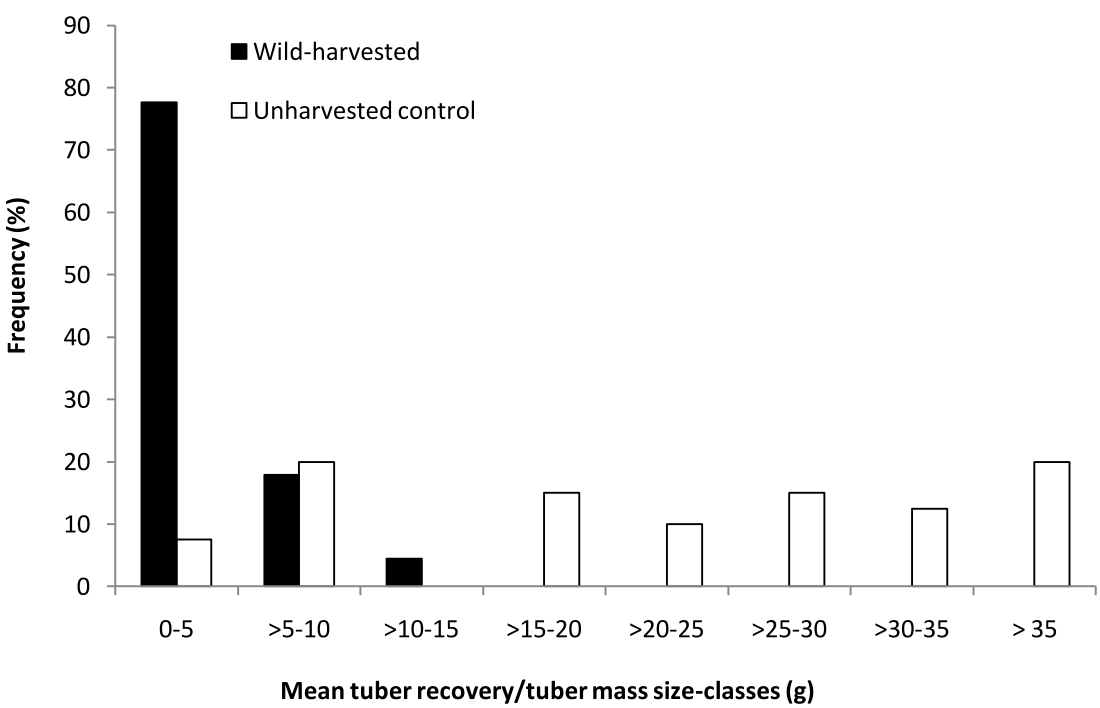
Figure 3.8. Comparisons on the number of stems/plant of Pelargonium sidoides plants when sites were grouped according to site type (WH-wild harvested, SW-semi-wild, A- agricultural and UC- unharvested control sites) in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.1.3. Tuber mass size-classes, tuber colour intensity and distribution across sites

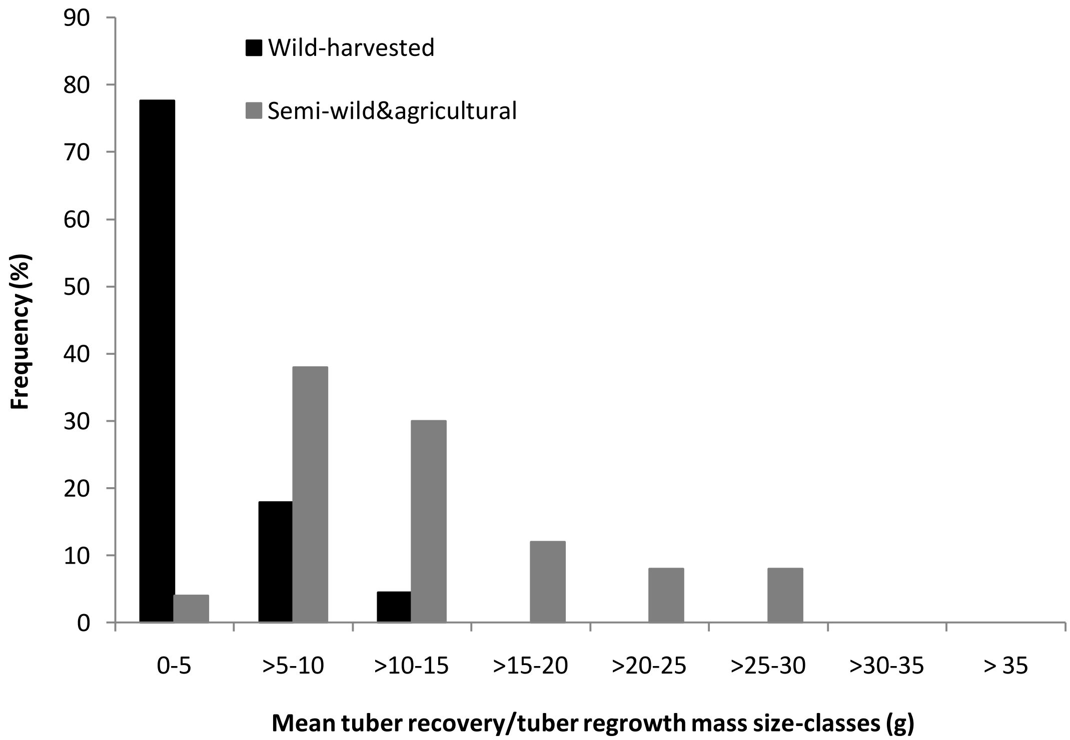
3.4.1.3.1 Tuber mass size-classes across sites

To determine population structure of *P. sidoides* across different types of sites, tuber mass size-class distribution was compared between wild-harvested against unharvested sites, wild-harvested against cultivated sites (semi-wild and agricultural), as well as unharvested against cultivated sites. In wild-harvested sites, most tubers fell into the 0-5 g size-class whereas in unharvested sites, tubers occupied almost all size-classes. There was, no significant difference between tuber mass size-class distribution for wild-harvested sites and unharvested sites (Kolmogorov-Smirnov D =0.625, $P > 0.05$) (Figure 3.9A). However, the distribution tended to be different at $P < 0.10$. Similarly, the tuber mass size-class distribution for wild-harvested sites did not differ significantly to that of cultivated sites (Kolmogorov-Smirnov D =0.375, $P > 0.05$) (Figure 3.9B). Furthermore, comparisons on tuber mass size-class distribution between unharvested and cultivated sites also showed no significant differences (Kolmogorov-Smirnov D =0.375, $P > 0.05$) (Figure 3.9C).

(A)

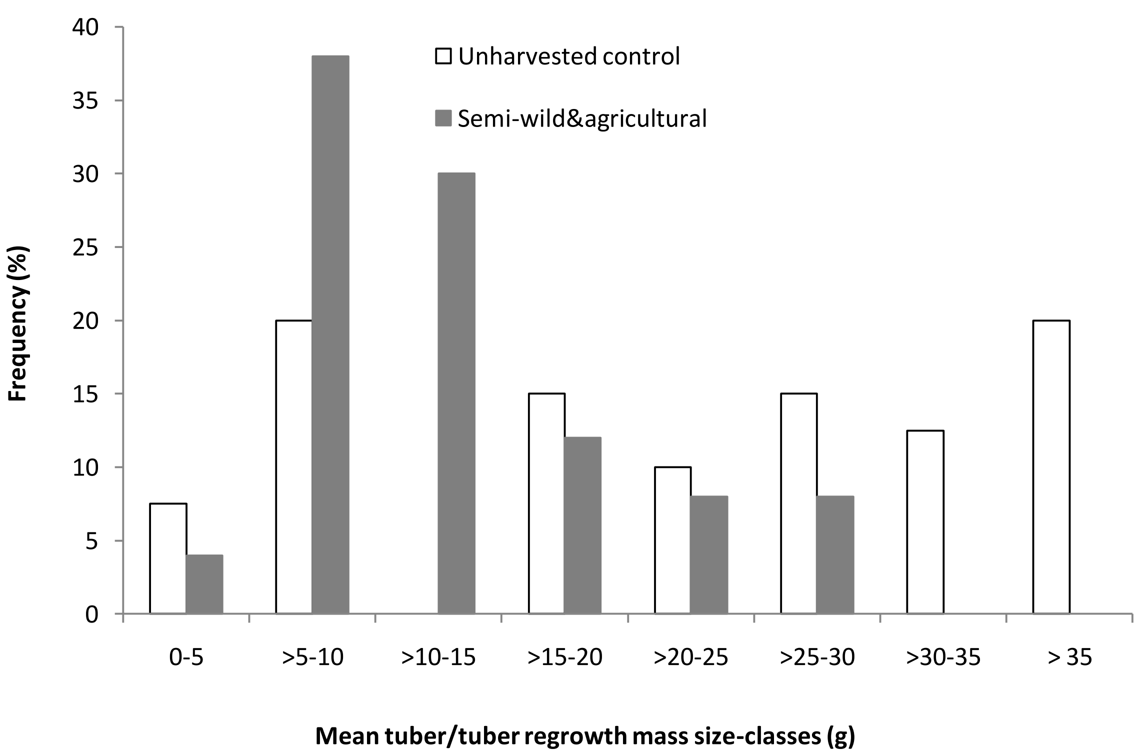


(B)



90
80
70
60
50
40
30
20
10
0
Frequency (%)
Wild-harvested
Semi-wild&agricultural
0-5
>5-10
>10-15
>15-20
>20-25
>25-30
>30-35
> 35
Mean tuber recovery/tuber regrowth mass size-classes (g)

(C)



40
35
30
25
20
15
10
5
0
Frequency (%)
Unharvested control
Semi-wild&agricultural
0-5
>5-10
>10-15
>15-20
>20-25
>25-30
>30-35
> 35
Mean tuber/tuber regrowth mass size-classes (g)

Figure 3.9. Tuber mass size-class distribution of Pelargonium sidoides plants from different types of sites (A-wild-harvested [n = 67] and unharvested control sites [n = 40], B- wild-harvested [n = 67] and cultivated (semi-wild and agricultural sites [n = 50] and C- unharvested [n = 40] and cultivated [n = 50] sites in the "lowveld" vegetation region.

3.4.1.3.2. Comparisons on tuber colour intensity across sites (wild-harvested- tuber recovery, semi-wild- tuber regrowth, agricultural- tuber regrowth and unharvested control sites- tuber)

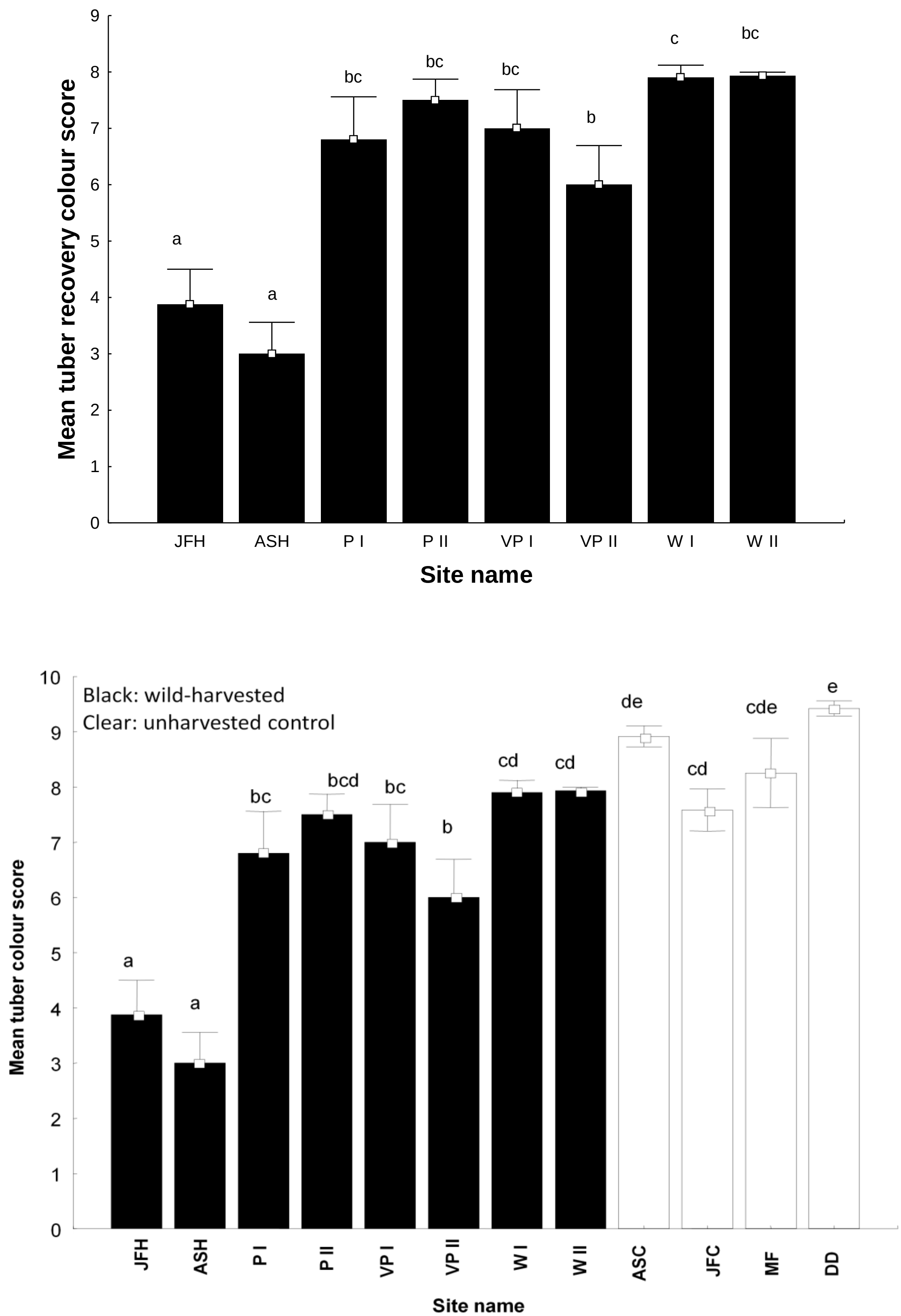
Tuber recovery colour intensity was significantly different across wild-harvested sites ($F_{7,55}$= 14.9177, P < 0.001) (Figure 3.10A). Although plants from W I were found to have tuber recovery colour intensity that was slightly darker than plants from JFH and ASH (Air-strip harvested), this was however, not significantly different.

When comparisons on tuber recovery and tuber colour intensity were made between wild harvested and unharvested control sites, significant differences were found ($F_{11,92}$= 16.1949, P < 0.001) (Figure 3.10B). Plants from unharvested control sites had tuber colour that was significantly more dark-red than plants from wild harvested sites. Of all the unharvested controls, Double-Drift (DD) had more dark-red tubers than all the other sites although this tuber colour intensity was not significantly different from that in other unharvested control sites.

There was a significant difference in tuber regrowth colour intensity between semi-wild and agricultural sites ($F_{4,45}$= 9.6196, P < 0.001) (Figure 3.10C). STA and STS were found to have plants with significantly darker coloured tuber regrowth than plants from the other sites except for RH II. This implies that the more time the plants are in cultivation, the darker the tuber regrowth colour.

A significant difference in tuber recovery, tuber regrowth and tuber colour intensity was found across all sites ($F_{16,137}$= 39.2169, P < 0.001) (Figure 3.10D). Thus plants from unharvested control sites were found to have significantly dark coloured tuber colour intensity than plants from the other sites. DD was found to have significantly darker tuber colour intensity than all the other sites.

(A)

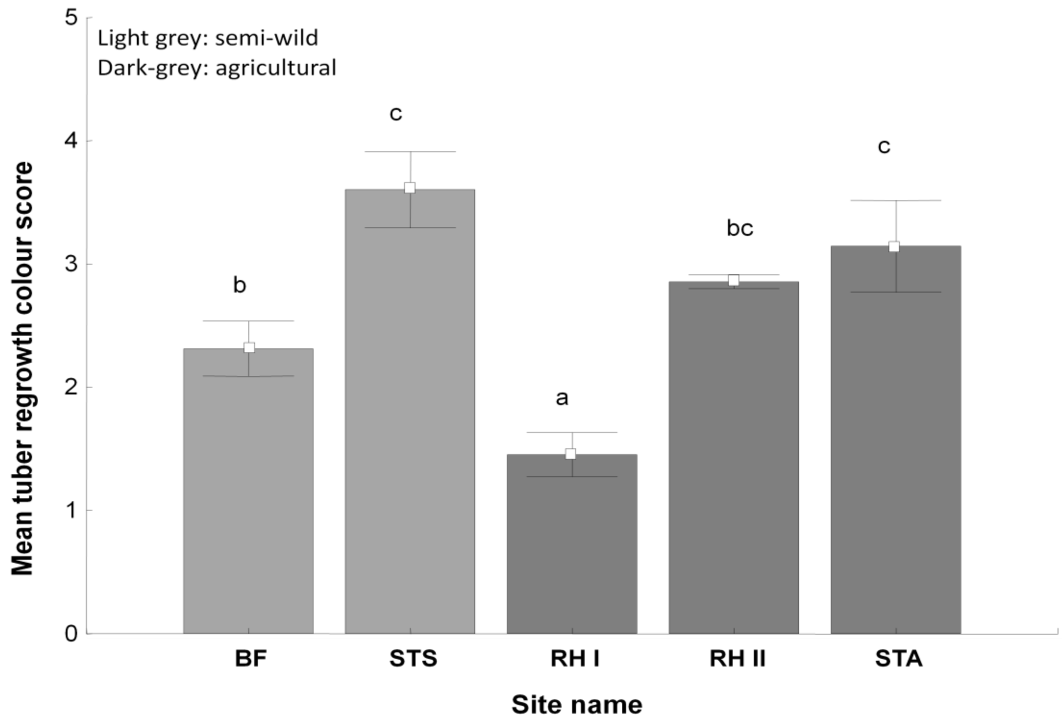


Mean tuber recovery colour score
0
1
2
3
4
5
6
7
8
9
a
a
bc
bc
bc
b
c
bc
JFH
ASH
P I
P II
VP I
VP II
W I
W II
Site name

(B)

Black: wild-harvested
Clear: unharvested control
Mean tuber colour score
0
1
2
3
4
5
6
7
8
9
10
a
a
bc
bcd
bc
b
cd
cd
de
cd
cde
e
JFH
ASH
P I
P II
VP I
VP II
W I
W II
ASC
JFC
MF
DD
Site name

(C)


Light grey: semi-wild
Dark-grey: agricultural
Mean tuber regrowth colour score
0
1
2
3
4
5
b
c
a
bc
c
BF
STS
RH I
RH II
STA
Site name

(D)

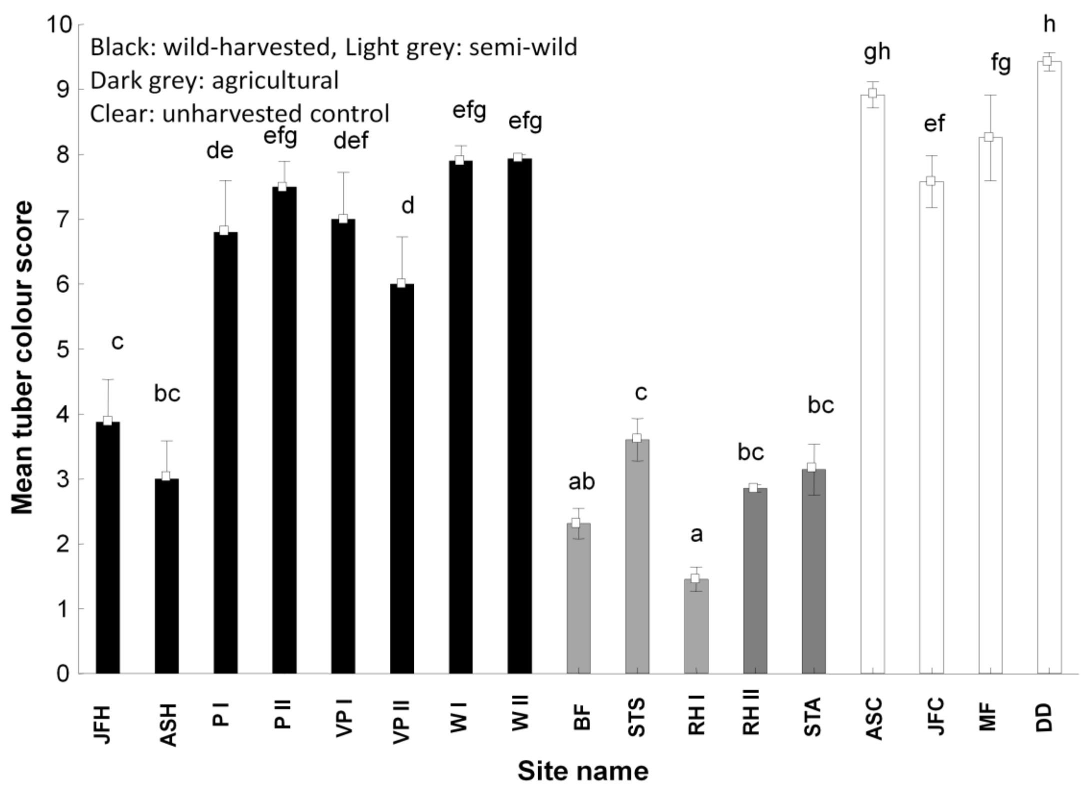

Black: wild-harvested, Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber colour score
0
1
2
3
4
5
6
7
8
9
10
c
bc
de
efg
def
d
efg
efg
ab
c
a
bc
bc
gh
ef
fg
h
JFH
ASH
P I
P II
VP I
VP II
W I
W II
BF
STS
RH I
RH II
STA
ASC
JFC
MF
DD
Site name

Figure 3.10. Comparisons on tuber recovery, tuber regrowth and tuber colour intensity in wild harvested sites (A= ASH= Airstrip harvested, P I= Peddie I, P II= Peddie II, VP I= Victoria Post I, VP II= Victoria Post II, W I= Wesley I and W II= Wesley II), wild harvested and unharvested control sites (B= unharvested control sites- ASC= Airstrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift), semi-wild and agricultural sites (C= Semi-wild - BF= Bold farm, STS= Stutterheim semi-wild and agricultural- RH I= Rhodes I, RH II= Rhodes II and Stutterheim agricultural) and all types of sites in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.1 for site ages (Chapter 2, Section 2.3.1.1.).

3.4.1.3.3. Comparisons on tuber colour intensity when sites are grouped according to site type (wild-harvested (WH)- tuber recovery, semi-wild (SW)- tuber regrowth, agricultural (A)- tuber regrowth and unharvested control (UC)- tuber sites)

There was a significant difference in tuber colour intensity when sites were grouped according to site type ($F_{3,150}$= 75.4811, P < 0.001) (Figure 3.11). As expected, the unharvested control sites had tubers that were on average darker than the rest of the sites. On the other hand, plants from wild-harvested sites had significantly dark-coloured tuber recovery than tuber regrowth in semi-wild and agricultural sites.

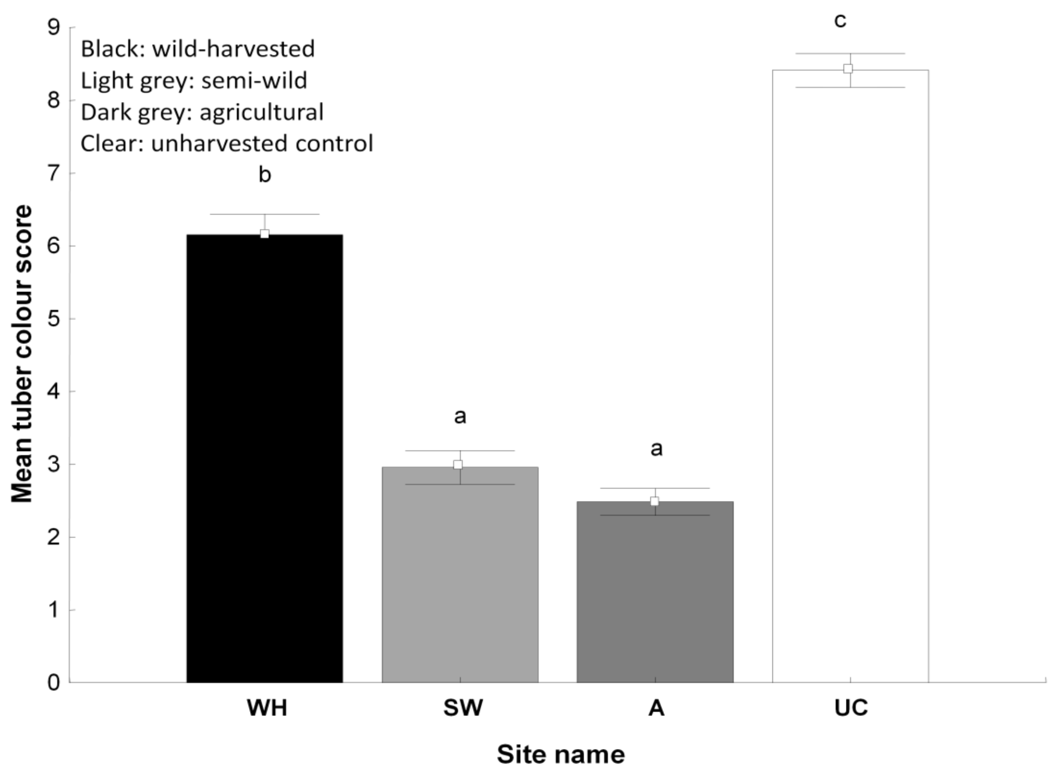


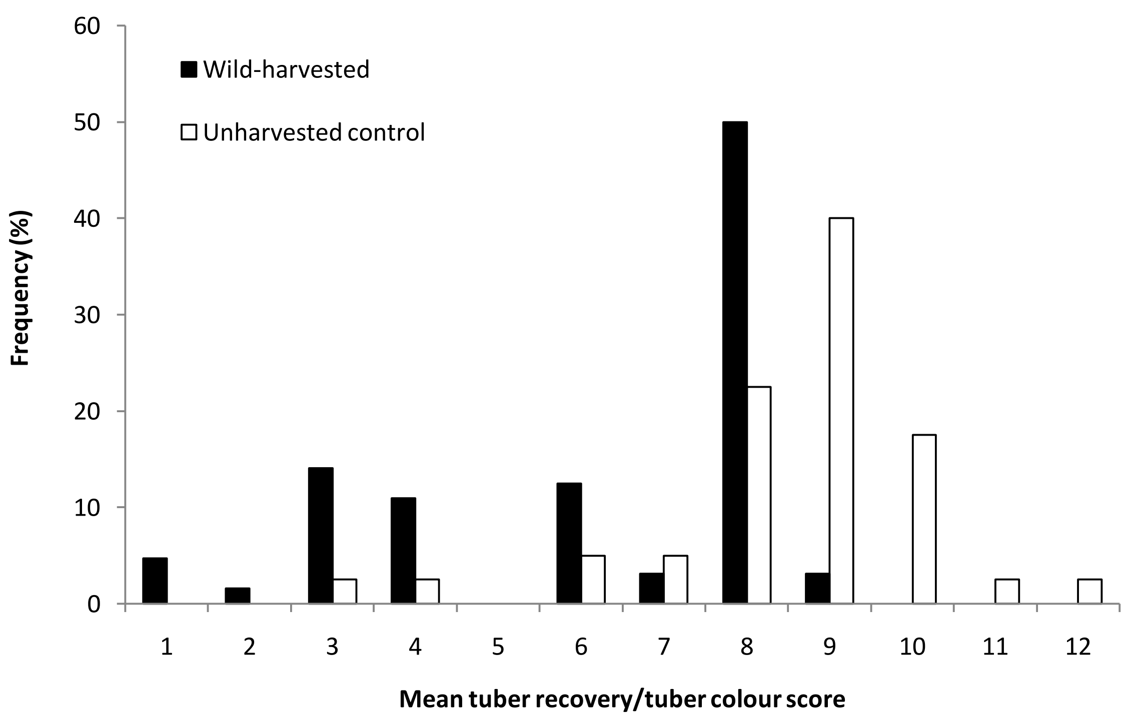
Figure 3.11. Comparisons on tuber recovery, tuber regrowth and tuber colour intensity when sites were grouped according to site type ((WH-wild harvested, SW-semi-wild, A- agricultural and UC- unharvested control sites) in the "lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.1.3.4. Tuber colour distribution across sites

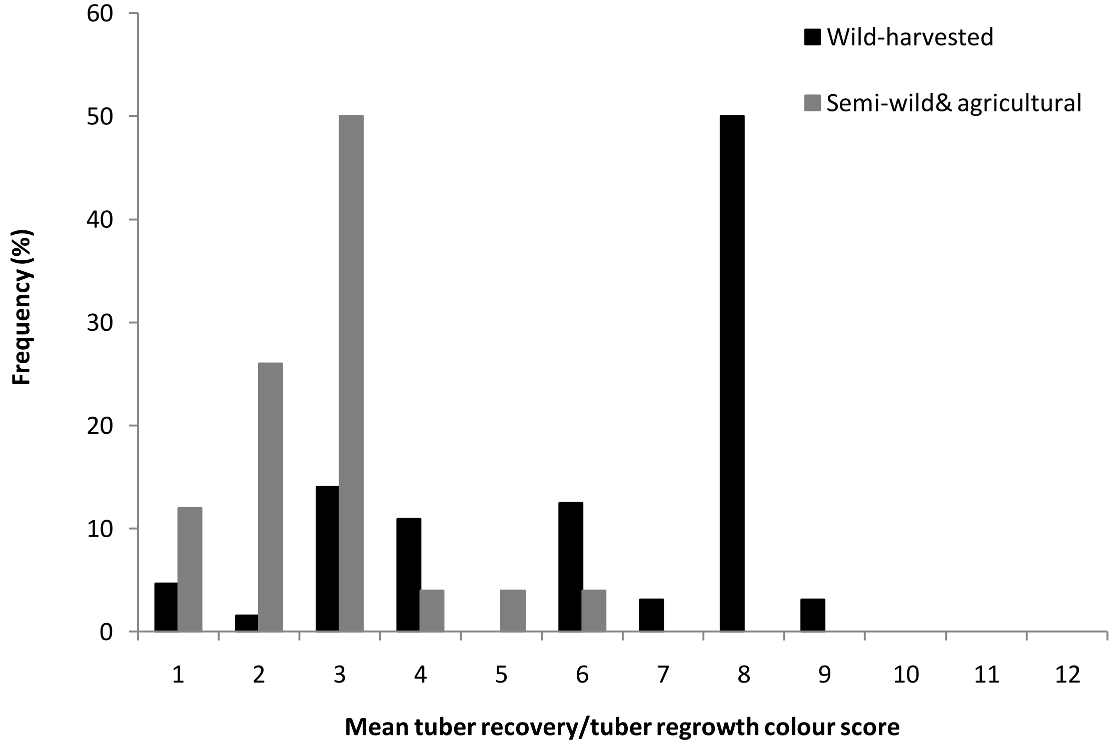
It was hypothesized that tuber colour is unevenly distributed between different types of sites, with more pale coloured tubers in previously wild-harvested sites compared to unharvested sites which have more dark-coloured tubers. To test this, comparisons on distribution of different tuber colours ranging in increasing intensity from 1 to 12 were made between site types. There was no significant difference in tuber colour between previously wild-harvested sites and unharvested sites (Figure 3.12A) (Kolmogorov-Smirnov, D =0.1667, P > 0.05). Similarly, significant differences in tuber colour distribution could not be detected between wild-harvested and cultivated (semi-wild and agricultural) sites (Figure 3.12B) (Kolmogorov-Smirnov, D =0.1859, P > 0.05). In the same manner, comparisons between unharvested and cultivated sites did not yield significant results (Figure 3.12C) (Kolmogorov-Smirnov, D =0.2115, P > 0.05).

Although no statistical analysis was done on comparing tuber colour distribution per site due to limited sites, the distribution was constructed and displayed graphically (Figure 3.12D).

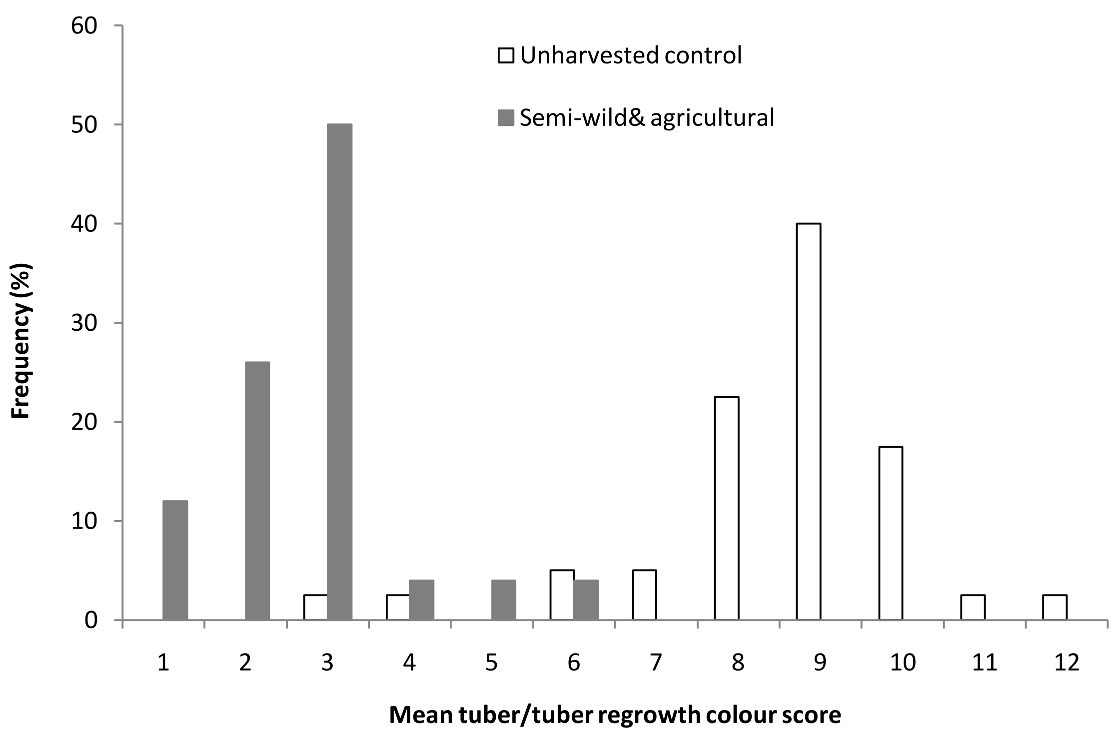
(A)



(B)


Frequency (%)
0
10
20
30
40
50
60
Wild-harvested
Semi-wild& agricultural
1
2
3
4
5
6
7
8
9
10
11
12
Mean tuber recovery/tuber regrowth colour score

(C)


Frequency (%)
0
10
20
30
40
50
60
Unharvested control
Semi-wild& agricultural
1
2
3
4
5
6
7
8
9
10
11
12
Mean tuber/tuber regrowth colour score

(D)

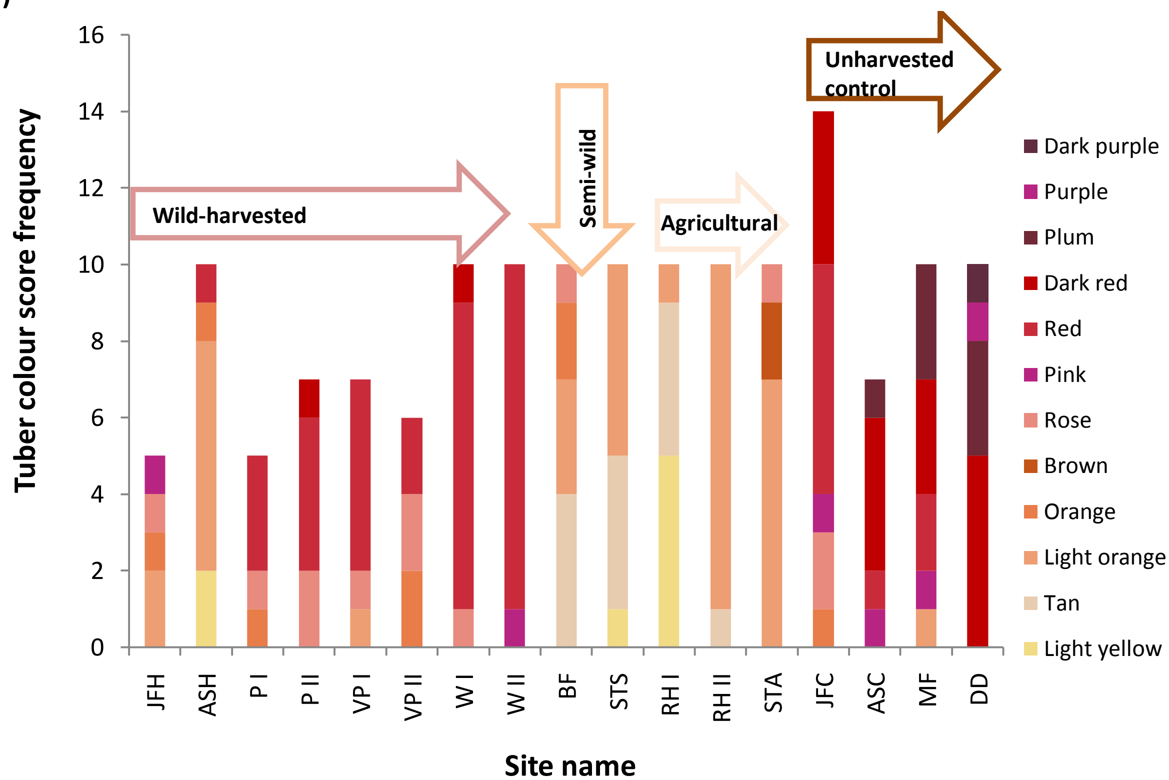


Figure 3.12. Comparison on tuber recovery, tuber regrowth and tuber colour distribution of Pelargonium sidoides plants between different types of sites (A- wild harvested [n = 67] and unharvested control sites [n = 40], B- wild-harvested [n = 67] and cultivated (semi-wild and agricultural sites [n = 50] and C- unharvested [n = 40] and cultivated [n = 50] sites in the "lowveld" vegetation region. D- tuber colour frequency/colour score/site in wild harvested sites- ASH= Airstrip harvested, P I= Peddie I, P II= Peddie II, VP I= Victoria Post I, VP II= Victoria Post II, W I= Wesley I and W II= Wesley II, semi-wild sites- BF= Bold farm, STS= Stutterheim semi-wild, agricultural- RH I= Rhodes I, RH II= Rhodes II and STA= Stutterheim agricultural, unharvested control sites- ASC= Airstrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift, in the "lowveld" vegetation region. Refer to Table 2.1 for site ages (Chapter 2, Section 2.3.1.1.).

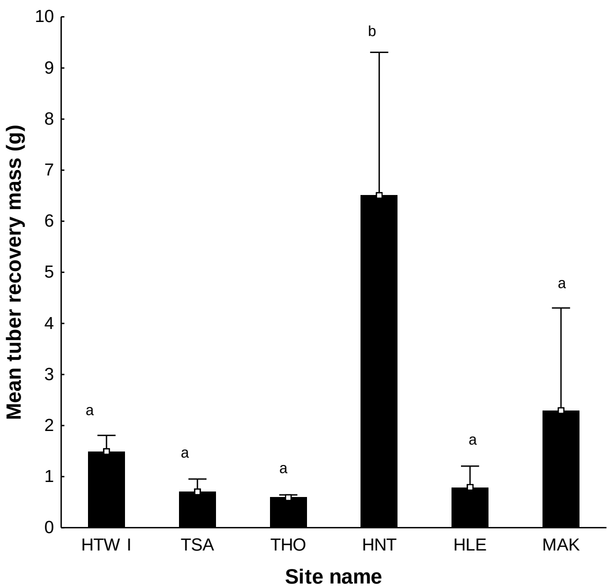
3.4.2. "Highveld" vegetation region

3.4.2.1. Below-ground plant growth across sites

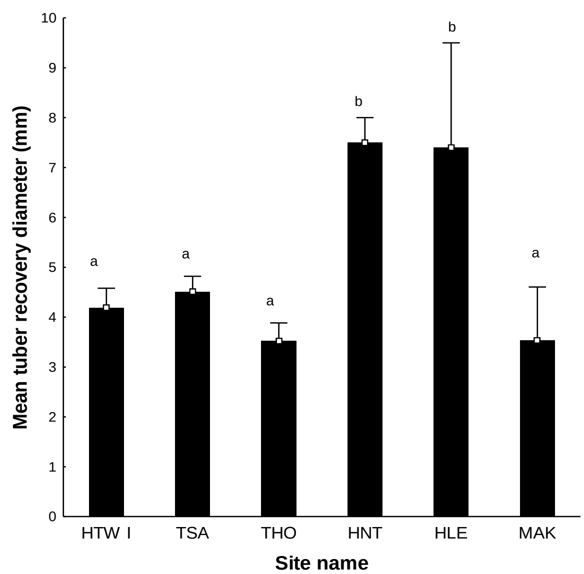
3.4.2.1.1. Comparisons on tuber recovery size in wild-harvested sites

Tuber recovery size was compared across wild-harvested sites of differing times since last harvest. A significant difference in mean tuber recovery mass was observed across sites ($F_{5,15}$= 3.7634, P < 0.028) (Figure 3.13A). Although HNT (Ha Ntho) was last harvested 1 year ago, it was found to have plants that had significantly larger mean tuber recovery mass than plants from the other sites. Additionally, when comparing tuber size using mean tuber recovery diameter, a significant difference was detected across sites ($F_{5,15}$= 4.1981, P = 0.001) (Figure 3.13B). Plants from HLE (Ha Lebelonyane) had significantly larger tuber recovery diameter than plants from the other sites. This was probably because plants from this site were last harvested 3 years ago. In contrast, plants from HTW I (Ha Thlaku) had larger mean tuber recovery length than plants from some sites (TSA- Tsatsane and HLE) although this was not significantly different to plants from THO, HNT and MAK (Makhoakhoeng). Furthermore, there was a significant difference in tuber recovery size across sites when comparing sites based on mean tuber recovery volume ($F_{5,15}$= 6.0373, P = 0.003) (Figure 3.13C). As expected, plants from HNT had significantly larger tuber recovery volume than plants from the other sites.

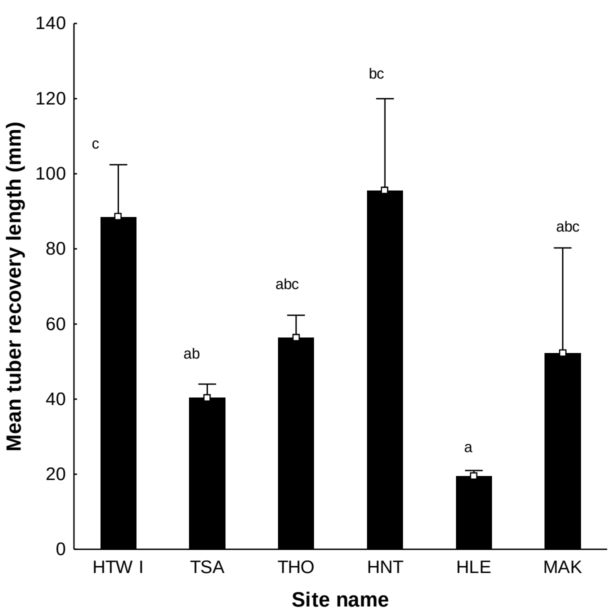
(A)



(B)



(C)



(D)

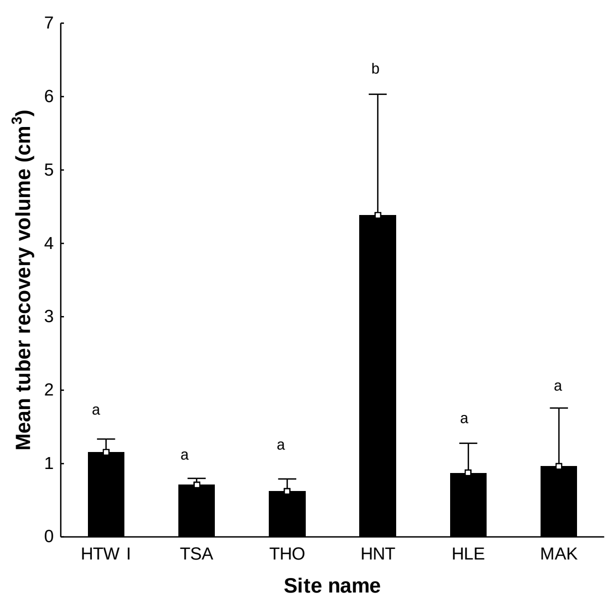


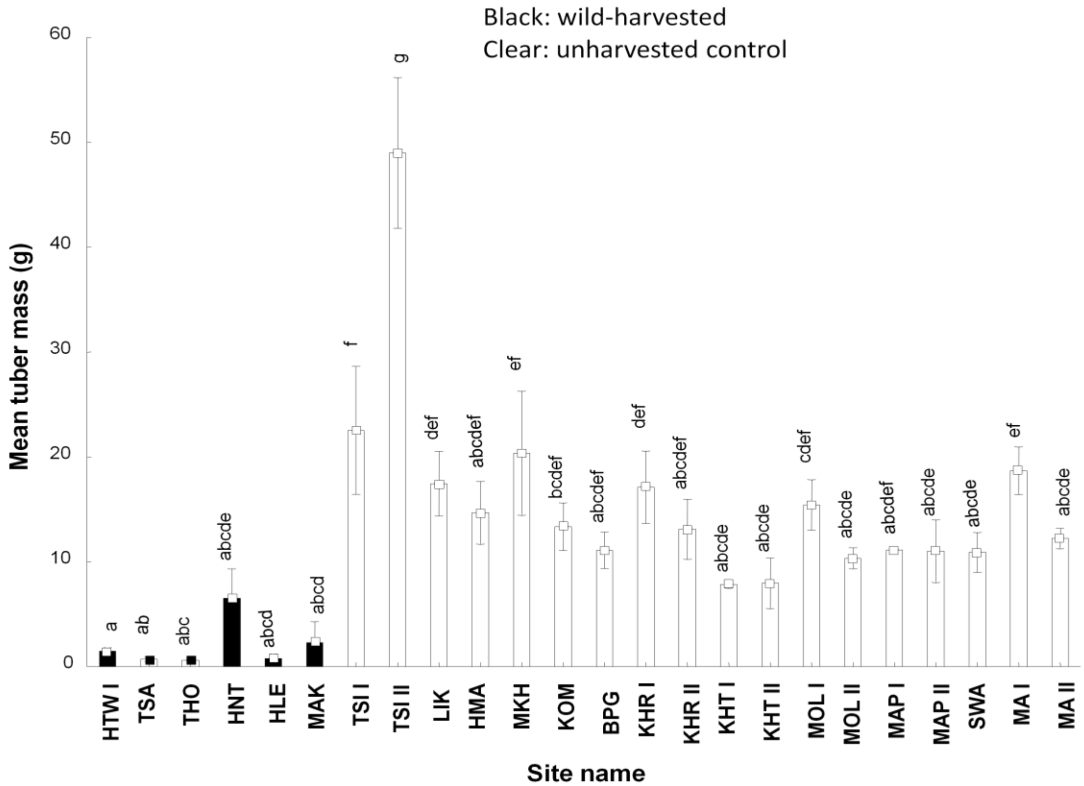
Figure 3.13. Comparisons of post-harvest tuber recovery size (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in wild-harvested sites of differing ages in the "highveld" vegetation region (HTW I= Ha Tlhaku wild (2 years), TSA= Tsatsane (2 years), THO= Thoteng (1 year), HNT= Ha Nthunya (1 year), HLE= Ha Lebelonyane (3 years), MAK= Makhoakhoeng (3 years)). Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

Slightly different results were found when tuber size was compared using total tuber size values (Appendix 1, Figure 3.13). For example, there was no significant difference detected across sites when comparisons were based on tuber diameter.

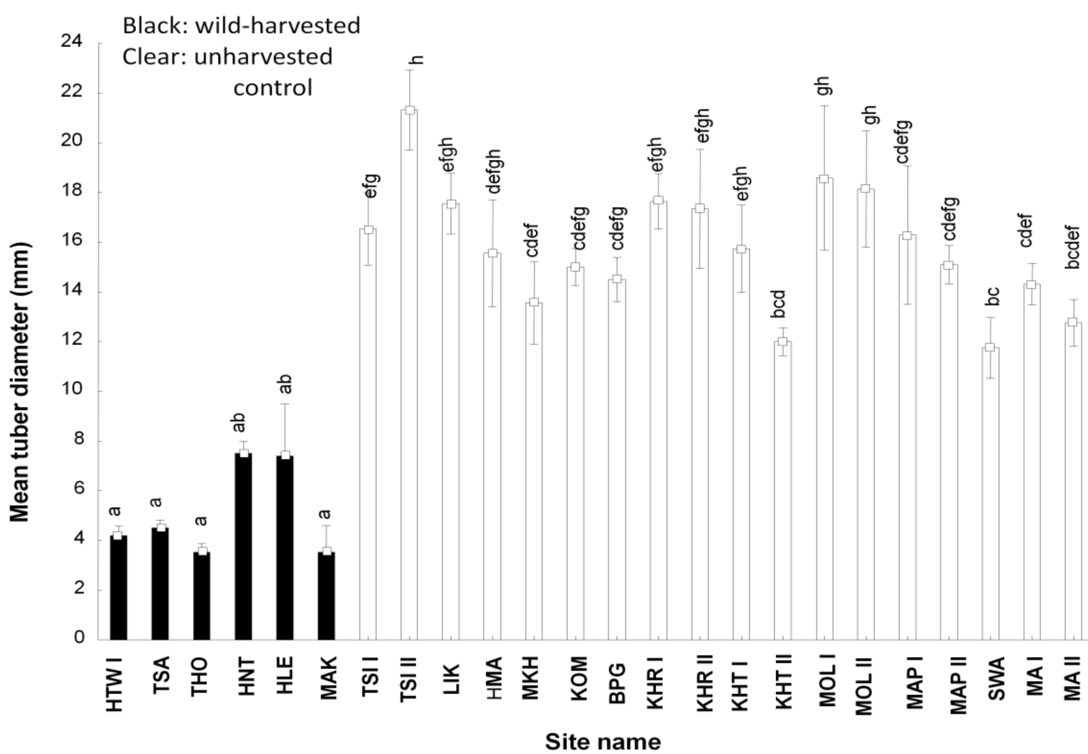
3.4.2.1.2. Comparisons on tuber recovery and tuber size in wild-harvested and unharvested control sites

To determine the impact of harvesting on tuber recovery of *P. sidoides* plants, tuber size was compared between previously wild-harvested sites and unharvested control sites. Mean tuber mass was found to be significantly different between wild-harvested and unharvested control sites ($F_{23,99}$= 7.0519, P < 0.001) (Figure 3.14A). Some unharvested control sites tended to have tubers that were significantly larger in tuber mass than tubers from wild-harvested sites. However, tubers from most unharvested control sites were not significantly larger in tuber mass than tubers from wild-harvested sites. Of all the unharvested control sites, TSI II had plants with tubers that had significantly larger mean tuber mass than plants from the other unharvested control sites and wild-harvested sites. On the other hand, when tuber size was compared based on mean tuber diameter, all unharvested control sites (except for KHT II- Katse Ha Theko and SWA- Swaartkop) tended to have plants that had significantly larger tuber diameter than plants from unharvested control sites ($F_{23,99}$= 10.3421, P < 0.001) (Figure 3.14B). Furthermore, tuber size was compared using mean tuber length and significant difference across sites were detected ($F_{23,99}$= 5.1941, P < 0.001) (Figure 3.14C). However, there was no obvious pattern observed. For instance, although TSI II was found to have plants with longer tubers, these were not significantly different to tubers obtained from other two wild-harvested sites (HTW I and HNT). Moreover, tubers from HTW I and HNT were significantly longer than tubers from most unharvested control sites. Similarly, although unharvested control sites had plants with larger mean tuber volume than plants from wild-harvested sites, this was not significantly different to mean tuber volume of plants from wild-harvested sites ($F_{23,99}$= 5.8808, P < 0.001) (Figure 3.14D). However, TSI II had plants with significantly larger mean tuber volume than plants from other unharvested control sites and wild-harvested sites.

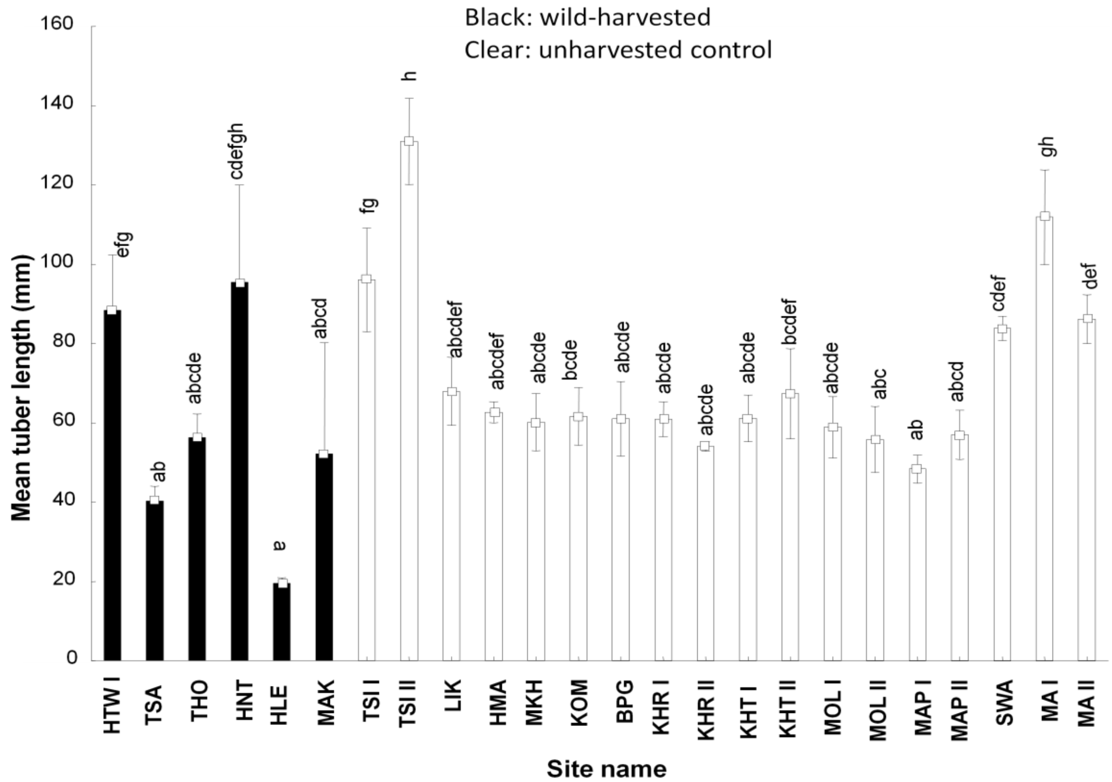
(A)


Black: wild-harvested
Clear: unharvested control
Mean tuber mass (g)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

(B)


Black: wild-harvested
Clear: unharvested control
Mean tuber diameter (mm)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

(C)


Black: wild-harvested
Clear: unharvested control
Mean tuber length (mm)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

(D)

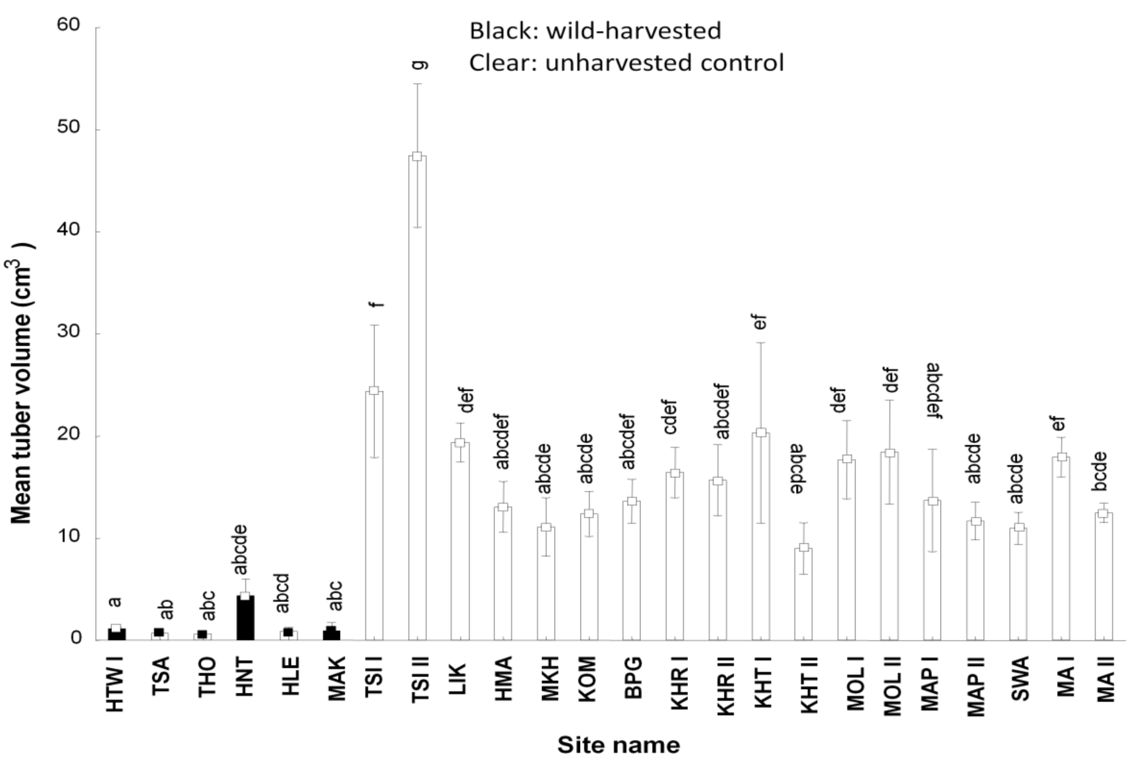

Black: wild-harvested
Clear: unharvested control
Mean tuber volume (cm^3)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

Figure 3.14. Comparisons tuber recovery and tuber size of Pelargonium sidoides in wild-harvested sites of differing ages (HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng) and unharvested control sites (TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II) in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.2 for site ages (Chapter 2, Section 2.3.1.2.).

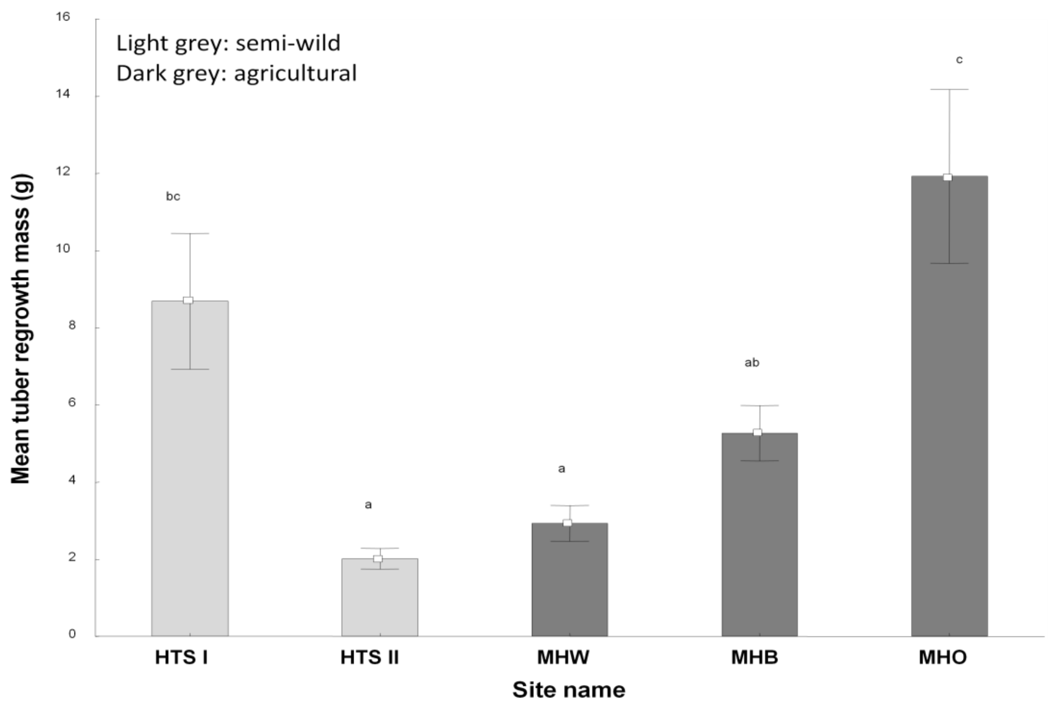
The results obtained above using mean tuber size values differed from those found when using total tuber size values (Appendix 1, Figure 3.14). For instance, plants from MKH (unharvested control site) were found to have significantly larger total tuber mass than plants from the other unharvested control sites and wild-harvested sites. However, total tuber mass of plants from MKH was not significantly larger than that of plants from TSI II. Furthermore, MOL II (Molumong II) had plants with largest total tuber diameter than other unharvested control sites (except HMA- Ha Matsa, KOM- Koma-koma, KHR I- Katse Ha Ramokoatsi I, MOL I- Molumong I and MAP II- Mapholaneng II) and wild-harvested sites. When comparing sites based on total tuber length, HMA had plants with longer tubers than plants from other few unharvested control sites and wild-harvested sites. Lastly, plants from MOL II had larger total tuber volume than plants from some unharvested control sites and wild-harvested sites. The inconsistency in the results may have been caused by unequal number of tubers/plant of different sites.

3.4.2.1.3. Comparisons on tuber regrowth size in semi-wild and agricultural sites

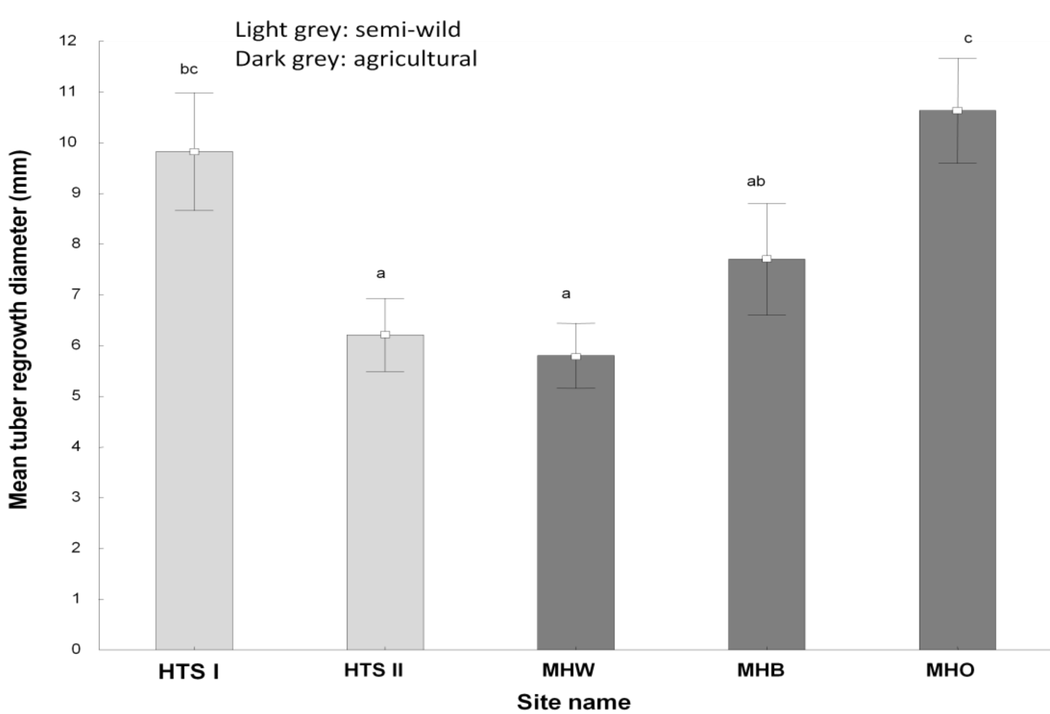
Comparison on tuber regrowth size was made between semi-wild and agricultural sites to investigate whether tuber regrowth size varied. There was a significant difference in mean tuber regrowth mass observed ($F_{4,40}$= 8.7809, P < 0.001) (Figure 3.15A). Plants from MHO (Mohale's Hoek open- agricultural) were found to have larger tuber regrowth than plants from other sites, however, this was not significantly different from plants obtained from HTS I (semi-wild). Similarly, MHO had larger mean tuber regrowth diameter than other agricultural and semi-wild sites, however, this was not significantly different from mean tuber regrowth diameter of plants from HTS I ($F_{4,40}$= 5.1141, P = 0.003) (Figure 3.15B). Additionally, there was a significant difference in mean tuber regrowth length across semi-wild and agricultural sites ($F_{4,40}$= 3.3246, P = 0.019) (Figure 3.15C). All agricultural sites as well as one semi-wild (HTS I) site had significantly longer tuber regrowth than plants from HTS II (Ha Tlhaku II). Mean tuber regrowth volume was also significantly different across sites ($F_{4,40}$= 8.5184, P < 0.001) (Figure

3.15D). Likewise, MHO and HTS I had plants with significantly larger tuber regrowth volume than plants from other sites.

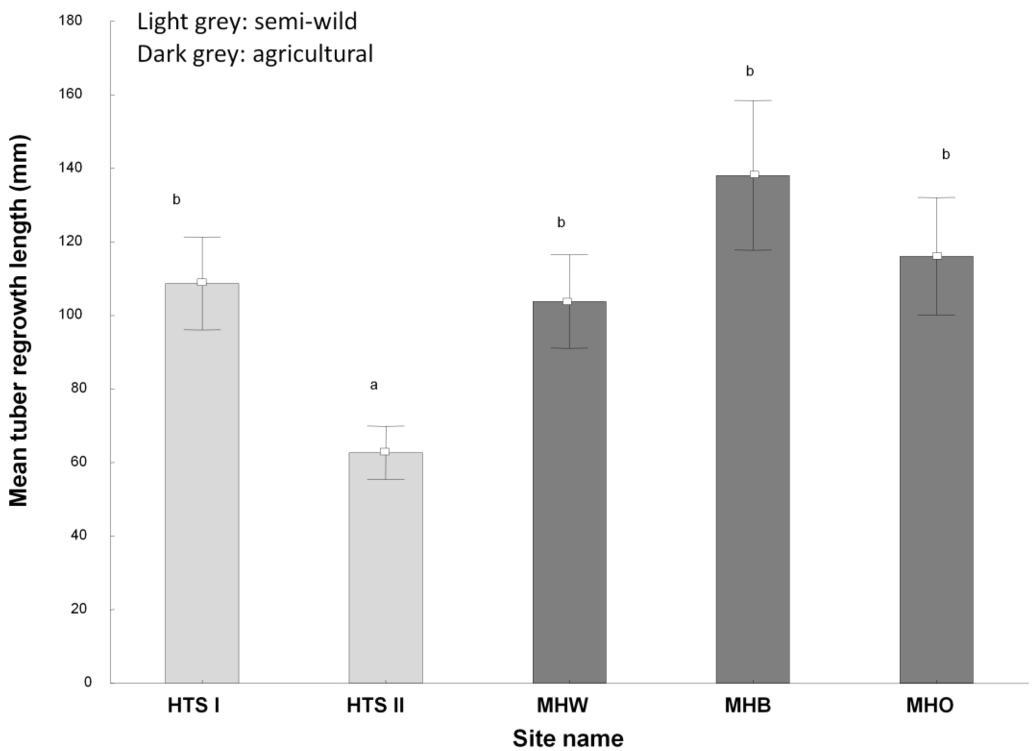
(A)



(B)



(C)


Light grey: semi-wild
Dark grey: agricultural
Mean tuber regrowth length (mm)
180
160
140
120
100
80
60
40
20
0
b
a
b
b
b
HTS I
HTS II
MHW
MHB
MHO
Site name

(D)

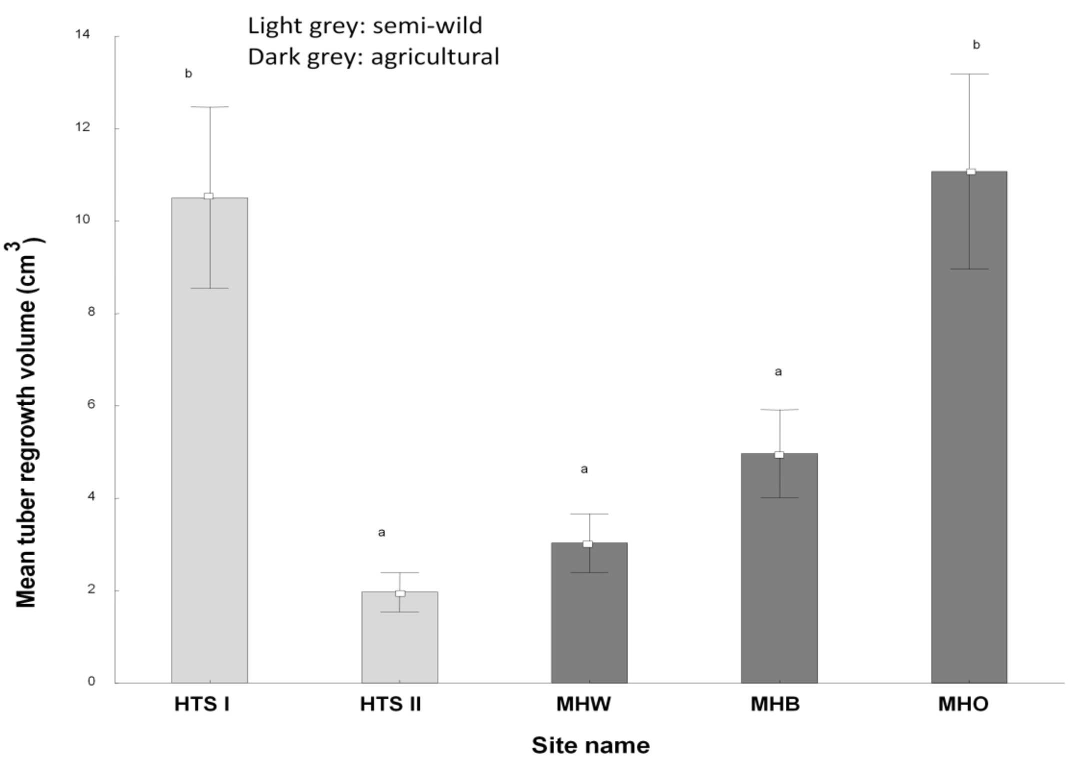

Light grey: semi-wild
Dark grey: agricultural
Mean tuber regrowth volume (cm^3)
14
12
10
8
6
4
2
0
b
a
a
a
b
HTS I
HTS II
MHW
MHB
MHO
Site name

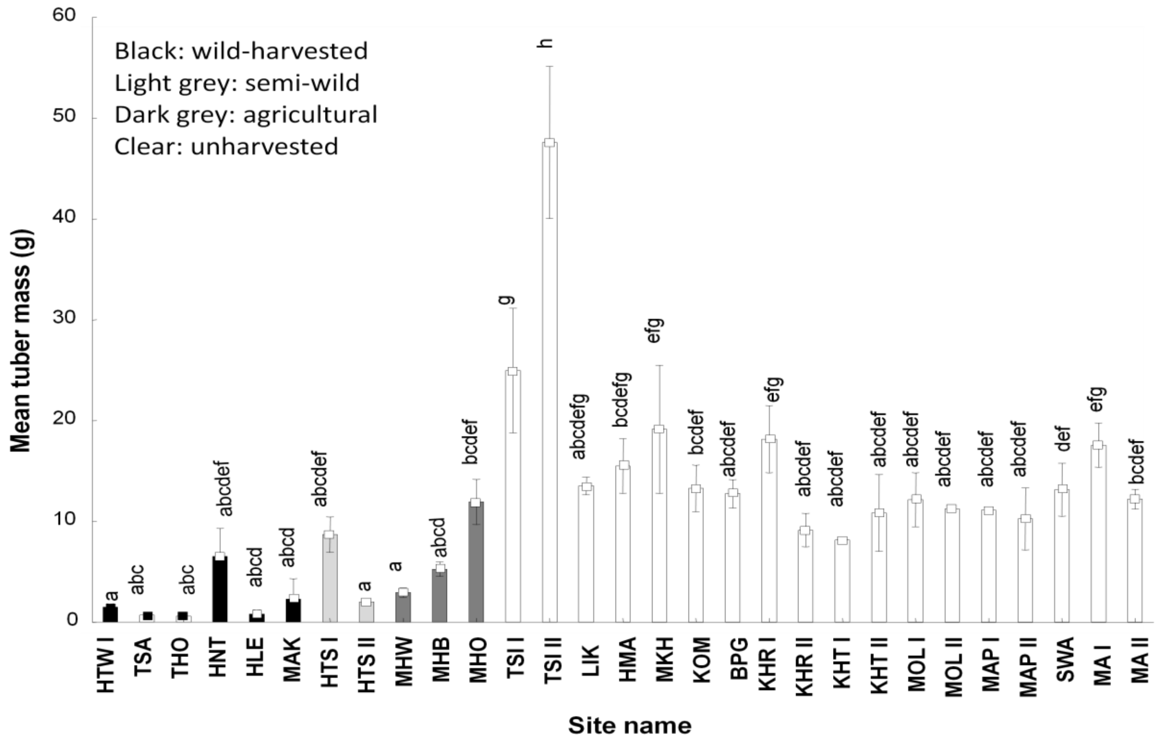
Figure 3.15. Comparisons of tuber regrowth size (A= tuber regrowth mass, B= tuber regrowth diameter, C= tuber regrowth length, D= tuber regrowth volume) of Pelargonium sidoides plants in semi-wild (HTS I= Ha Tlhaku I (2 years), HTS II= Ha Tlhaku II (1 year), and agricultural sites (MHW= Mohale's Hoek white (0.5 years), MHB= Mohale's Hoek black (0.5 years), MHO= Mohale's Hoek open (1 year)) of differing ages in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

Nevertheless, using total tuber size values to compare sites produced minor differences (Appendix 1, Figure 3.15). For example, only HTS I was found to have plants with significantly larger tuber regrowth than all the other sites. This was the case when tuber regrowth size was measured based on tuber rgrowth mass, tuber regrowth diameter, tuber regrowth length and tuber regrowth volume. This was probably the case because HTS I was longest in cultivation as compared to all the other sites and had more tubers/plant than other sites.

3.4.2.1.4. Comparisons on tuber recovery, tuber regrowth and tuber size across all types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

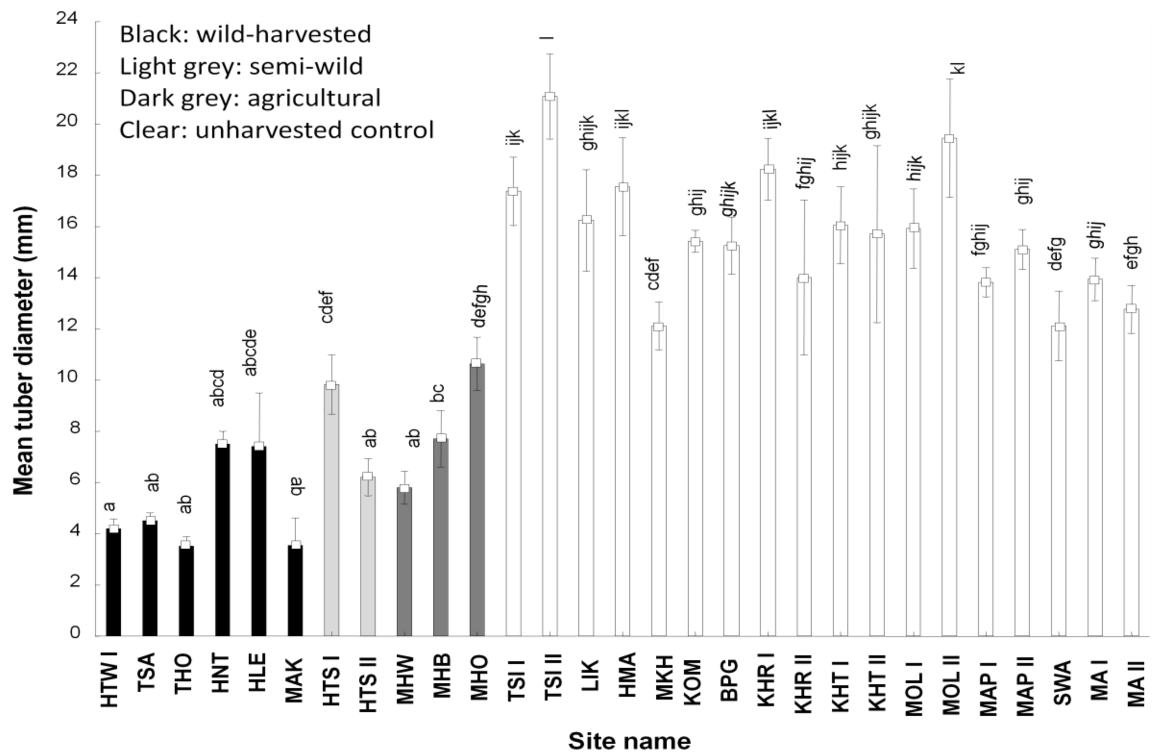
To investigate how tuber size varies across different management regimes, comparisons were made across all types of sites. There was a highly significant difference found in mean tuber mass across sites ($F_{28,138}$= 7.9993, $P < 0.001$) (Figure 3.16A). Although this was not detected in all sites, unharvested control sites tended to have plants with significantly larger tuber mass than plants from other types of sites. Plants from TSI II had significantly larger tuber mass than plants from all other sites. Similarly, when comparisons on tuber size were based on mean tuber diameter, unharvested control sites had plants with significantly larger tuber diameter than plants from other site types ($F_{28,138}$= 13.3518, $P <$ 0.001) (Figure 3.16B). Additionally, tuber size was compared using mean tuber length and significant difference across sites was observed ($F_{28,138}$= 4.7816, $P < 0.001$) (Figure 3.16C). However, although no obvious pattern was evident, agricultural sites had longer tubers than all the other site types. For example, while HTS I was found to have larger tubers than all the other site types, this was not significantly different to mean tuber length of sites from some of the wild-harvested and unharvested control sites. However, unharvested control sites had significantly larger mean tuber volume than plants from other types of sites ($F_{28,138}$= 7.4373, $P < 0.001$) (Figure 3.16D) although this was not the case with other unharvested control sites.

(A)



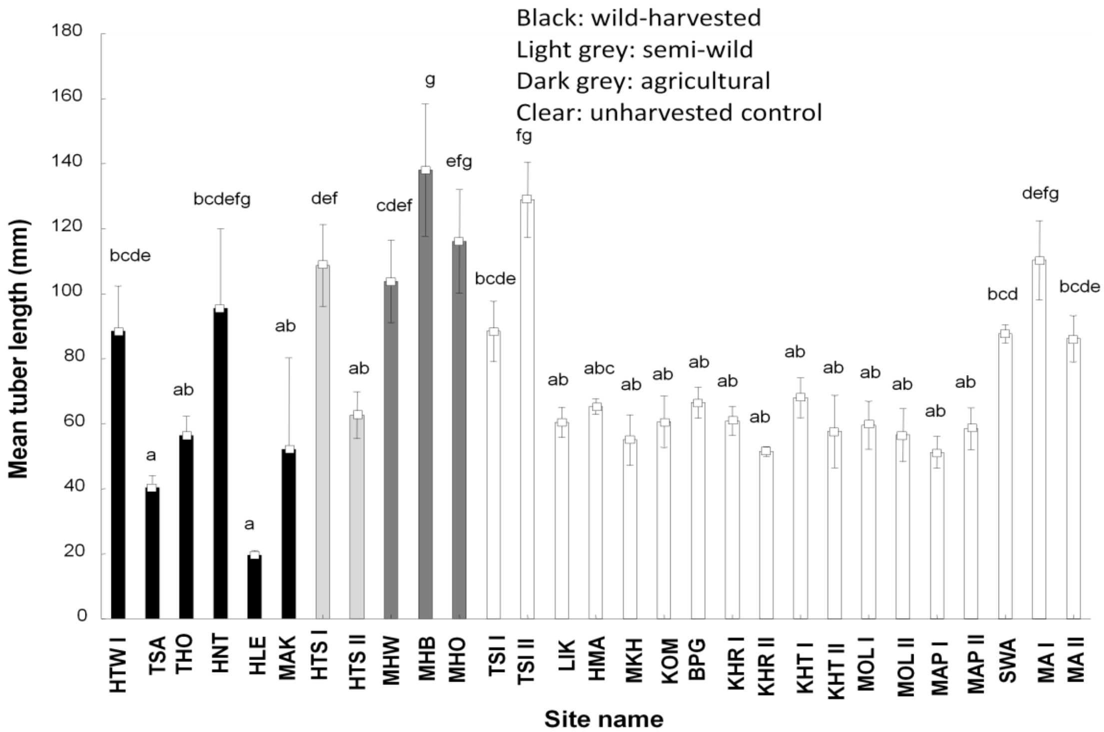
Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested
Mean tuber mass (g)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
HTS I
HTS II
MHW
MHB
MHO
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

(B)



Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber diameter (mm)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
HTS I
HTS II
MHW
MHB
MHO
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

(C)


Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber length (mm)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
HTS I
HTS II
MHW
MHB
MHO
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

(D)

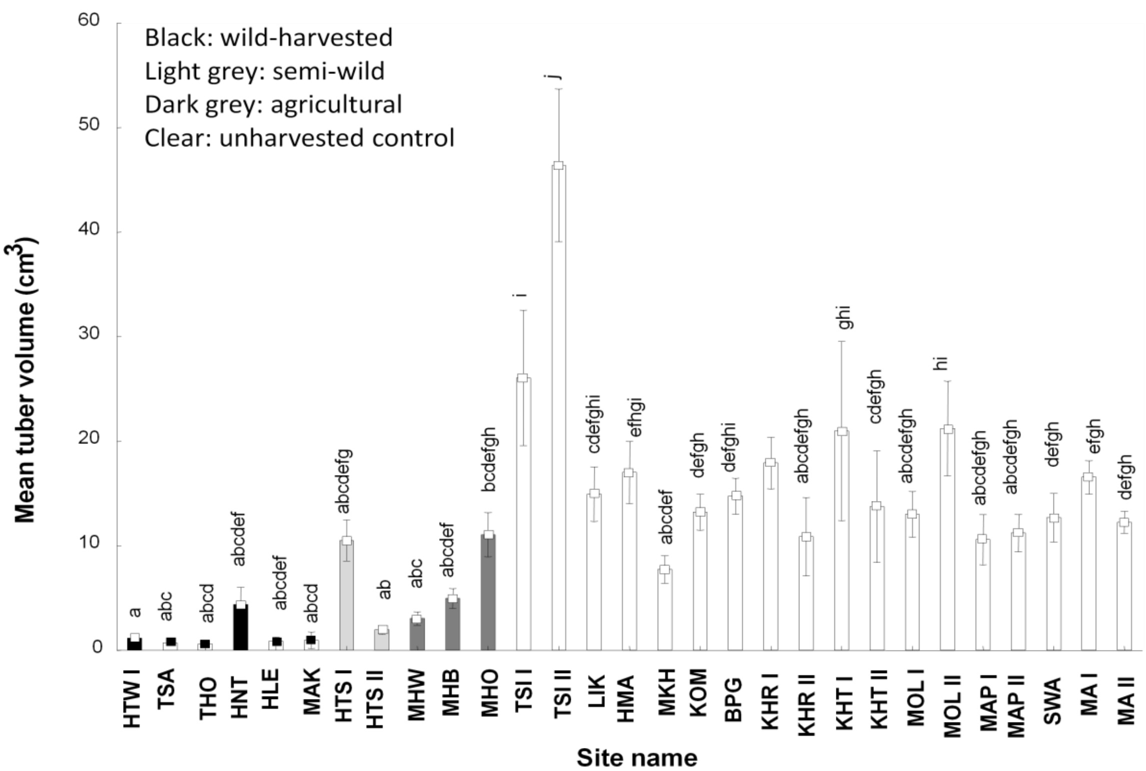

Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber volume (cm3)
Site name
HTW I
TSA
THO
HNT
HLE
MAK
HTS I
HTS II
MHW
MHB
MHO
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II

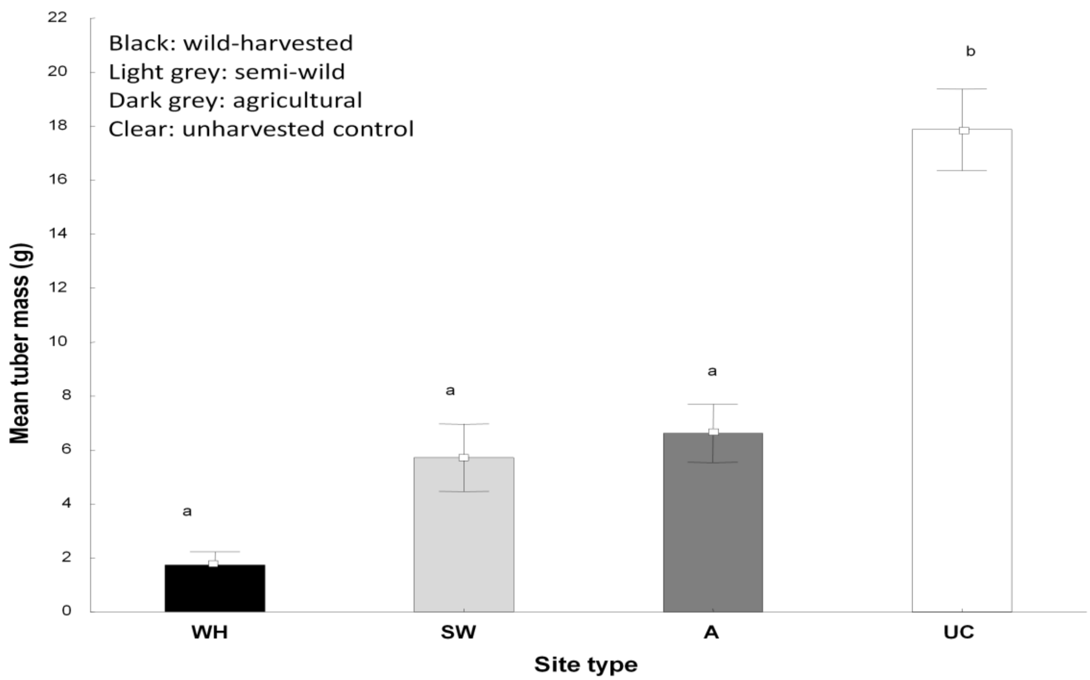
Figure 3.16. Comparisons of tuber recovery, tuber regrowth and tuber size (A= tuber recovery, tuber regrowth and tuber mass, B= tuber recovery, tuber regrowth and tuber diameter, C= tuber recovery, tuber regrowth and tuber length, D= tuber recovery, tuber regrowth and tuber volume) of Pelargonium sidoides plants in wild-harvested (HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng), semi-wild (HTS I= Ha Tlhaku I, HTS II= Ha Tlhaku II and agricultural sites (MHW= Mohale's Hoek white- MHB= Mohale's Hoek black, MHO= Mohale's Hoek open) and unharvested control sites (TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II) in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.2 for site ages (Chapter 2, Section 2.3.1.2.).

When tuber size was compared based on total tuber size values, the results found differed from above-mentioned results (Appendix 1, Figure 3.16). Instead of TSI II having significantly larger tuber mass as above, MKH (Makhoareng) was found to have larger tuber mass than other sites although this was not significantly different to tuber mass of plants from TSI II. Furthermore, using total tuber diameter values resulted in MOL II to have larger tuber diameter than other sites although this was not significantly different to plants from TSI II. Additionally, HTS I had plants with significantly largest tuber length when using total tuber length values whereas MHO was found to have largest tuber length when mean tuber length values were used. As expected, results for tuber volume also differed. MOL II was found to have larger tuber volume when total tuber volume was used while TSI II had larger tuber volume values when mean tuber volume values were used.

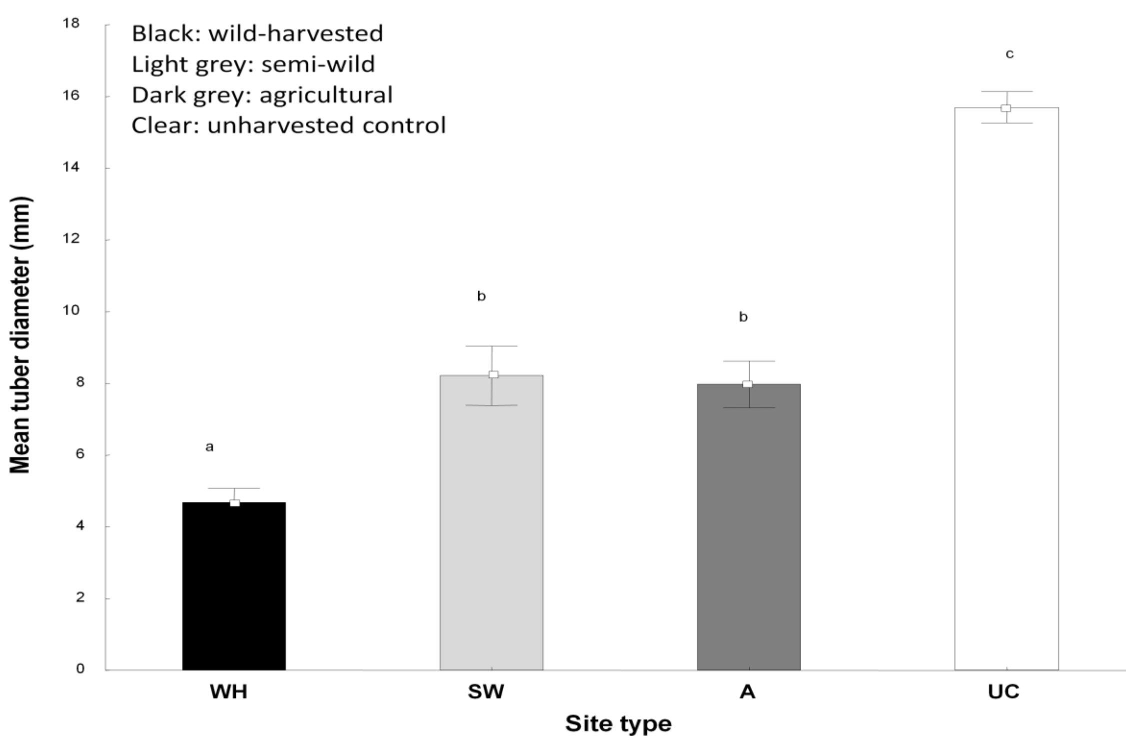
3.4.2.1.5. Comparisons on tuber recovery, tuber regrowth and tuber size when sites are grouped according to site type (wild-harvested- WH, semi-wild- SW, agricultural- A and unharvested control- UC sites)

Sites were grouped according to their type regardless of the times since last harvest or times in cultivation. When comparisons were made across these types of sites, highly significant differences in tuber size (mass, diameter, length and volume) were detected ($F_{3,163}$= 15.765, P < 0.001) (Figure 3.17A). Plants from unharvested control sites had significantly larger mean tuber mass than plants from other site types. Equally, unharvested control sites had plants with significantly larger mean tuber diameter than plants from other site types ($F_{3,163}$= 70.2567, P < 0.001) (Figure 3.17B). However, plants from agricultural sites had significantly larger tuber length than plants from other types of sites ($F_{3,163}$= 10.6696, P < 0.001) (Figure 3.17C). On the other hand, unharvested control sites were found to have plants with significantly larger mean tuber volume than plants from other site types ($F_{3,163}$= 18.0158, P < 0.001) (Figure 3.17D).

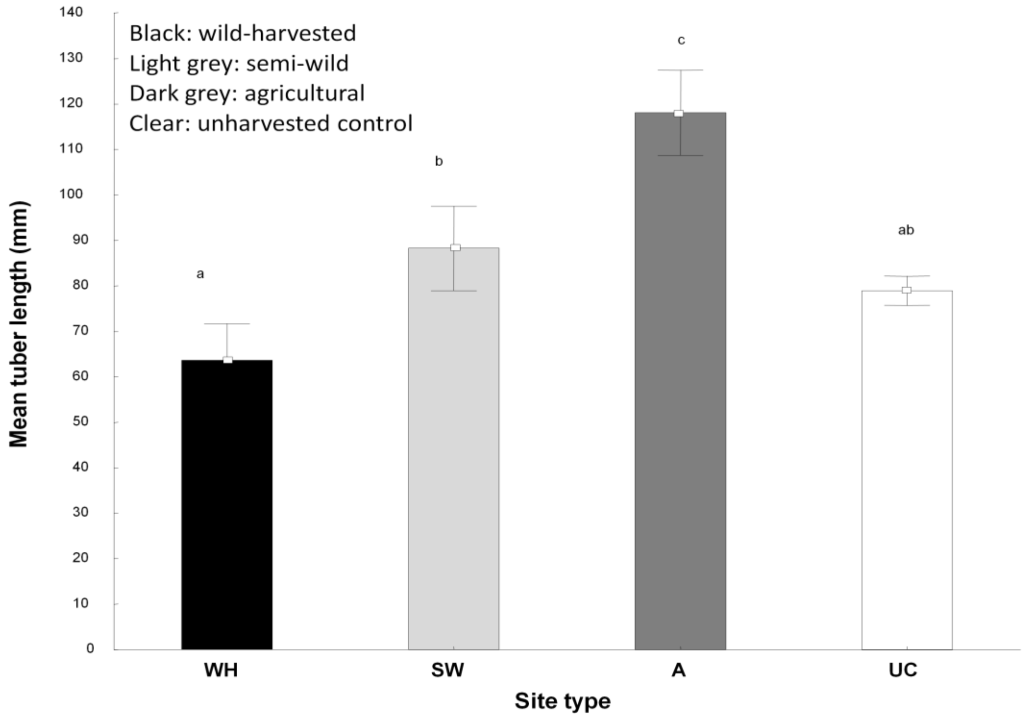
(A)



(B)

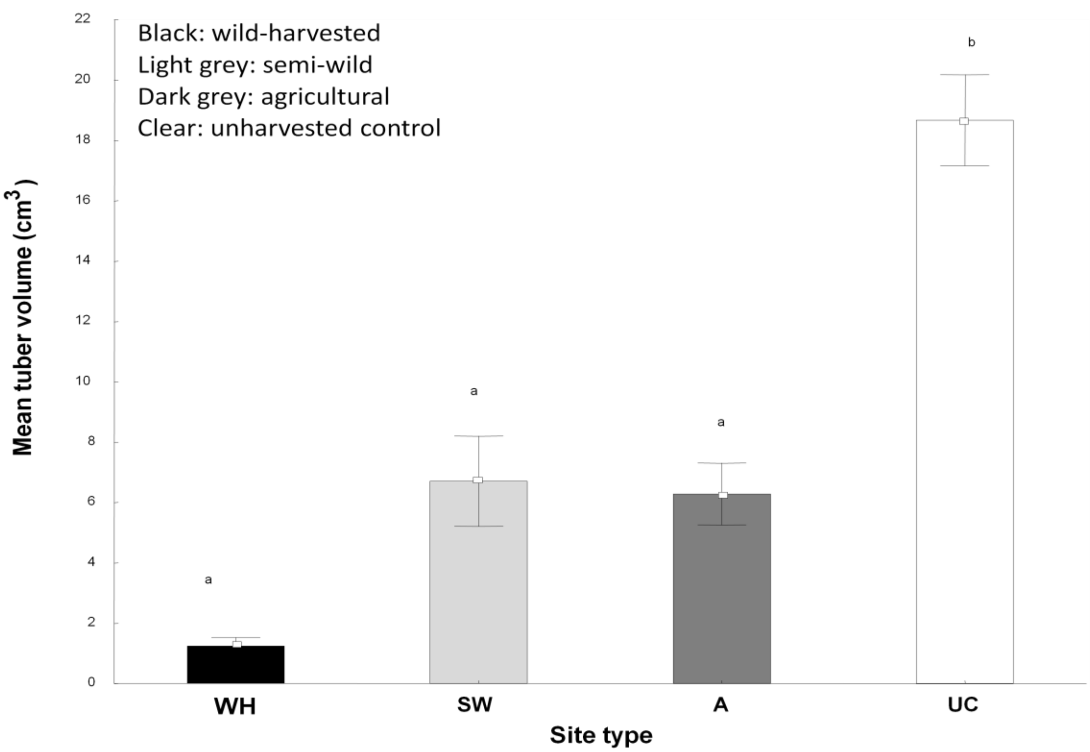


(C)



Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber length (mm)
Site type
WH
SW
A
UC
a
b
c
ab
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

(D)



Black: wild-harvested
Light grey: semi-wild
Dark grey: agricultural
Clear: unharvested control
Mean tuber volume (cm3)
Site type
WH
SW
A
UC
a
a
a
b
0
2
4
6
8
10
12
14
16
18
20
22

Figure 3.17. Comparisons of tuber recovery, tuber regrowth and tuber size (A= tuber recovery, tuber regrowth and tuber mass, B= tuber recovery, tuber regrowth and tuber diameter, C= tuber recovery, tuber regrowth and tuber length, D= tuber recovery, tuber regrowth and tuber volume) of Pelargonium sidoidies in wild-harvested (WH), semi-wild (SW), agricultural (A) and unharvested control (UC) sites in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

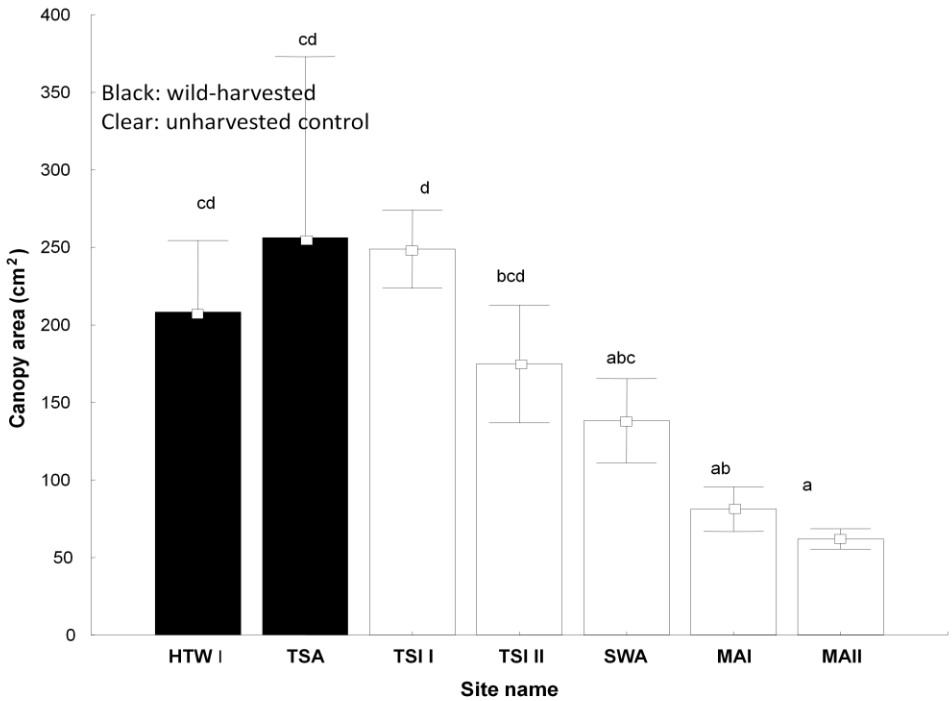
While the results obtained when using mean tuber size values as above did not differ from those found when using total tuber mass values (Appendix 1, Figure 3.17), semi-wild sites had significantly longer tubers than all the other site types. However, when mean tuber length values were used, agricultural sites had larger tuber length than all the other site types.

3.4.2.2. Above-ground plant growth across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

3.4.2.2.1. Comparisons of canopy area across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

To determine the impacts of harvest on *P. sidoides* plants, comparisons of above-ground plant growth measured using canopy area were made across sites. Canopy area was found to be significantly different across wild-harvested and unharvested control sites ($F_{6,51}$= 3.9058, P < 0.003) (Figure 3.18A). Plants from TSI I (Tsiame I) had bigger canopies than plants from other sites, however, this was not significantly different from canopy area of plants from other unharvested control sites such as TSI II (Tsiame II) and the wild-harvested sites. Likewise, canopy area across all sites was highly significant ($F_{11,91}$= 7.8019, P= 0.0001) (Figure 3.18B). Semi-wild and agricultural sites had plants with bigger canopies that wild-harvested and unharvested control sites. Plants from HTS I and MHO (Mohale's Hoek Open) were found to have bigger canopies than plants from the rest of the other sites.

(A)


Black: wild-harvested
Clear: unharvested control
Canopy area (cm^2)
Site name
HTW I
TSA
TSI I
TSI II
SWA
MAI
MAII
cd
cd
d
bcd
abc
ab
a

(B)

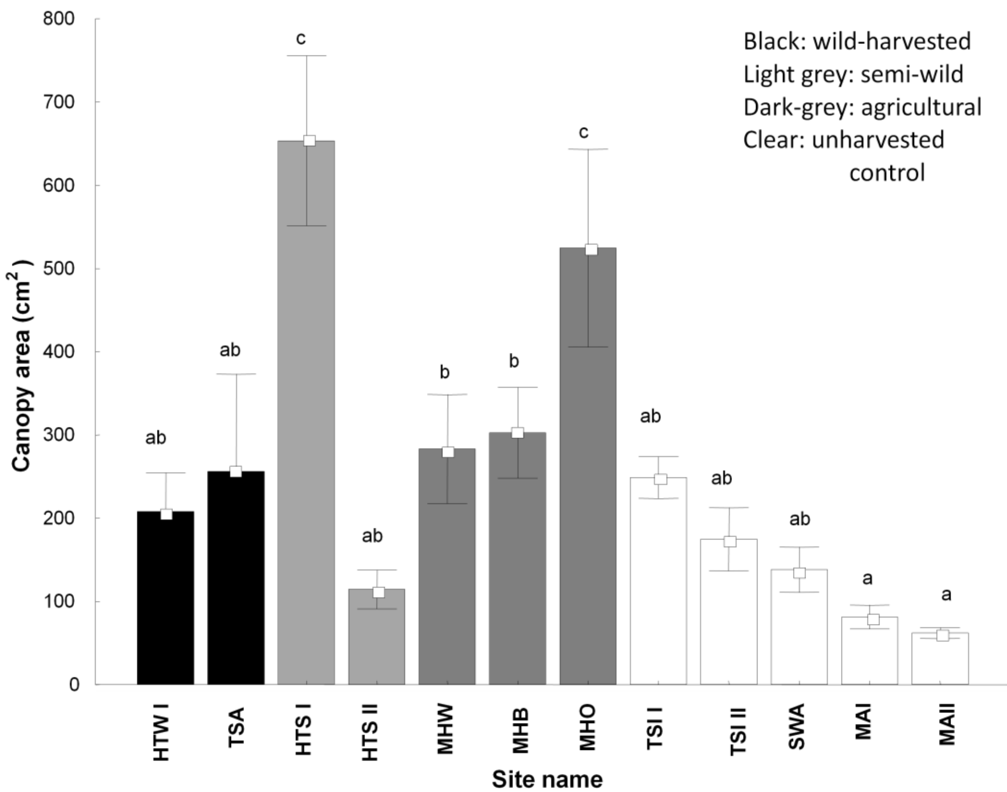

Black: wild-harvested
Light grey: semi-wild
Dark-grey: agricultural
Clear: unharvested control
Canopy area (cm^2)
Site name
HTW I
TSA
HTS I
HTS II
MHW
MHB
MHO
TSI I
TSI II
SWA
MAI
MAII
ab
ab
c
ab
b
b
c
ab
ab
ab
a
a

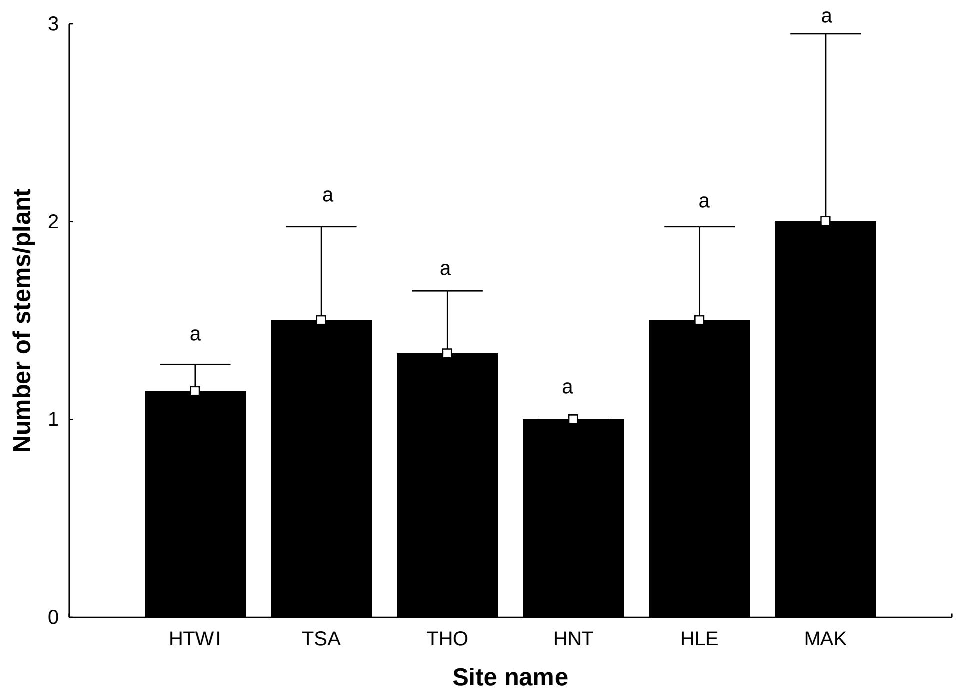
Figure 3.18. Comparisons on canopy area (cm^2) of Pelargonium sidoides plants in wild-harvested sites (A= HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng) and all types of sites (B= HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng (wild harvested), HTS I= Ha Tlhaku I-semi-wild, HTS II= Ha Tlhaku II (semi-wild), MHW= Mohale's Hoek white- MHB= Mohale's Hoek black, MHO= Mohale's Hoek open (agricultural) and TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II (unharvested controls) in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.2 for site ages (Chapter 2, Section 2.3.1.2.).

3.4.2.2.2. Comparisons on the number of stems/plant across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

P. sidoides plants recover from harvest by developing stems. Therefore to investigate the impacts of harvest on above-ground plant growth, the number of stems/plant was compared across sites. There was however, no significant difference in the number of stems/plants across the wild harvested sites ($F_{5,15}$= 0.5248, P = 0.754) (Figure 3.19A). On the other hand, the number of stems/plant in wild harvested and unharvested control sites was compared, a significant difference was obtained ($F_{23,98}$= 2.092, P = 0.007) (Figure 3.19B). Unharvested control had significantly more stems/plants than wild-harvested sites. TSI I was found to have the highest number of stems/plant than other sites. However, this was not significantly different from the number of stems/plant from several other unharvested control sites.

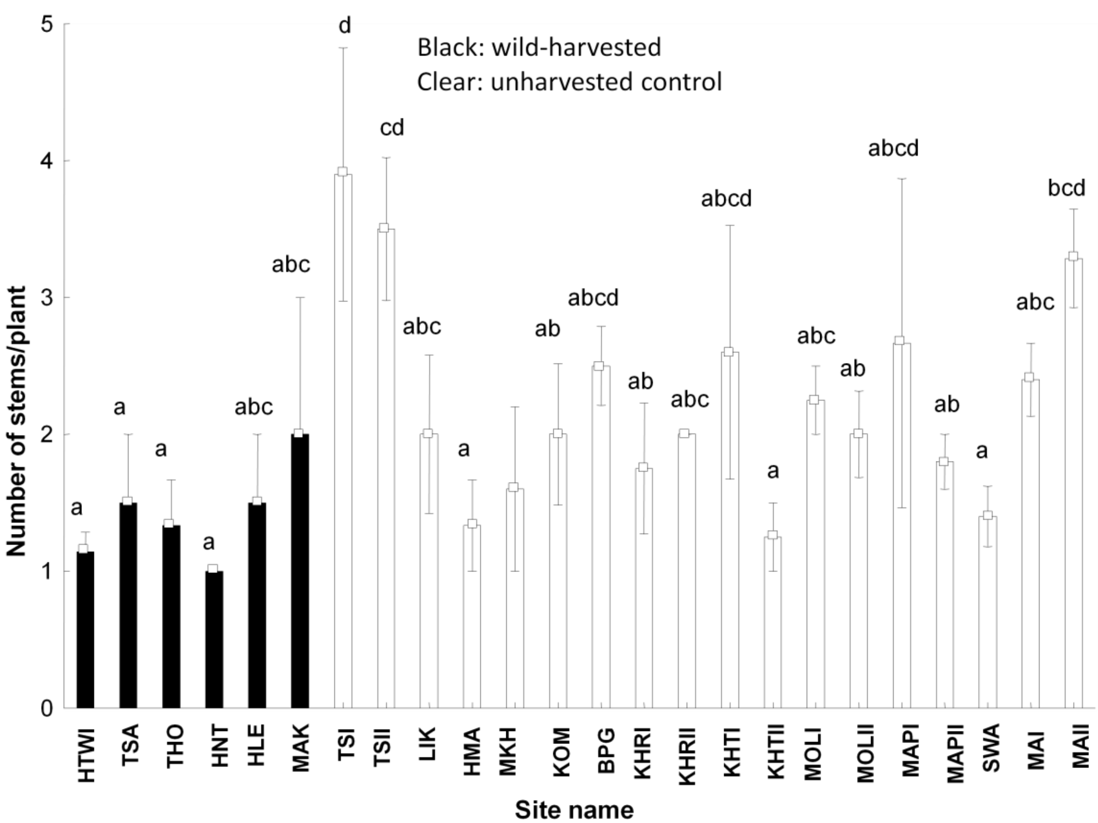
When semi-wild and agricultural sites were compared, semi-wild sites had plants with significantly more stems/plant than agricultural sites ($F_{4,40}$= 8.5797, P < 0.001) (Figure 3.19C). Furthermore, plants from HTS I (Ha Tlhaku I) were found to have more stems/plant than all the other sites. Comparisons on the number of stems/plant across all sites produced a highly significant outcome with TSI I and HTS I having the highest number of stems/plant than all the rest of the sites ($F_{28,138}$= 2.917, P < 0.001) (Figure 3.19D).

(A)



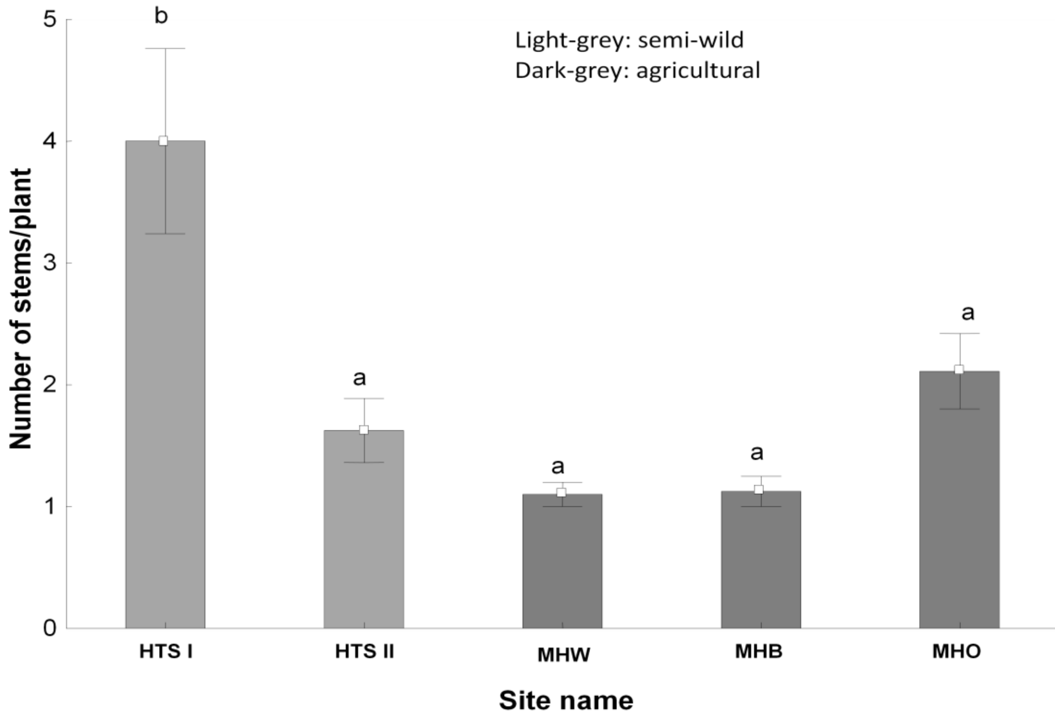
Number of stems/plant
Site name
HTWI
TSA
THO
HNT
HLE
MAK

(B)



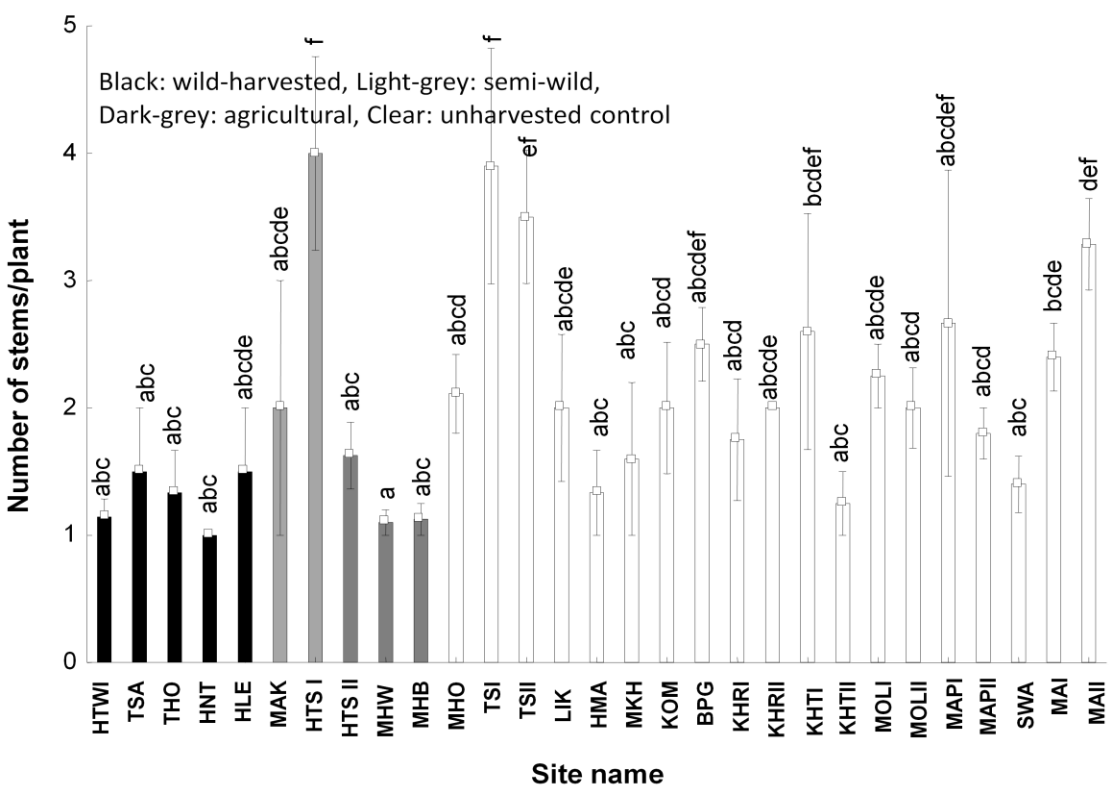
Black: wild-harvested
Clear: unharvested control
Number of stems/plant
Site name
HTWI
TSA
THO
HNT
HLE
MAK
TSI
TSII
LIK
HMA
MKH
KOM
BPG
KHRI
KHRII
KHTI
KHTII
MOLI
MOLII
MAPI
MAPII
SWA
MAI
MAII

(C)



Light-grey: semi-wild
Dark-grey: agricultural
Number of stems/plant
Site name
HTS I
HTS II
MHW
MHB
MHO
b
a
a
a
a

(D)



Black: wild-harvested, Light-grey: semi-wild,
Dark-grey: agricultural, Clear: unharvested control
Number of stems/plant
Site name
HTWI
TSA
THO
HNT
HLE
MAK
HTS I
HTS II
MHW
MHB
MHO
TSI
TSII
LIK
HMA
MKH
KOM
BPG
KHRI
KHRII
KHTI
KHTII
MOLI
MOLII
MAPI
MAPII
SWA
MAI
MAII

Figure 3.19. Comparisons on the number of stems/plant of Pelargonium sidoides plants in wild-harvested sites (A= HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng), wild-harevsted and unharvested control sites (B= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II), semi-wild and agricultural sites (C= semi-wild= HTS I= Ha Tlhaku I, HTS II= Ha Tlhaku II and agricultural- MHW= Mohale's Hoek white- MHB= Mohale's Hoek black, MHO= Mohale's Hoek open) and all types of sites (D) in the "highveld" vegetation region. Refer to table 3.2 for site ages. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05). Refer to Table 2.2 for site ages (Chapter 2, Section 2.3.1.2.).

3.4.2.2.3. Comparisons on the number of stems/plant when sites are grouped according to site type (wild-harvested- WH, semi-wild- SW, agricultural- A and unharvested control- UC sites)

A significant result was obtained when the number of stems/plant were compared across different sites grouped according to site type and irrespective of times since last harvest or time in cultivation ($F_{3,163}$= 6.7763, P < 0.001) (Figure 3.20). Semi-wild and unharvested control sites had plants with significantly more stems/plant than all the other site types. However, this may be a biased result as times since last harvest and times in cultivations varied greatly per site type.

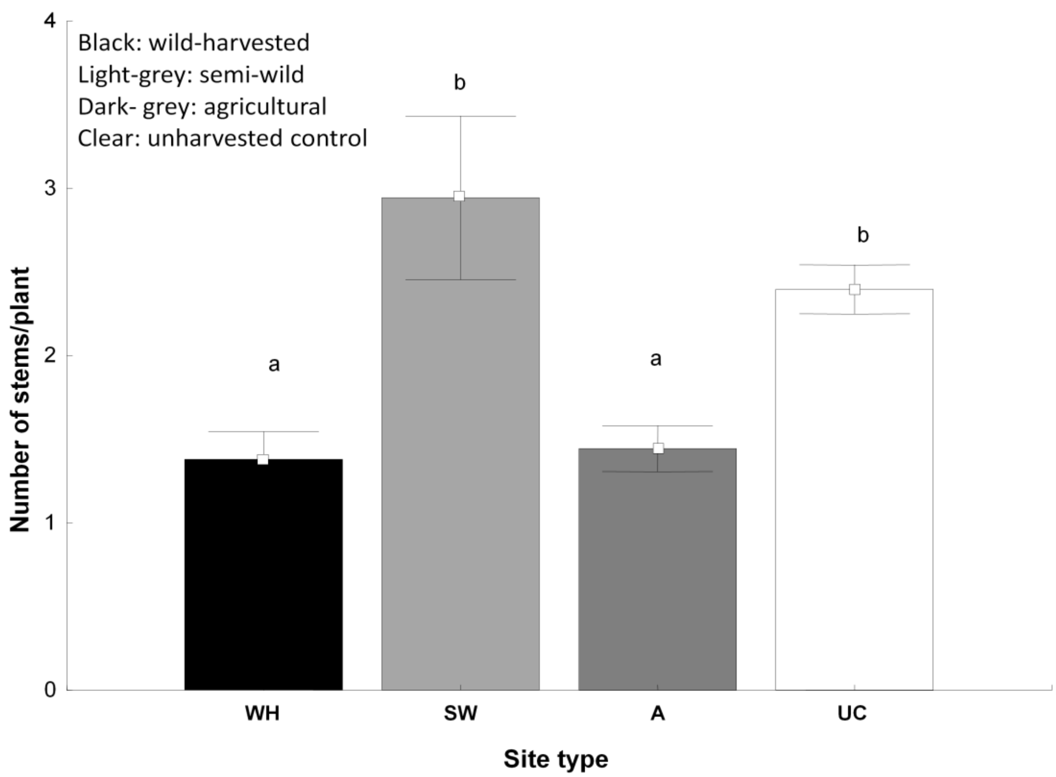


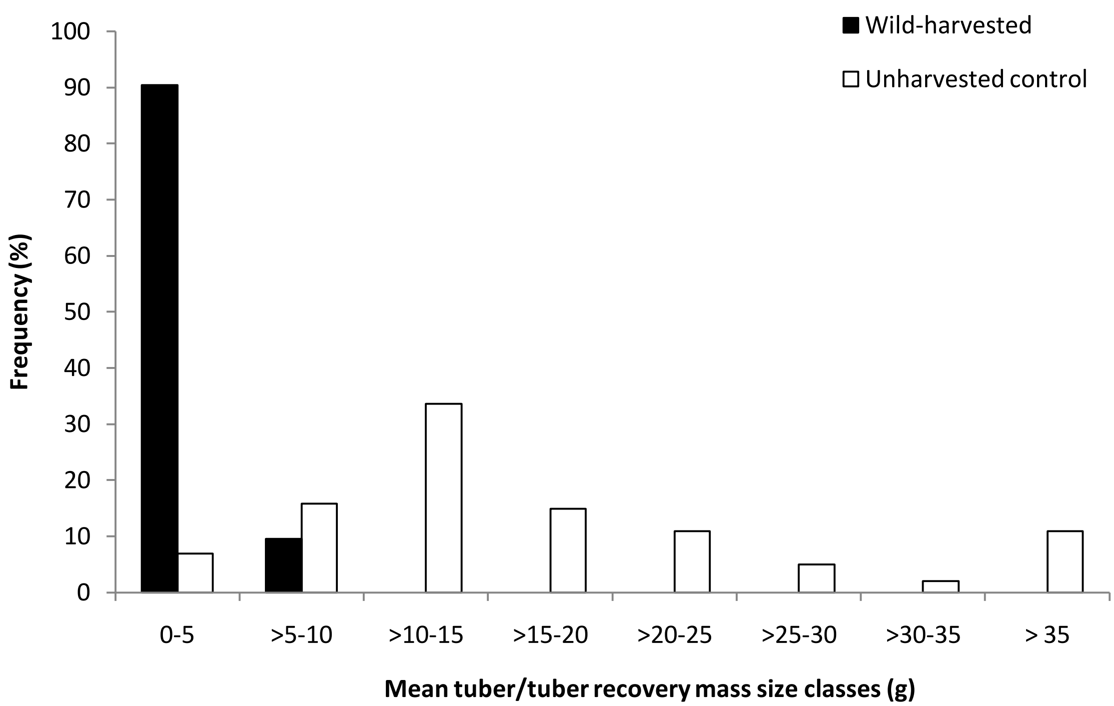
Figure 3.20. Comparisons on the number of stems/plants of Pelargonium sidoides plants when sites were grouped according to site type (WH-wild harvested, SW-semi-wild, A- agricultural and UC- unharvested control sites) in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2.3. Tuber mass size-classes, tuber colour intensity and distribution across sites

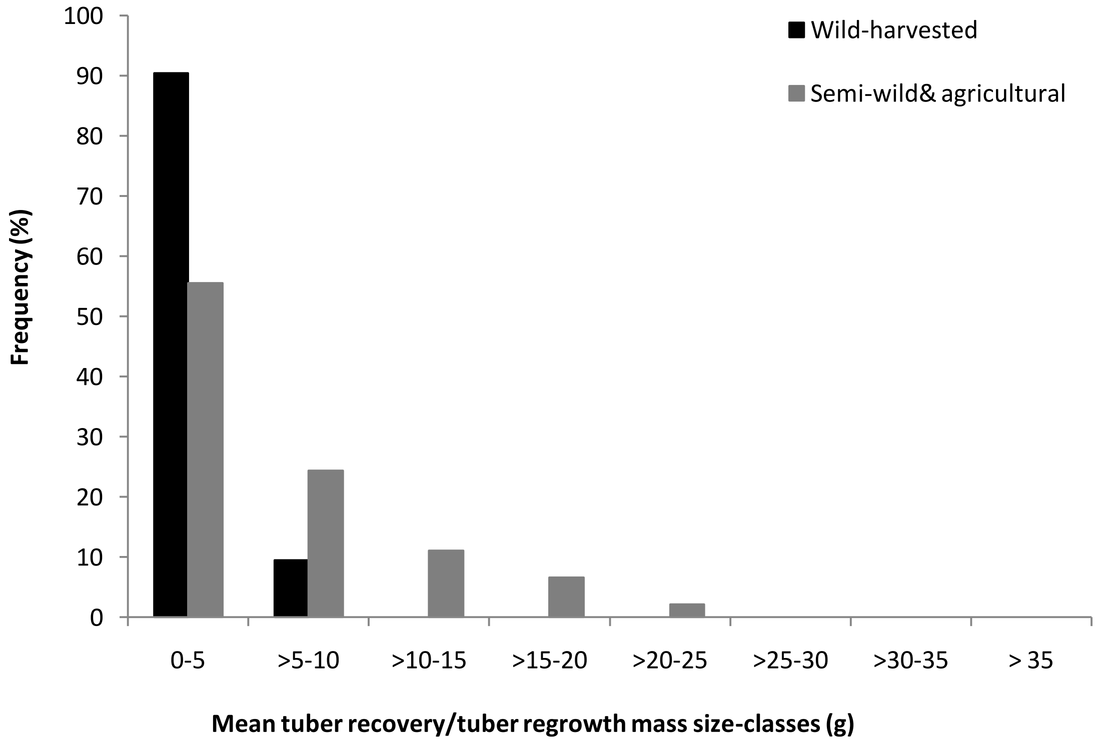
3.4.2.3.1. Tuber mass size-classes across sites

Harvesting operations may alter *P. sidoides* population structure. To determine this, tuber mass size-class distribution was compared between wild-harvested against unharvested sites, wild-harvested against cultivated sites (semi-wild and agricultural), as well as unharvested against cultivated sites. In wild-harvested sites, most tubers fell into the 0-5 g size-class whereas in unharvested sites, tubers occupied all size-classes. Tuber mass size-class distribution for wild-harvested sites was found to be significantly different to that of unharvested sites (Kolmogorov-Smirnov, D =0.75, $P < 0.05$) (Figure 3.21A). However, the tuber mass size-class distribution for wild-harvested sites did not differ significantly to that of cultivated sites (Kolmogorov-Smirnov, D =0.375, $P > 0.05$) (Figure 3.21B). Similarly, comparisons on tuber mass size-class distribution between unharvested and cultivated sites did not produce significant results (Kolmogorov-Smirnov, D =0.375, $P > 0.05$) (Figure 3.21C).

(A)

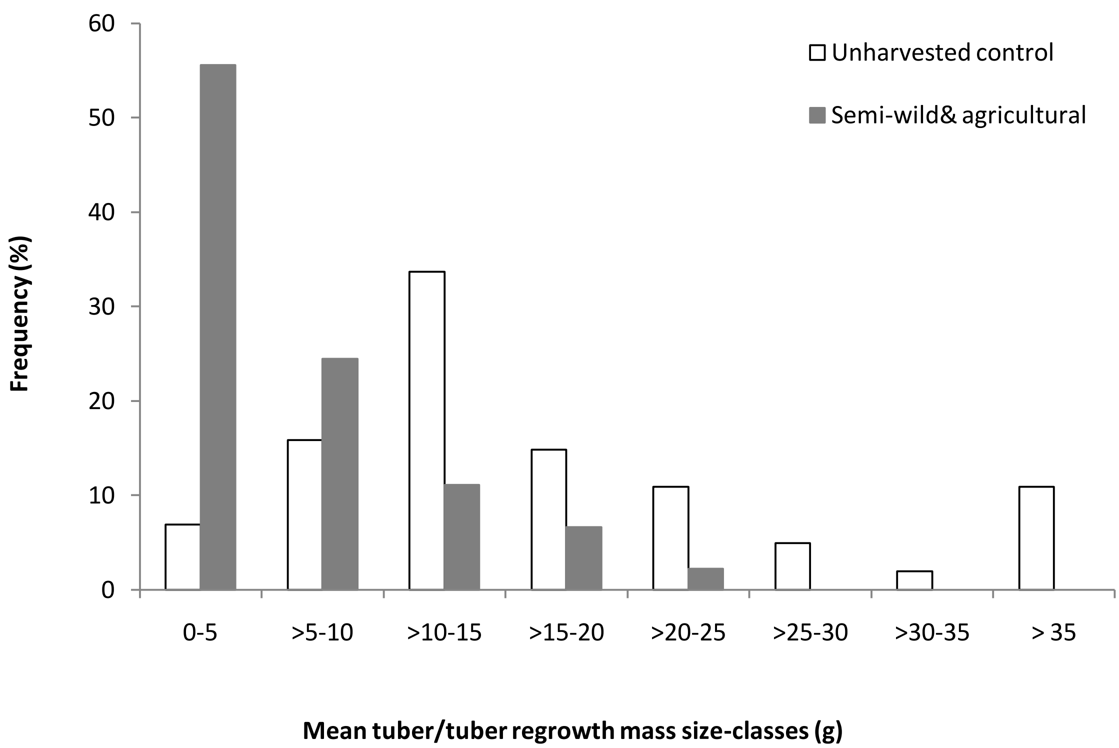


(B)



Wild-harvested
Semi-wild& agricultural
Frequency (%)
100
90
80
70
60
50
40
30
20
10
0
0-5
>5-10
>10-15
>15-20
>20-25
>25-30
>30-35
> 35
Mean tuber recovery/tuber regrowth mass size-classes (g)

(C)



Unharvested control
Semi-wild& agricultural
Frequency (%)
60
50
40
30
20
10
0
0-5
>5-10
>10-15
>15-20
>20-25
>25-30
>30-35
> 35
Mean tuber/tuber regrowth mass size-classes (g)

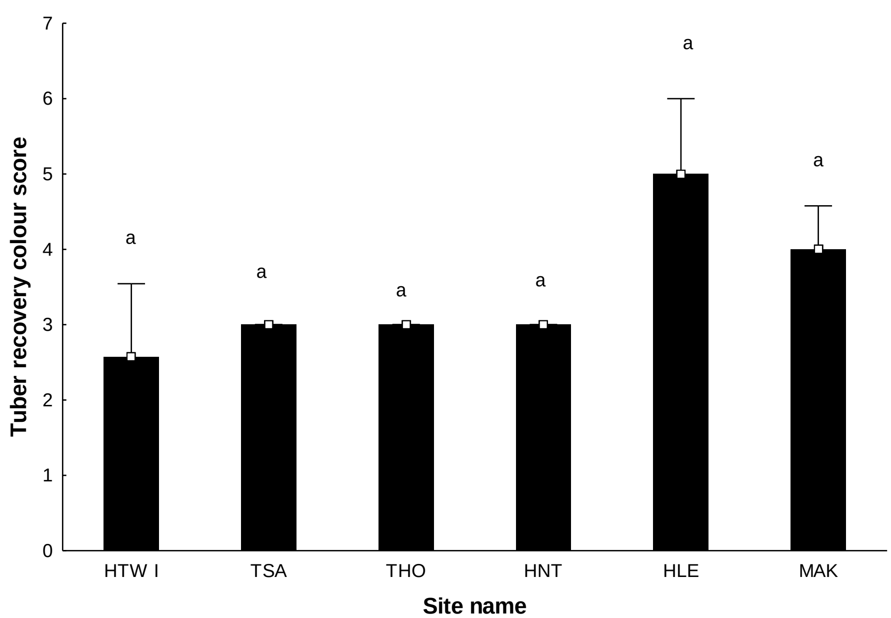
Figure 3.21. Comparison on tuber mass size-classes distribution of Pelargonium sidoides plants from different types of sites (A- wild-harvested [n = 27] and unharvested control sites [101], B- wild-harvested [n = 27] and cultivated (semi-wild and agricultural sites) [45], C- unharvested control [101] and cultivated sites [n = 45]) in the "highveld" vegetation region.

3.4.2.3.2. Comparisons on tuber colour intensity across sites (wild-harvested-tuber recovery, semi-wild- tuber regrowth, agricultural- tuber regrowth and unharvested control sites- tuber)

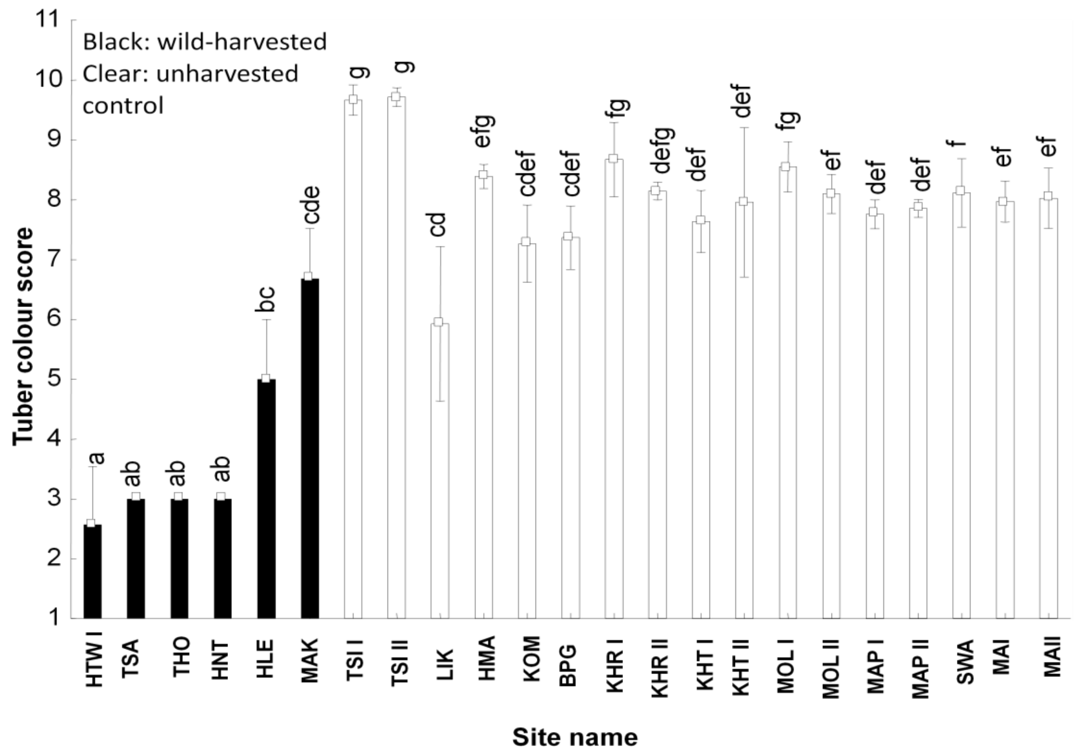
Since tuber colour can also determine whether *P. sidoides* plants are commercially mature, comparisons on tuber recovery, tuber regrowth and tuber colour intensity was made across sites. Tuber recovery colour intensity across wild harvested sites was not significantly different ($F_{5,15}$= 0.791, P = 0.573) (Figure 3.22A). Thus tuber recovery colour from the six wild-harvested sites was not significantly darker or paler across sites. However, comparisons between wild-harvested and unharvested control sites showed significant differences in tuber colour with TSI I and TSI II (Tsiame II) having darkest tubers ($F_{22,99}$= 11.204, P < 0.001) (Figure 3.22B). Equally, a significant difference in tuber regrowth colour intensity was obtained when comparing semi-wild and agricultural sites ($F_{4,40}$= 10.584, P < 0.001) (Figure 3.22C). MHO (Mohale's Hoek open) was found to have darker coloured tuber regrowth than the rest of the other sites.

Additionally, there was a significant difference in tuber colour intensity when all sites were compared ($F_{27,139}$= 32.5396, P < 0.001) (Figure 3.22D). As expected, plants from unahrvested control sites had darkest tubers compared to all other wild-harvested, semi-wild and agricultural sites.

(A)

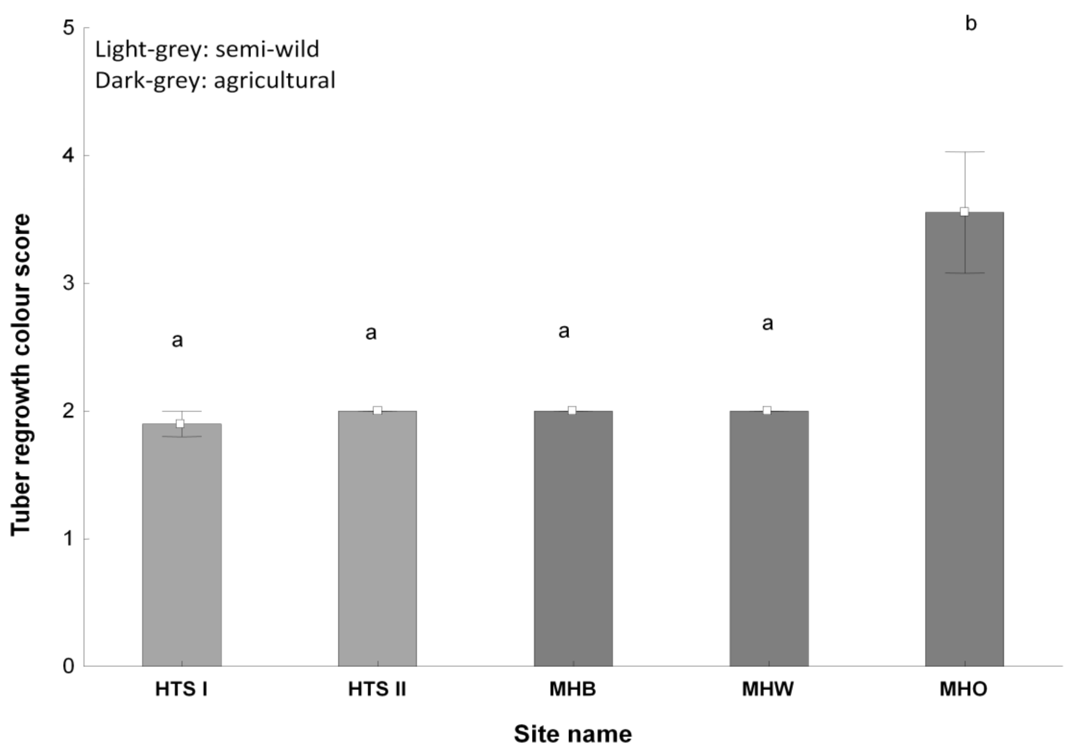


(B)



Black: wild-harvested
Clear: unharvested control
Tuber colour score
Site name
HTW I
TSA
THO
HNT
HLE
MAK
TSI I
TSI II
LIK
HMA
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MAI
MAII
a
ab
ab
ab
bc
cde
g
g
cd
efg
cdef
cdef
fg
defg
def
def
fg
ef
def
def
f
ef
ef

(C)



Light-grey: semi-wild
Dark-grey: agricultural
Tuber regrowth colour score
Site name
HTS I
HTS II
MHB
MHW
MHO
a
a
a
a
b

(D)

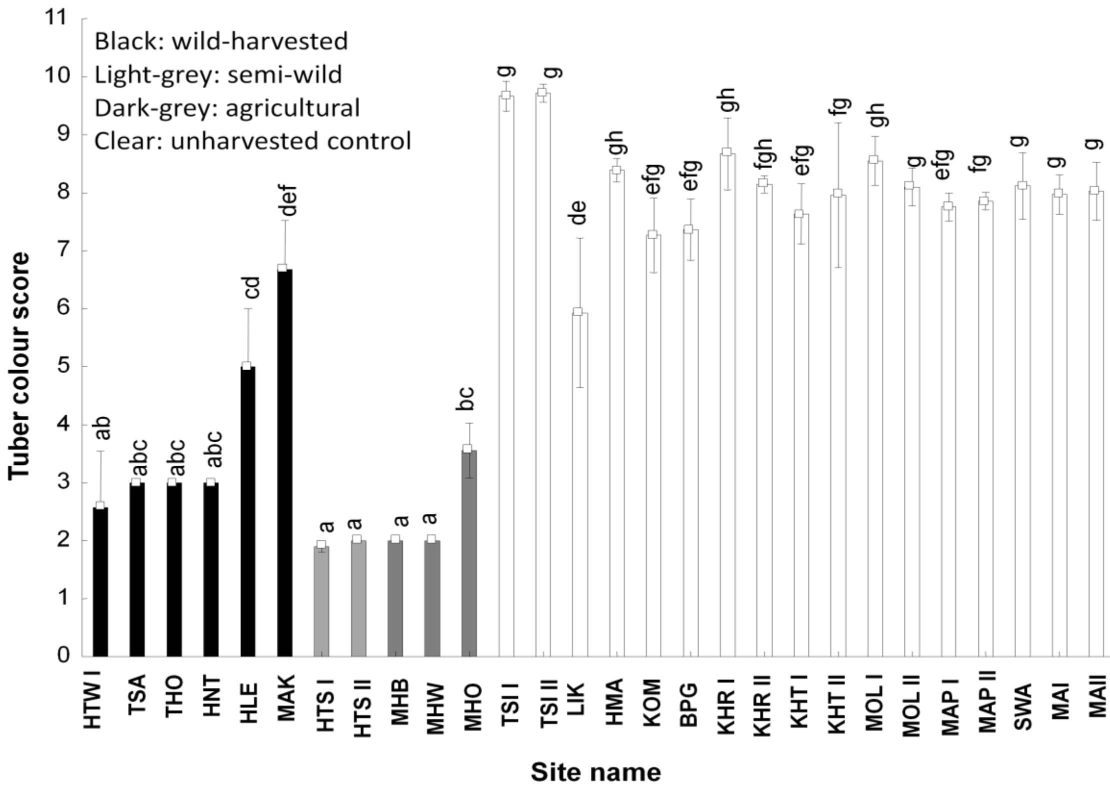


Figure 3.22. Comparisons on tuber colour intensity of Pelargonium sidoides plants in wild-harvested sites (A= HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng), wild-harvested and unharvested control sites (B= Wild harvested- HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng and unharvested control sites- TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II), semi-wild and agricultural sites (C= Semi-wild -HTS II= Ha Tlhaku II and agricultural- MHW= Mohale's Hoek white- MHB= Mohale's Hoek black, MHO= Mohale's Hoek open and all types of sites (D). Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2.3.3. Comparisons on tuber recovery, tuber regrowth and tuber colour intensity when sites are grouped according to site type (wild-harvested (WH)- tuber recovery, semi-wild (SW)- tuber regrowth, agricultural (A)- tuber regrowth and unharvested control (UC)- tuber sites)

Tuber colour intensity is expected to increase with time. Therefore, tuber colour intensity was compared when sites were grouped according to site type and regardless of times since last harvest or time in cultivation. There was a highly significant difference in tuber colour intensity across sites ($F_{3,163}$= 252.1648, P < 0.001) (Figure 3.23). Plants from unharvested control sites were found to have tubers that were darker than those obtained from the other types of sites. However, wild-harvested sites had darker coloured tubers than the semi-wild and agricultural sites.

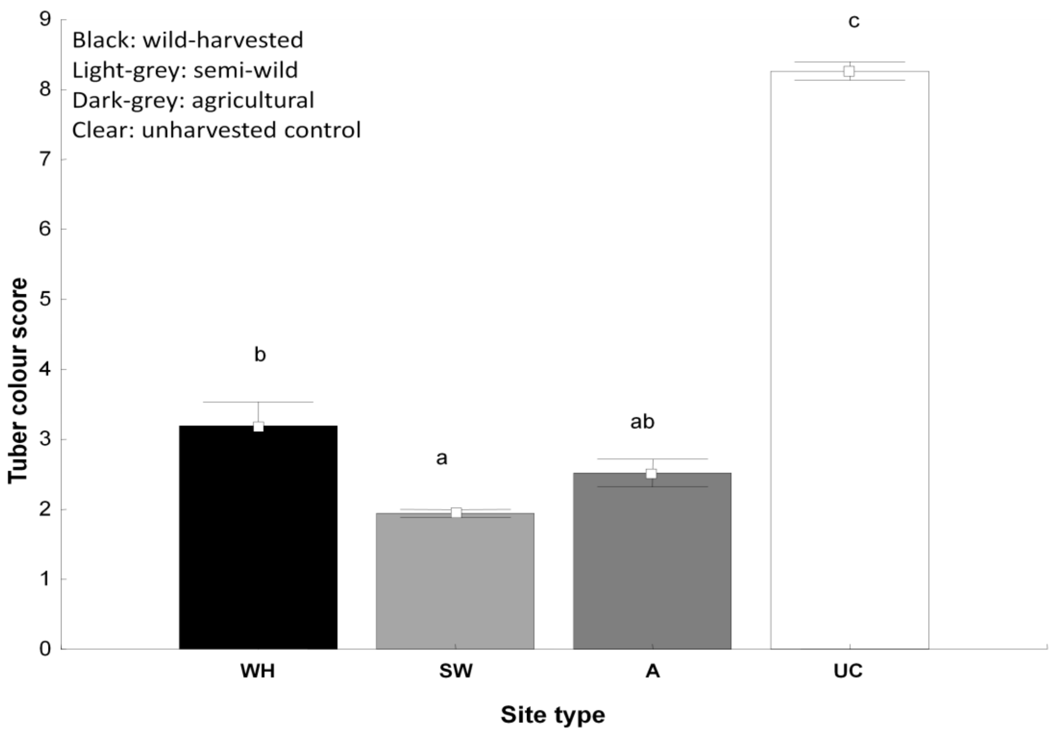


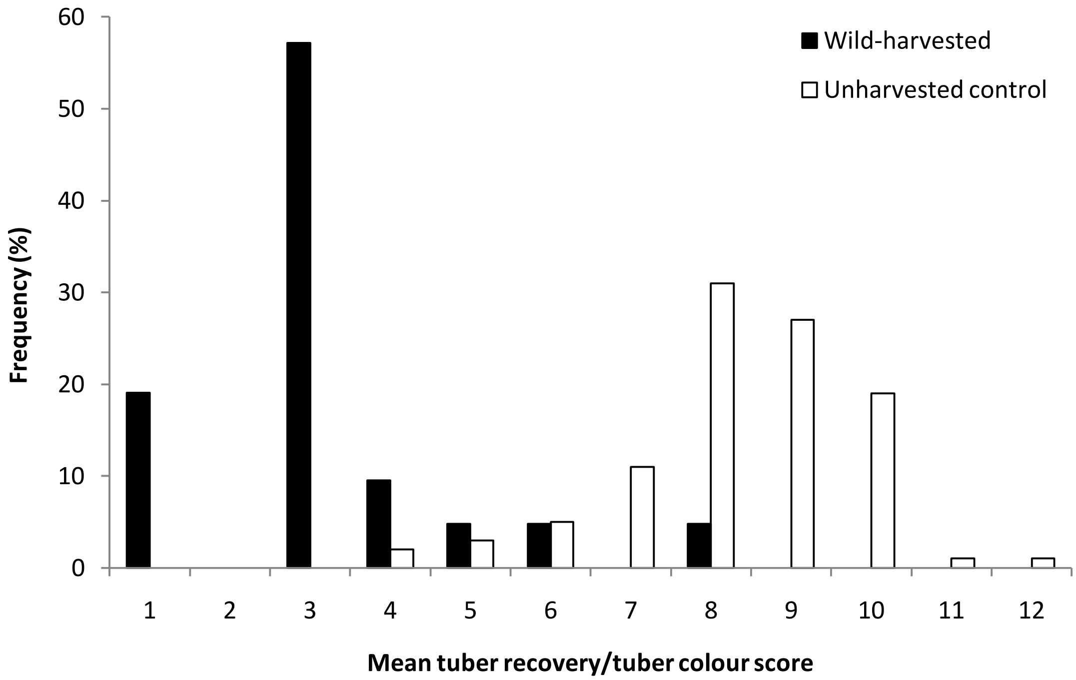
Figure 3.23. Comparison on tuber colour intensity of Pelargonium sidoides plants when sites were grouped according to site type ((WH-wild harvested, SW-semi-wild, A- agricultural and UC- unharvested control sites) in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2.3.4. Tuber colour distribution across sites

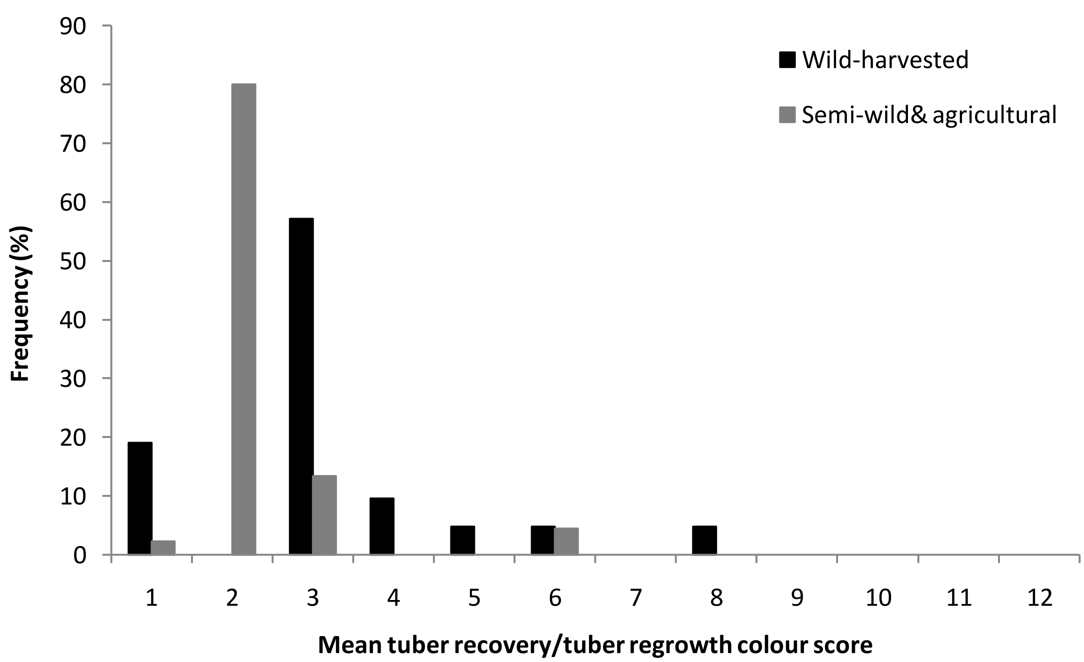
One of the hypotheses for this study was that there is uneven distribution of tuber colour between sites, with pale coloured tubers more concentrated in wild-harvested sites compared to dark-coloured tubers in unharvested sites. Therefore, to investigate this, tuber colour distribution between wild-harvested and unharvested control sites was made. However, there was no significant difference between the distributions (Kolmogorov-Smirnov, D =0.25, P > 0.05) (Figure 3.24A). Similarly, a significant difference between distributions was not found between wild-harvested and cultivated (semi-wild and agricultural) sites (Kolmogorov-Smirnov, D =0.3333, P > 0.05) (Figure, 3.24B). In the same manner, no significant differences were detected between unharvested and cultivated sites (Kolmogorov-Smirnov, D =0.4167, $P > 0.05$) (Figure 3.24C).

Furthermore, tuber colour distributions were determined and displayed graphically per site, however, due to limited data, no statistical analysis was made (Figure 3.24D)

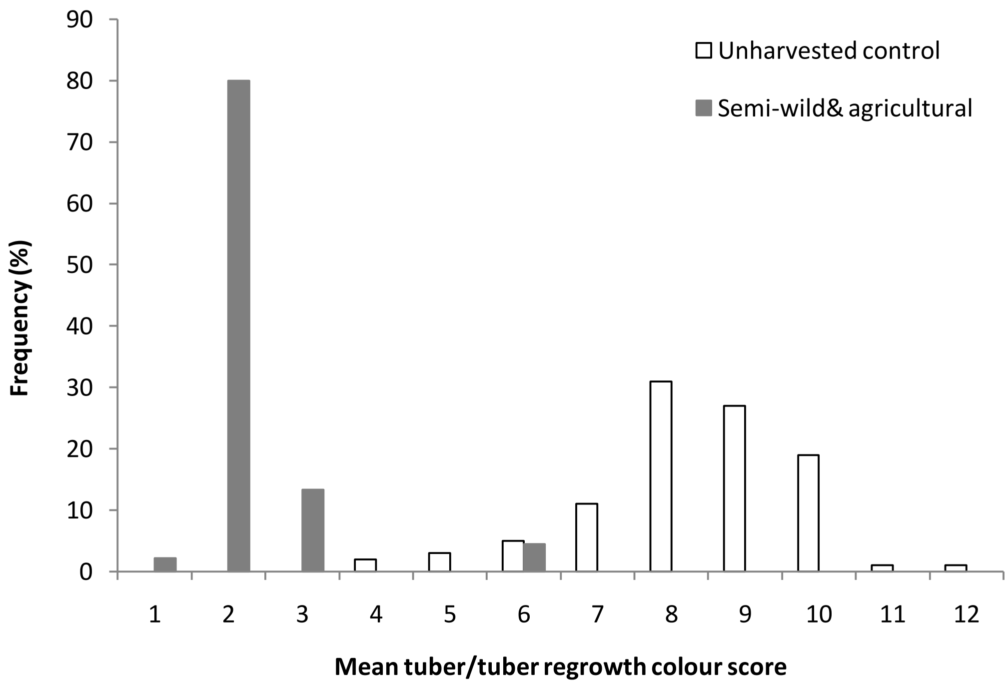
(A)



(B)

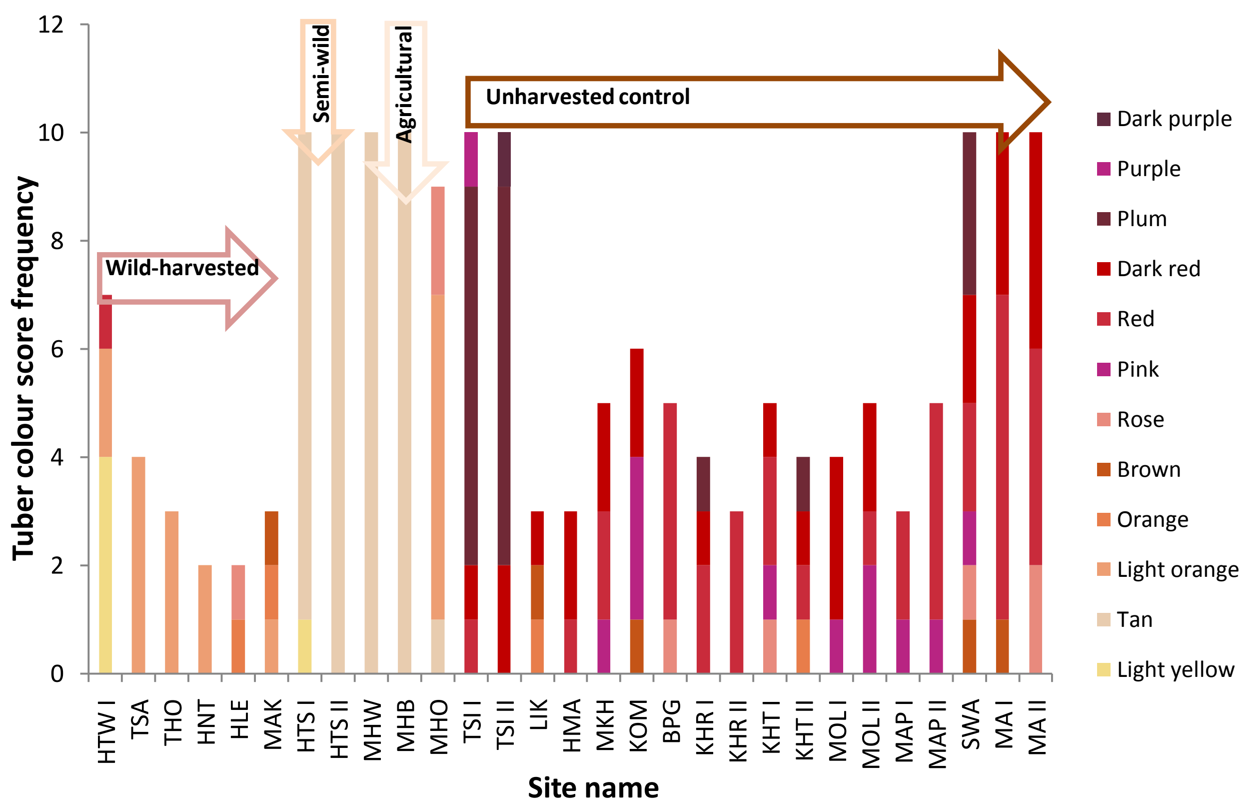


(C)



Frequency (%)
Unharvested control
Semi-wild& agricultural
Mean tuber/tuber regrowth colour score

(D)



Tuber colour score frequency
Wild-harvested
Semi-wild
Agricultural
Unharvested control
Dark purple
Purple
Plum
Dark red
Red
Pink
Rose
Brown
Orange
Light orange
Tan
Light yellow
HTW I
TSA
THO
HNT
HLE
MAK
HTS I
HTS II
MHW
MHB
MHO
TSI I
TSI II
LIK
HMA
MKH
KOM
BPG
KHR I
KHR II
KHT I
KHT II
MOL I
MOL II
MAP I
MAP II
SWA
MA I
MA II
Site name

Figure 3.24. Comparison on tuber recovery, tuber regrowth and tuber colour distribution of Pelargonium sidoides plants from different types of sites (A- wild harvested [n = 27] and unharvested control sites [N = 101], B- wild-harvested [n = 27] and cultivated (semi-wild and agricultural sites) [n = 45], C- unharvested control [n = 101] and cultivated sites [n = 45]) in the "highveld" vegetation region. D- tuber colour frequency/colour score/site in wild harvested sites- HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng , semi-wild- HTS I= Ha Tlhaku I, HTS II= Ha Tlhaku II and agricultural- MHW= Mohale's Hoek white- MHB= Mohale's Hoek black, MHO= Mohale's Hoek open, unharvested control sites- TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II. Refer to Table 2.2 for site ages (Chapter 2, Section 2.3.1.2.).

3.4.3. "Lowveld" and "highveld" vegetation regions

3.4.3.1. Below-ground plant growth between "lowveld" and "highveld" vegetation regions according to site type

3.4.3.1.1. Comparisons on tuber recovery size in wild-harvested sites

Tuber recovery size was compared in wild-harvested sites from the "lowveld" and "highveld" vegetation regions to investigate whether it varies. There was however no significant difference in mean tuber recovery mass between the regions (t_{86}= 1.48, P = 0.1419) (Figure 3.25A) although plants from the 'lowveld" vegetation region tended to have more mean tuber recovery mass. Conversely, mean tuber recovery diameter was found to be significantly different between regions (t_{86}= 2.69, P = 0.0086) (Figure 3.25B). Mean tuber recovery diameter of plants from the "lowveld" vegetation region was significantly larger than that of plants from the "highveld" vegetation region. When tuber recovery size was compared using mean tuber recovery length, no significant difference was detected between the regions (t_{86}= - 1.67, P = 0.0976) (Figure 3.25C). Although there was no significant difference in mean tuber recovery length between regions, plants from the "highveld" vegetation region tended to have longer tubers than those from the "lowveld" vegetation region. Comparing tuber size based on mean tuber recovery volume produced a significant difference between the regions and the "lowveld" vegetation region was found to have plants with larger tuber recovery volume (t_{86}= 2.16, P = 0.0339) (Figure 3.25D).

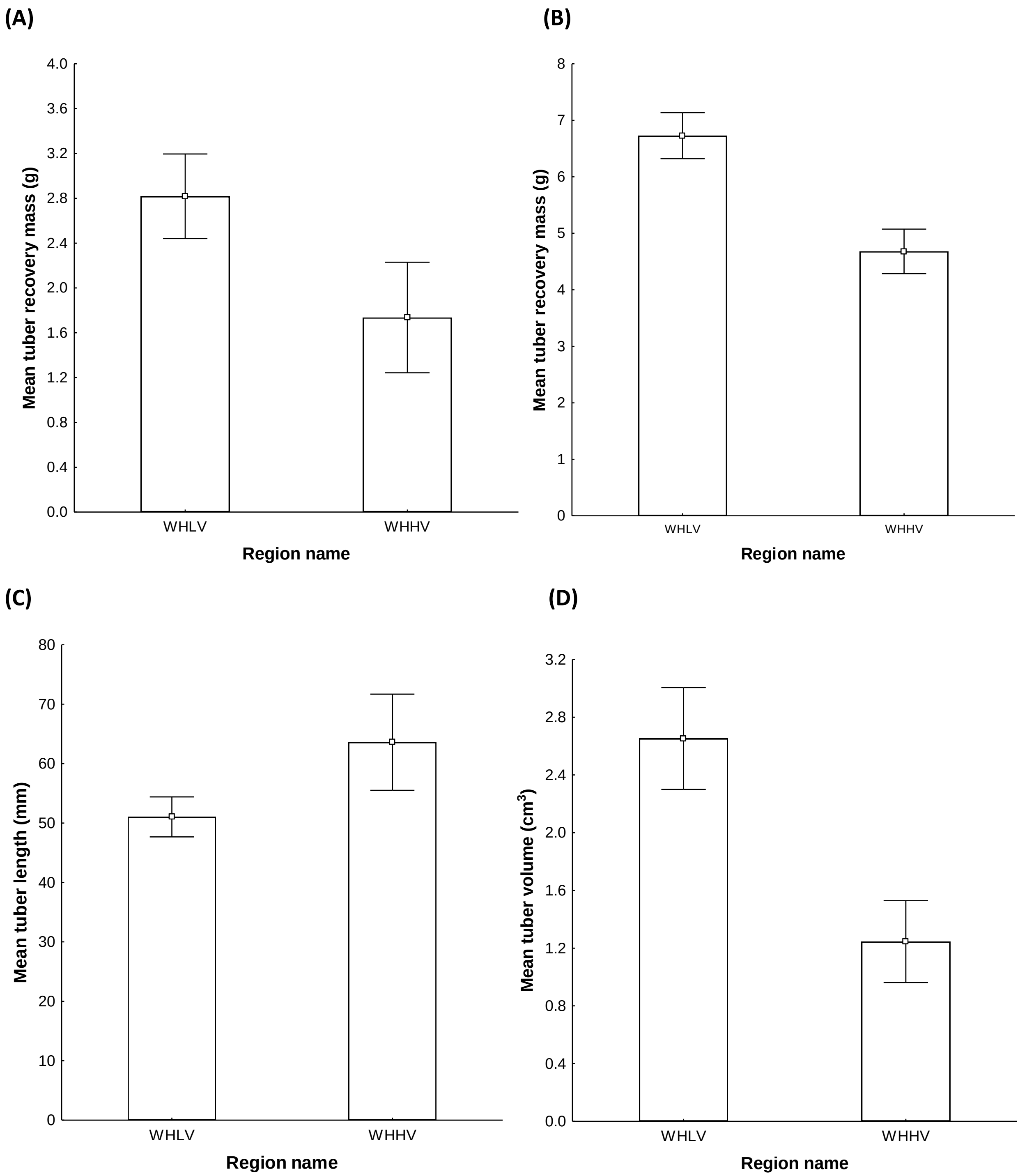


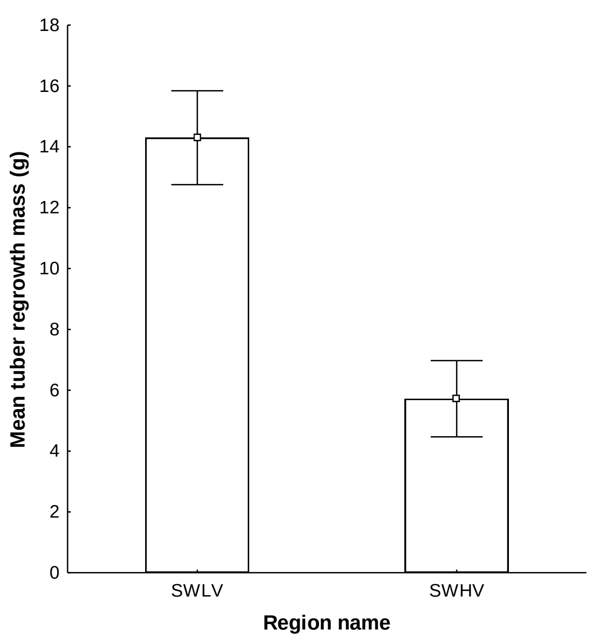
Figure 3.25. Comparisons of post harvest tuber recovery growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in wild-harvested sites from the "lowveld" (WHLV) and "higveld" (WHHV) vegetation regions. Error bars represent standard error of a mean. Significant differences detected using using student t-tests.

The results obtained above when tuber size was compared based on mean tuber size values did not differ to those found using total tuber size values except for tuber recovery diameter (Appendix 1). When using total tuber recovery diameter, there was no significant difference observed whereas using mean tuber recovery diameter yielded significant results.

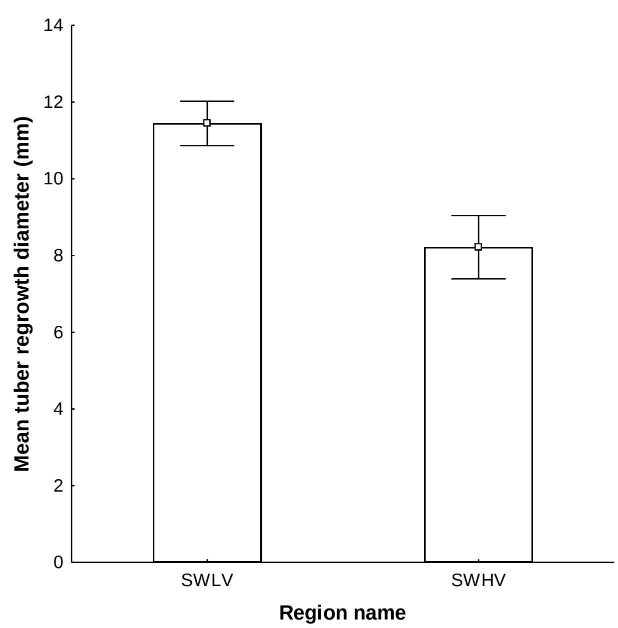
3.4.3.1.2. Comparisons on tuber regrowth size in semi-wild sites from "lowveld" and "highveld" vegetation regions

There was a highly significant difference in tuber regrowth size between the "lowveld" and "highveld" vegetation regions when comparisons were made based on mean tuber regrowth mass (t_{36}= 4.26, P = 0.0001) (Figure 3.26A). The "lowveld" vegetation region was found to have plants that were significantly larger in mean tuber regrowth mass than plants from the "highveld" vegetation region. Similarly, plants from the "lowveld" vegetation region had significantly larger mean tuber diameter than plants from the "highveld" vegetation region (t_{86}= 4.45, P = 0025) (Figure 3.26B). On the other hand, while plants from the "lowveld" vegetation region tended to be slightly larger in mean tuber recovery length than plants from the "highveld" vegetation region, the difference in the size was not significant (t_{86}= 1.87, P = 0.0697) (Figure 3.26C). Comparison on tuber regrowth size using mean tuber regrowth volume however resulted in significant difference between the two regions (t_{86}= 3.28, P = 0.0023) (Figure 3.26D).

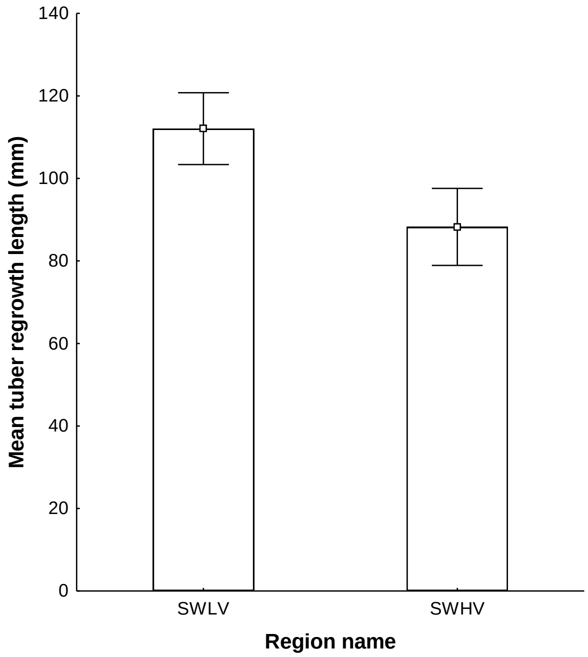
(A)



(B)



(C)



(D)

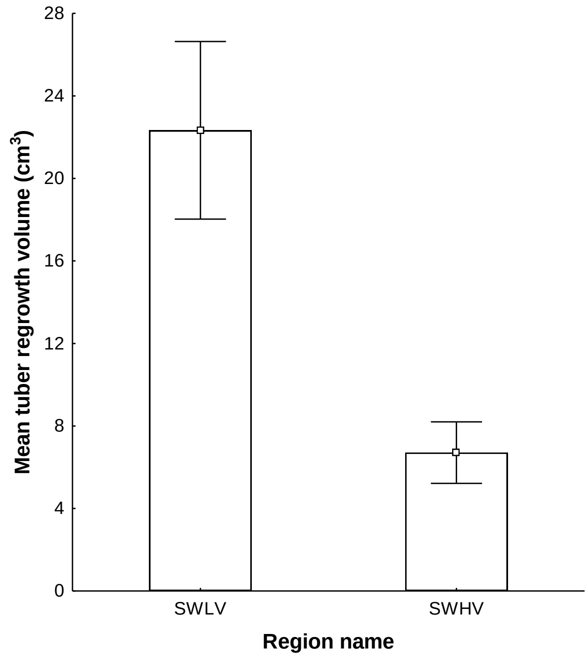


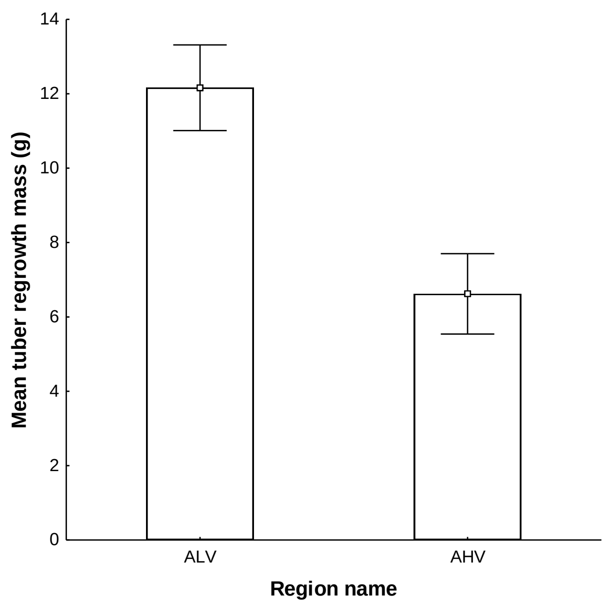
Figure 3.26. Comparisons of tuber regrowth growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in semi-wild sites from the "lowveld" (WHLV) and "higveld" (WHHV) vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

When tuber regrowth size was compared based on mean tuber regrowth sizes as above, the results obtained were not different from the results obtained when total tuber regrowth values were used (Appendix 1). However, tuber regrowth diameter was not significantly different between regions when total tuber regrowth values were used as opposed to above when mean tuber regrowth values were used.

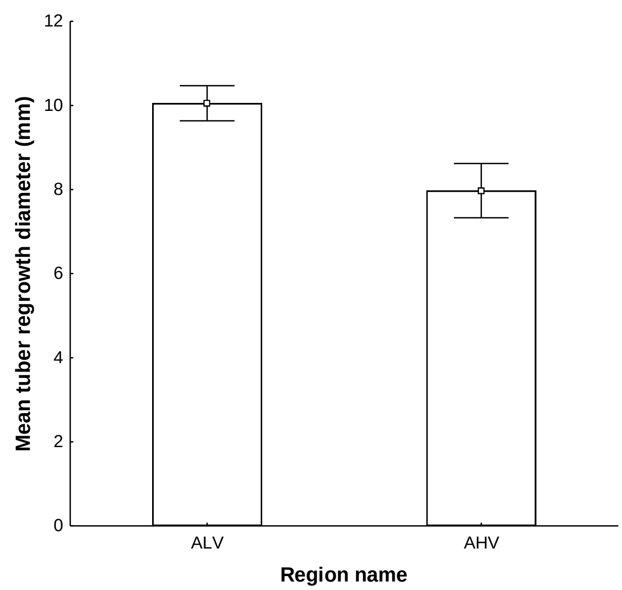
3.4.3.1.3. Comparisons on tuber size in agricultural sites from "lowveld" and "highveld" vegetation regions

To investigate how tuber regrowth size varies between the "lowveld" and "highveld" vegetation regions, comparisons were made based on mean tuber regrowth mass, tuber regrowth diameter, tuber regrowth length and tuber regrowth volume. Plants from the "lowveld" vegetation region were found to have significantly larger mean tuber regrowth mass than plants from the "highveld" vegetation region (t_{55}= 3.50, P = 0.0010) (Figure 3.27A). In the same manner, the "lowveld" vegetation region had plants with significantly larger tuber regrowth diameter than plants from the “highveld” vegetation region (t_{55}= 2.75, P = 0.0080) (Figure 3.27B). However, although plants from the “lowveld” vegetation region seemed to have larger mean tuber regrowth length than plants from the “highveld” vegetation region, the difference was not significant (t_{55}= 1.77, P = 0.0829) (Figure 3.27C). Using mean tuber regrowth volume to compare tuber regrowth size however resulted in significant difference between region with plants from the “lowveld” vegetation region depicting larger mean tuber regrowth volume than plants from the “highveld” vegetation region (t_{55}= 4.03, P = 0.0002) (Figure 3.27D).

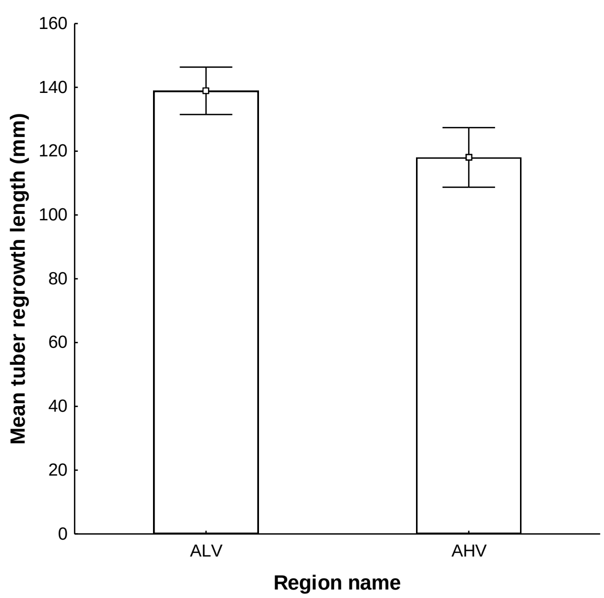
(A)



(B)



(C)



(D)

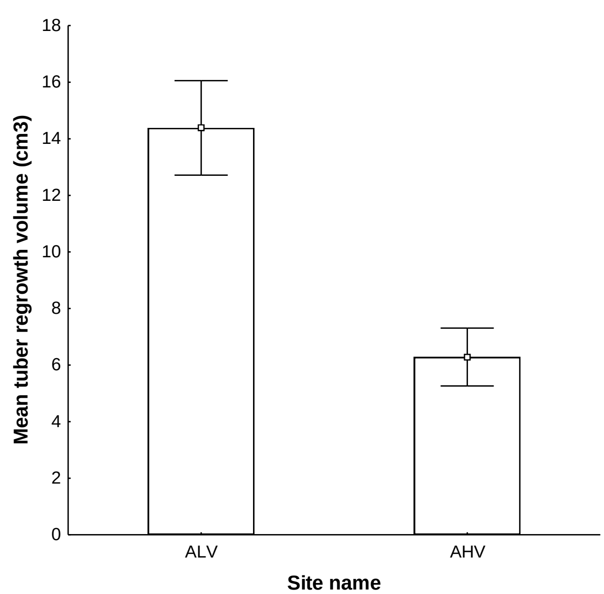


Figure 3.27. Comparisons of tuber regrowth growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in agricultural sites from the "lowveld" (WHLV) and "higveld" (WHHV) vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

Although the results obtained above when comparing tuber size using mean tuber size values were similar to those found when total tuber size values were used, using total tuber regrowth values resulted in highly significant differences in tuber regrowth size between regions (Appendix 1). This can be attributed to different times since cultivation of sites from the two regions which resulted in sites having unequal number of tubers/plant. Hence basing tuber regrowth comparisons on total tuber regowth sizes only was biased.

3.4.3.1.4. Comparisons on tuber size in unharvested control sites from "lowveld" and "highveld" vegetation regions

Tuber size of plants from the "lowveld" and "highveld" vegetation regions was compared to test if it varies between regions. A significant difference in mean tuber mass was found between the two regions (t_{140}= 2.96, P = 0.0036) (Figure 3.28A). The "lowveld" vegetation region had plants with significantly larger tuber mass than plants from the "highveld" vegetation region. However, mean tuber diameter was not significantly different between the regions (t_{140}= 0.53, P = 0.5969) (Figure 3.28B). Comparing tuber size based on tuber length produced significant difference between the regions with plants from the "lowveld" vegetation region having significantly larger tuber length than plants from the "highveld" vegetation region (t_{140}= 5.95, P < 0.0001) (Figure 3.28C). Similarly, mean tuber volume was significantly larger in the "lowveld" vegetation region as compared to the "highveld" vegetation region (t_{140}= 4.65, P < 0.0001) (Figure 3.28D).

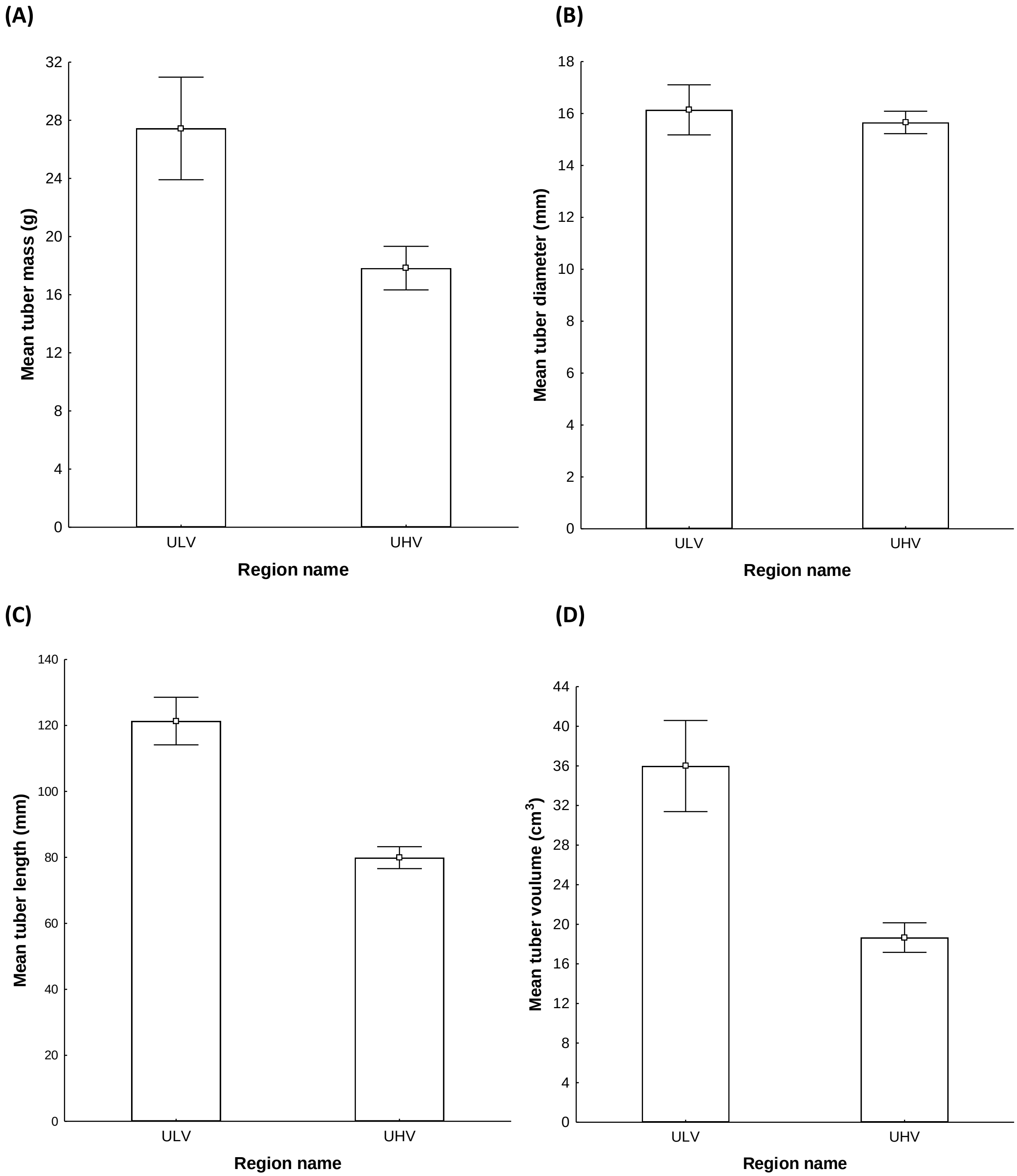


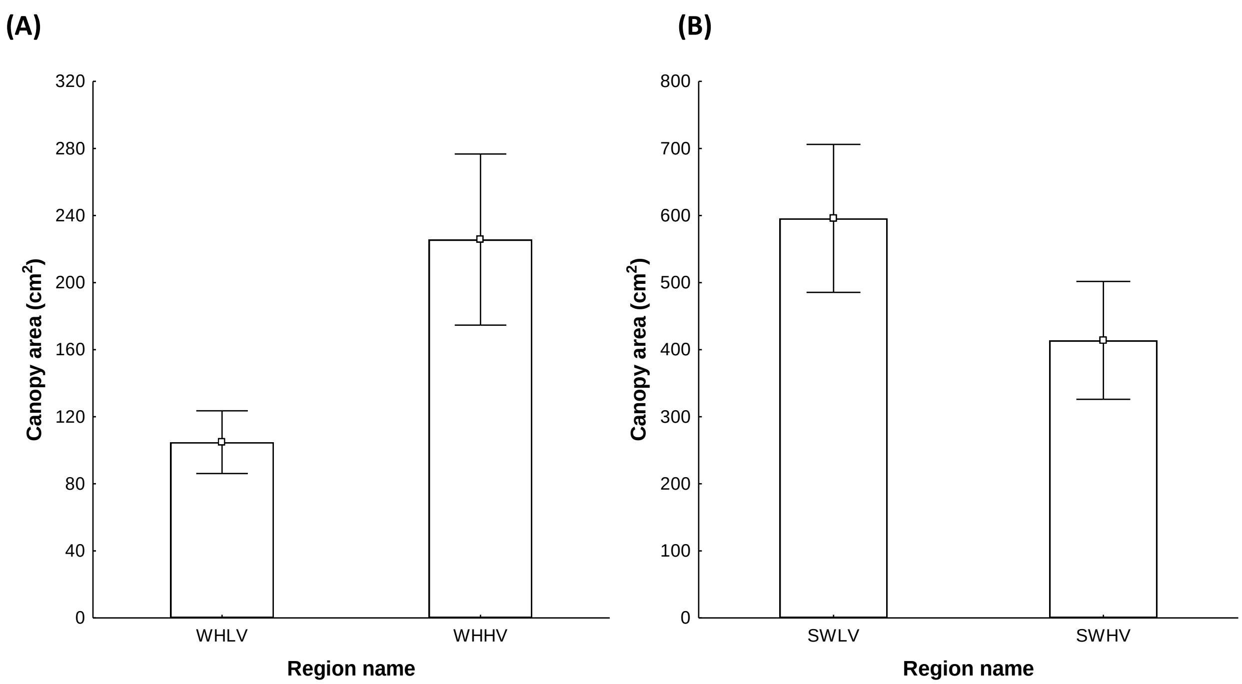
Figure 3.28. Comparisons of tuber growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in unharvested control sites from the "lowveld" (WHLV) and "highveld" (WHHV) vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

Comparing tuber size in unharvested control sites between regions using total tuber size values produced completely different results (Appendix 1). While the “lowveld” vegetation region was observed to have larger tubers when using mean tuber size values, using total tuber size values implied that plants from the “highveld” vegetation region were larger. The inconsistent results may have been caused by unequal number of tubers/plant between the two regions.

3.4.3.2. Above-ground plant growth across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

3.4.3.2.1. Comparison on canopy area between vegetation regions

Canopy area between the regions was significantly different in wild-harvested sites (t_{86}= -2.3918, *P* = 0.0192) (Figure 3.29A). Plants from the “highveld” vegetation region had larger canopies than plants from the “lowveld” vegetation region. No significant difference were obtained in canopies between semi-wild sites from the two regions (t_{36}=1.2703, *P* = 0.2121) (Figure 3.29B). Agricultural sites also had canopy area that did not differ significantly between the regions (t_{55}= 1.2188, *P* = 0.8005) (Figure 3.29C). In the same way, canopy area between unharvested control sites was not significantly different (t_{140}= -1.2150, *P* = 0.8597) (Figure 3.29D).



(C) (D)

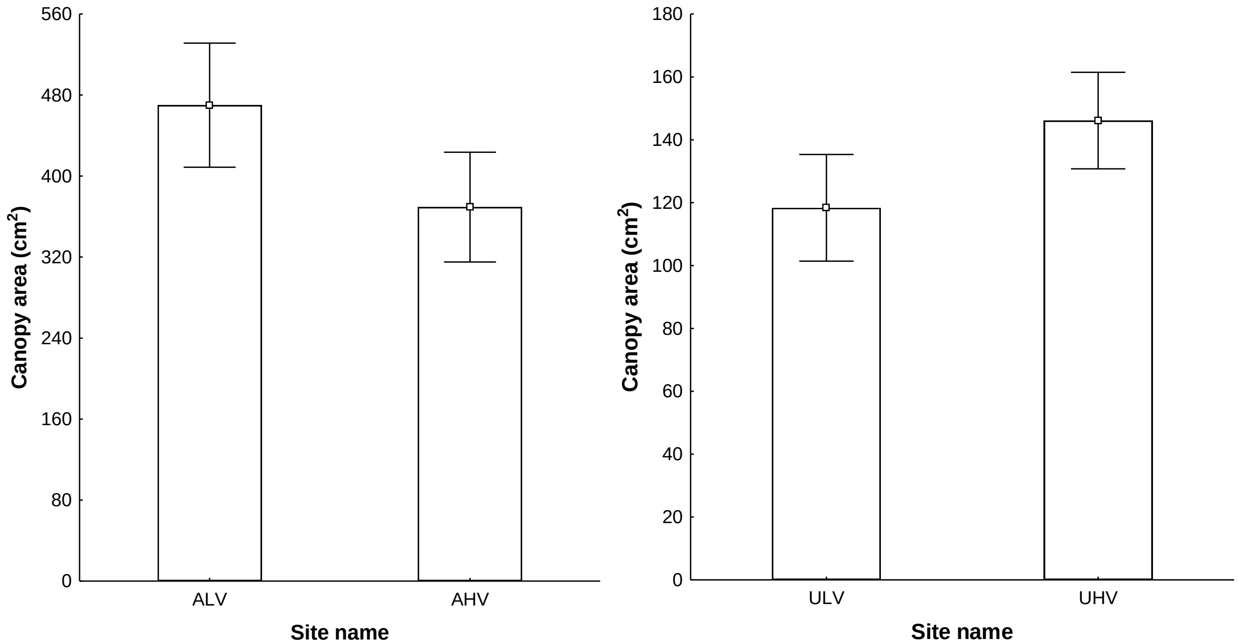


Figure 3.29. Comparisons of canopy area of Pelargonium sidoides plants in wild-harvested (A-wild harvested lowveld- WHLV, wild-harvested highveld- WHHV), semi-wild (B- semi-wild lowveld-SWLV, semi-wild highveld- SWHV), agricultural (C- agricultural lowveld- ALV, agricultural highveld- AHV) and unharvested control sites (D-unharvested control lowveld- UCLV, unharvested control highveld- UCHV) from the "lowveld" and "highveld" vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

3.4.3.2.2. Comparisons on number of stems/plant between vegetation regions

The number of stems/plant between wild-harvested sites from the "lowveld" (WHLV) and the "highveld" (WHHV) vegetation regions did not differ significantly (t_{86}= 1.2862, P = 0.0810) (Figure 3.30A). Similarly, there was no significant difference in the number of stems/plant between semi-wild sites from the two regions (SWLV-lowveld and SWHV-highveld) (t_{36}= 1.0040, P = 0.0985) (Figure 3.30B). Conversely, agricultural sites from the "lowveld" region (ALV) had significantly more stems/plant than the "highveld" region (AHV) (t_{55}= 5.2237, P < 0.0001) (Figure 3.30C). In the same way, the number of stems between unharvested control sites from the "lowveld" (UCLV) and the "highveld" (UCHV) region differed significantly (t_{140}= 3.1187, P = 0.0457) (Figure 3.30D). The unharvested control sites from the "highveld" region had more stems/plant than plants from the "lowveld" vegetation region.

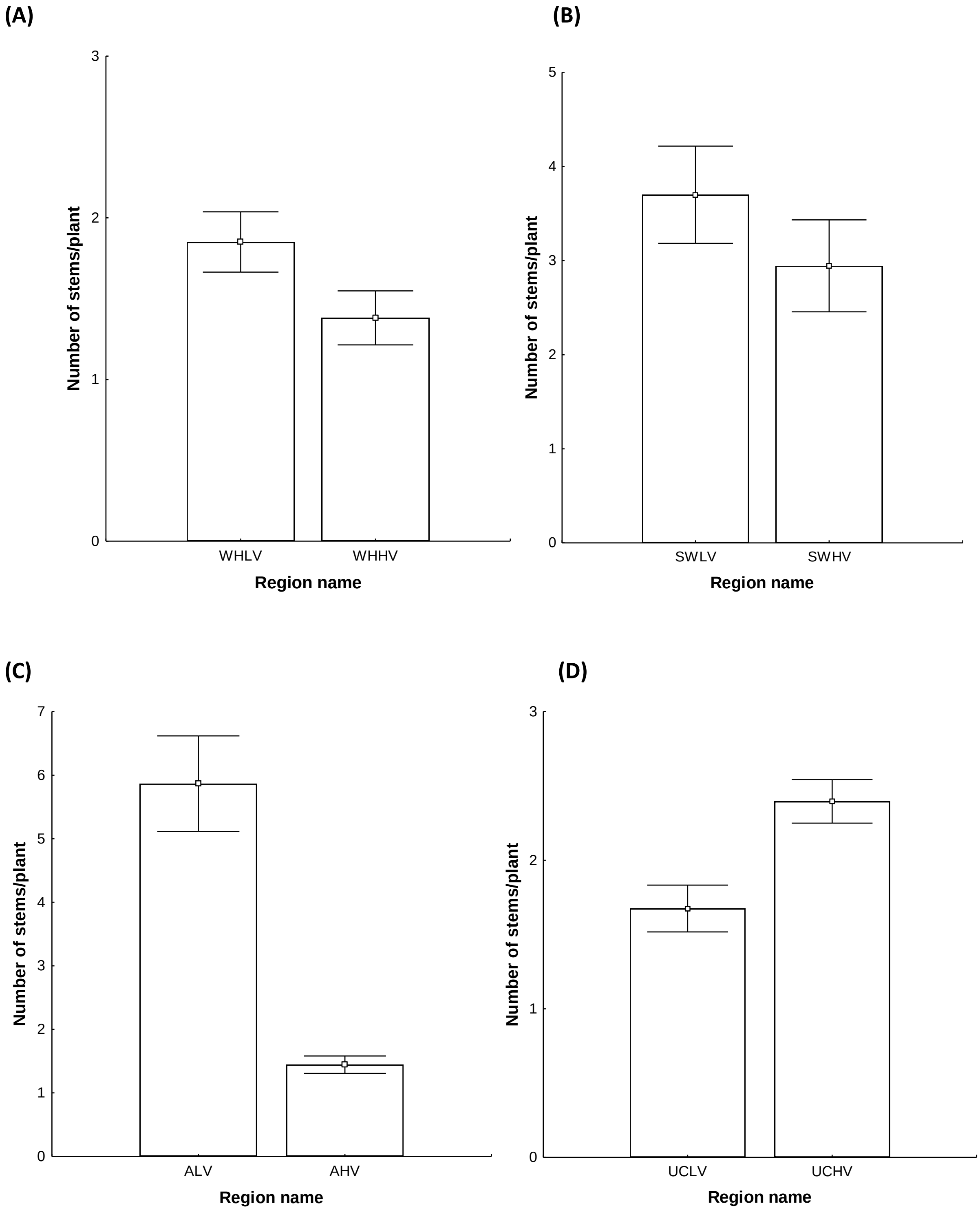


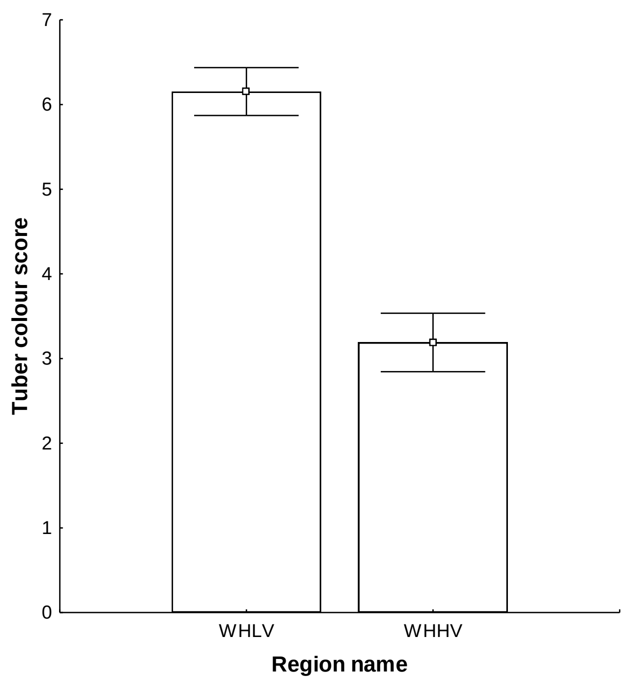
Figure 3.30. Comparisons on number of stems/plant of Pelargonium sidoides plants from different site types (WHLV, SWLV, ALV, UCLV-"lowveld" and WHHV, SWHV, AHV, UCHV- "highveld") in the "lowveld" and "highveld" vegetation region. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

3.4.3.3. Tuber mass size classes, tuber colour intensity and distribution across sites

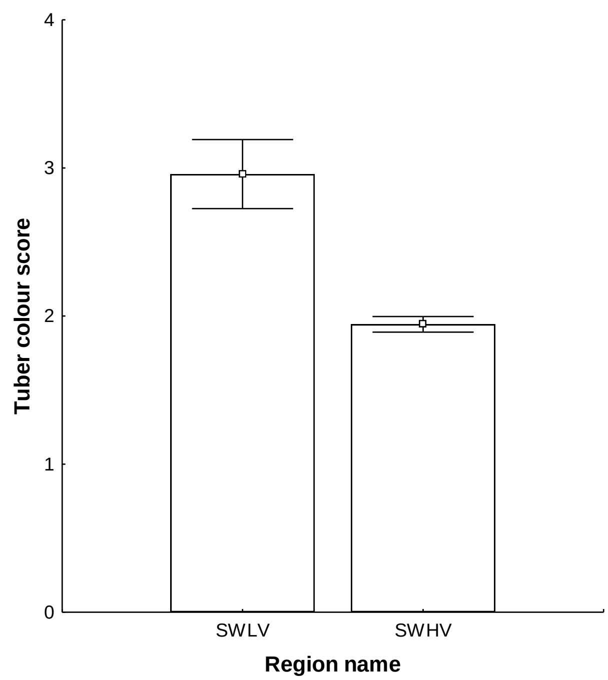
3.4.3.3.1. Tuber colour intensity between vegetation regions

There was a highly significant difference in tuber recovery colour intensity between wild-harvested sites from the "lowveld" (WHLV) and the "highveld" (WHHV) vegetation regions (t_{86}= 5.2805, $P < 0.0001$) (Figure 3.31A). The wild-harvested sites from the "lowveld" had darker coloured tuber recovery than their counterparts from the "highveld". Likewise, the semi-wild sites from the "lowveld" (SWLV) region were found to have tuber recovery that was darker than that from the semi-wild sites in the "highveld (SWHV) (t_{36}= 3.8332, P = 0.0251) (Figure 3.31B). However tuber recovery colour intensity did not differ significantly between agricultural sites from both regions (ALV-lowveld and AHV- highveld) (t_{55}= -0.1171, P = 0.0901) (Figure 3.31C). Likewise, there was no significant difference in tuber colour intensity between unharvested control sites from the two regions (t_{140}= 0.5464, P = 0.0825) (Figure 3.31D).

(A)



(B)



(C) (D)

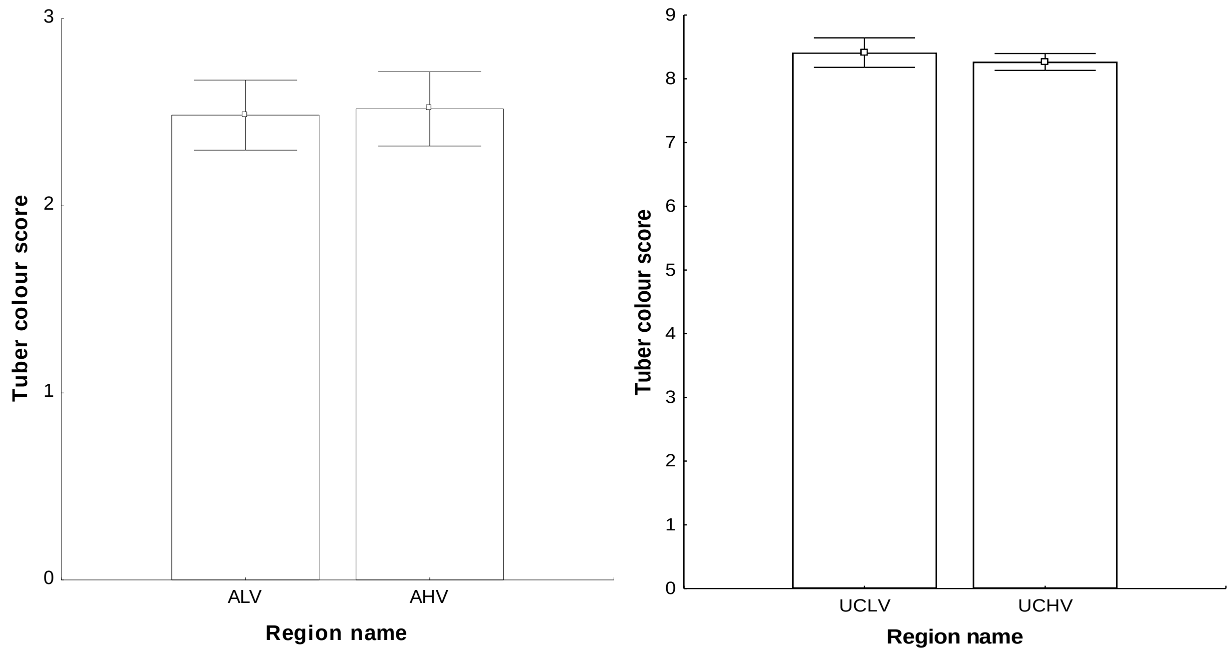


Figure 3.31. Comparisons on tuber colour intensity of Pelargonium sidoides plants in different site types (WHLV, SWLV, ALV, UCLV-"lowveld" and WHHV, SWHV, AHV, UCHV- "highveld") in the "lowveld" and "highveld" vegetation region. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

3.5. DISCUSSION

3.5.1. Below-ground plant growth across sites (wild-harvested, semi-wild, agricultural and unharvested control sites) in the "lowveld" and "highveld" vegetation regions

3.5.1.1. Comparisons on tuber size across sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

The way species respond to disturbances is dependent on their life history and physiological traits; and by characteristics of a disturbance (Gomez *et al*., 1999). For medicinal plants, the ability to reproduce (or regenerate tubers) post harvest can determine how they respond to harvest as well as environmental conditions (Ticktin, 2004a). Furthermore, for perennial plants, storage organs enable them to start spring growth (Heilmeier *et al*., 1986) and to bridge temporal gaps that often exist between resource availability and demand (Bloom *et al*., 1985; Chapin *et al*., 1990). However, it usually becomes difficult to predict how long wild populations of medicinal plants will persist when part of the population is frequently harvested because vital rates vary over time as they respond to different environmental conditions (Nantel *et al*., 1996).

Tuber recovery size in wild-harvested sites was found to differ significantly across sites. In the "lowveld" vegetation region, sites that had the longest time to recover (8 years) had tuber recovery size that was significantly larger than tuber recovery size from sites that were last harvested 3 to 7 years ago. For example, plants from W II (Wesley II) had larger tuber recovery mass, diameter and volume than plants from the rest of the sites (Figure 3.1). This indicates that *P. sidoides* tubers can recover if harvested sites are left for 10 to 15 years post harvest without any repeat harvest (Chapter 2). On the other hand, in the "highveld" vegetation region, one site that was last harvested a year ago (HNT- Ha Ntho) had significantly larger tuber recovery mass, tuber recovery length and tuber recovery volume than sites that were last harvested 3 years ago (Figure 3.13). These kind of results may have been obtained probably because the sites that were covered by the NDF study may have been harvested in the past for subsistence use but had no record of commercial extraction.

While *P. sidoides* tubers seem to recover post harvest, tuber recovery rate takes very long for sustainable commercial trade and for sustaining people's livelihoods as many people in developing countries derive an important portion of their livelihoods from harvest and sale of medicinal plants (Iqbal, 1993). Long population recovery times have also been reported for other medicinal plants such as cycads. Raimondo *et al*. (2003) found that although *Encephalartos cycadifolius* is highly persistent, it also has low levels of recruitment and is unable to recover within a reasonable conservation time frame (< 100 years). Thus the conservation of long-lived plants can be a challenge for conservation (Raimondo *et al*., 2003).

When wild-harvested and unharvested control sites were compared in the "lowveld" vegetation region, unharvested control sites had significantly larger tuber mass, tuber diameter, tuber length and tuber volume than wild-harevsted sites except for ASC (Airstrip control) (Figure 3.2). The explanation for ASC having smaller tubers than other unharvested control sites may be attributed to over-harvesting that has been reported in the area (McMaster, Private farm owner, *pers. comm*., 2009). This indicates that almost all mature plants had been previously harvested through too regular return harvest and that during field work, although the plants that were selected had been unharvested, they may have been young or recovering from very small remnant tubers. These results suggest that there is a negative impact of harvest on *P. sidoides* tuber recovery as a result of collection to meet local and international demand. Thus populations of species of anthropogenic importance have frequently been associated with reduction in frequencies of larger size classes (Rao *et al*., 1990; Shackleton *et al*., 1994) and also regeneration bottlenecks (e.g. Wilson and Witkowski, 2003). Furthermore, the results show that even after 8 years, wild harvested populations have still not recovered to pre harvest size which was found to take 10-15 years (Chapter 2). Similarly, in the "highveld" vegetation region, plants from unharvested control sites had larger tuber size than plants from wild-harvested sites (Figure 3.16). However, only four unharvested control sites had significantly larger tuber mass, tuber diameter and tuber volume than tuber recovery of plants from wild-harvested sites. When using tuber length, wild-harvested and unharvested control sites had similar tuber size except for some few sites. On the other hand, most unharvested control sites from the NDF did not differ significantly in tuber size with tuber recovery from wild-harvested sites. One reason might have been that sample size from some of the NDF sites was too small (e.g. *n*= 2) which might have obscured presence of significant results. Secondly, although unharvested, some plants from the NDF sites looked small and immature (*pers*. *obs*.). One major limitation for this study was lack of information on age structure of *P. sidoides*.

Many studies have found that population recovery following harvest of medicinal plants varies between land use types or different land management regimes and is also dependent on diameter size-classes selected. For example, Ghimire *et al*. (2005) established that rhizomes of *Nardostachys grandiflora* extracted from the national park (where harvest for trade is prohibited) were larger in diameter than those collected from the buffer zone (where harvest for trade is permitted). Furthermore, harvesters collecting rhizomes in the national park seemed to concentrate on mature size classes and left immature ones to grow and as a result population declines were reported in the buffer zone. In another study, although the population of *Adansonia digitata* was found to be generally stable in northern Venda, Venter and Witkowski (2010) concluded that there were lower densities of juveniles to mature trees in villages. This suggested that adult trees in the villages did not recruit as successfully as those in the plains. Botha *et al*. (2004) also noted that basal diameters and height of *Catha edulis* were significantly lower in harvested populations as opposed to unharvested populations.

On the contrary, other authors have argued that some disturbances may be associated with increased plant abundance and the net impact of extractive use restrictions may therefore depend on trade-offs between a population composed of many small plants and one composed of a few large plants (McGeoch *et al*., 2008). This maybe because species respond differently to disturbances depending on where they fit along the continuum between K and r strategies (Primack, 2002; Shackleton *et al*., 1994).

Generally, tuber regrowth size was similar between semi-wild and agricultural sites in the "lowveld" and "highveld" vegetation regions (Figure 3.3 and Figure 3.15). However, in the "lowveld" vegetation region, some semi-wild sites (STS- Stutterheim semi-wild) had significantly larger tuber regrowth volume than agricultural sites despite being in existence for three years compared to agricultural sites established four years ago (STA- Stutterheim agricultural). This was unexpected because plants under agricultural care received more water than plants from semi-wild sites and were thus expected to have larger tuber regrowth size. Additionally water was seen to increase the number of tubers/plants (*pers*. *obs*.). This may be because irrigation has been suggested to increase biomass yield (*Anon*., 1993). Other authors have also found that plants grown under greenhouse conditions where they receive irrigation yield more than those grown under field conditions. For example, White (2007) and White *et. al*. (2008) concluded that *P. sidoides* plants grown under greenhouse conditions exhibited six times more leaf and tuber yield than those grown under field conditions. Thus cultivation of *P. sidoides* plants can be one conservation strategy used to produce the resource and hence reduce pressure on wild populations. von Willet and Sanders (2004) however warn that water can be a limiting factor for cultivation in the dry areas of Southern Africa (von Willet and Sanders, 2004).

Comparisons across all sites regardless of their type from both regions also produced significant results with unharvested control sites having significantly larger tuber mass, tuber diameter and tuber volume than plants from wild-harvested, semi-wild and agricultural sites. Plants from semi-wild and agricultural sites had more tuber regrowth length. This may be because cultivated sites received more water than other types of sites. Similarly, when sites were combined according to site type despite the age, unharvested control sites had plants with significantly larger tuber mass, tuber diameter and tuber volume than other types of sites. On the other hand, agricultural sites were found to have significantly more tuber regrowth length than tuber recovery or tuber length from other types of sites.

Comparisons on tuber mass size-classes and tuber colour frequencies between sites produced inconsistent results in the “lowveld” and “highveld” vegetation regions. In the “lowveld” vegetation region, significant differences in tuber mass size-classes were not found at $P < 0.05$ (Figure 3.9A). However, they were found at $P < 0.10$ suggesting that increasing replication would have yielded different results. A significant difference in tuber mass size-class was found between wild-harvested and unharvested control sites in the “highveld” vegetation region (Figure 3.21A). Tuber colour frequency distributions and tuber mass size-classes were also not significantly different between different types of sites in the “lowveld” and “highveld” vegetation regions. A small sample size probably resulted into these type of results particularly because there seemed to be significant results when the data was displayed graphically.

3.5.1.2. Above-ground plant growth across sites (wild-harvested, semi-wild, agricultural and unharvested control sites) in the "lowveld" and "highveld" vegetation regions

In a changing environment, plants have various ways to adapt and they can do this when resources are limiting (Lepik *et al*., 2004). When there is nutrient shortage, plants allocate more biomass to fine roots and root: shoot ratio may increase (Aerts *et al*., 1991; Shibaike *et al*., 1996; Li *et al*., 1999; Calhill, 2003). Canopy area was significantly different across sites in the "lowveld" and "highveld" vegetation regions. In the "lowveld" vegetation region, when wild-harvested sites were compared, sites that were last harvested 8 years ago (W II- Wesley II) had plants with bigger canopies than plants from sites that were harvested 3 to 7 years ago (Figure 3.6A). This may have been the case because there was a lot of vegetation in this site (*pers*. *obs*.) which may have caused these plants to grow taller and bigger to trap enough light for photosynthesis. However, to retain competitive ability above-ground, especially at high nutrient levels, root: shoot ratios usually decline (Shibaike *et al*., 1996; van Hinsberg and van Tienderen, 1997). There was less vegetation on the other sites thus no need for plants to grow taller to get light. Another reason may have been that W II was found where there was cow dung (*pers. obs*.) and this may have contributed to more fertile soils. When wild-harvested and unharvested control sites were compared W II had bigger canopies although this was not significantly different from canopy area of plants from MF (McMaster Farm). Furthermore, because W II was harvested 8 years ago, the plants had more time to grow. This may be because a surplus of below-ground biomass can cause plants to grow bigger and form denser canopies (Shibaike *et al*., 1996; van Hinsberg and van Tienderen, 1997; Huber and Hutchings, 1997).

Plants perform differently under different habitats which differ in environmental conditions. For example, the dominant environmental stress in arctic and alpine habitats is low temperature. Plant growth in such environments can be severely restricted by low temperatures as well as by desiccation and mineral nutrient stress (Sonnesson and Callaghan, 1991). Canopy area was significantly higher in wild-harvested sites compared to unharvested control sites in the "highveld" vegetation region (Figure 3.18). This was probably because most wild-harvested sites were located at lower altitudes compared to unharvetsed control sites such as Golden Gates Highland Nature Reserve located at higher altitudes. Furthermore, plants that were obtained from wild-harvested sites that were located at lower altitudes had significantly bigger canopies than plants from sites located at higher altitudes. In particular, TSA had plants with bigger canopies than all the other sites. This may have been because plant species that inhabit harsh environments often have inherently low maximum relative growth rates compared to species from more favourable conditions (Chapin, 1980; Lambers and Poorter, 1992) such as those from lower altitudes. Additionally, the lower growth rates may be associated with low specific leaf area values of high altitudes plant (Korner and Diemer, 1987; Atkin *et al*., 1996). On the other hand, sampling season differed between wild-harvested and unharvested control sites. For instance, wild-harvested sites were sampled in the middle of March 2009 whereas the unharvested control sites were harvested in May 2009 which was towards the end of the growing season for *P. sidoides*.

In the "lowveld" and "highveld" vegetation region, canopy area between semi-wild and agricultural sites was similar (Figure 3.6 and Figure 3.18). However, in the "lowveld" vegetation region, plants from STS had slightly bigger canopies than STA although this was not significantly different. An explanation can be that STS was found in a site that had lots of vegetation and as plants strive towards maximum sunlight entrapment, they developed bigger canopies. Likewise, when all sites in the "lowveld" and "highveld" vegetation regions were compared, plants from semi-wild and agricultural sites had larger canopies. Therefore plants from cultivated sites tend to have more above-ground biomass than those from wild-harvested and unharvested control sites.

The number of stems/plant was significantly higher in sites that were last harvested 8 years ago compared to those harvested 3 to 7 years ago in wild-harvested sites from the "lowveld" vegetation region (Figure 3.7). For instance, W II had more stems/plant than all the other wild-harvested sites. This indicates that mother tubers had more time to accumulate enough biomass to recover. On the other hand, the number of stems/plant was similar in wild-harvested sites in the "highveld" vegetation region (Figure 3.19). This was probably because sites were last harvested only 1-3 years ago and hence there was not much variation in the times since last harvest to produce significant results.

When wild-harvested sites were compared with unharvested controls in the "lowveld" vegetation region, wild-harvested sites had higher number of stems/plant than unharvested control sites. *P. sidoides* seems to recover from harvesting by regenerating new stems from the point of cut (*pers*., *obs*.), thus plants from wild-harvested sites would have more stems in order to recover compared to unharvested plants which were not disturbed by harvest. This trait seems to be dependent on whether the harvesting hole was covered or not covered post harvest, size of the mother tuber, time since last harvest and on the positioning of the remaining mother tuber (*pers*. *obs*.). This may explain why the trend (more stems/plant in wild-harvested versus unharvested control sites) was not observed across all wild-harvested sites. Furthermore, the ability to resprout after a disturbance also depends on surviving meristems and availability of enough stored reserves to support regrowth (Bond and Midgley, 2001). Similarly, comparisons on the number of stems/plant between wild-harvested and unharvested control sites in the "highveld" vegetation region produced significant results. Unlike in the "lowveld" vegetation region, unharvested control sites had higher number of stems/plant than wild-harvested sites. Specifically, TSI I (Tsiame I) and TSI II (Tsiame II) had more stems/plant than other unharvested sites and wild-harvested sites. This trend might have been detected because wild-harvested sites that were compared with unharvested control sites were harvested quite recently implying that the mother tuber had still not recovered and matured fully.

In the “lowveld” vegetation region, agricultural sites were found to have more stems/plant than semi-wild sites (Figure 3.7). Furthermore, RH I (Rhodes I) had more stems/plant than other agricultural sites and semi-wild sites despite being in cultivation for one year. One reason for these results might be that the seeds that were used for initial propagation at RH I came from *P. sidoides* cultivars that were fast growing compared to RH II, other agricultural sites (established from tubers) and semi-wild sites. These results suggest that *P. sidoides* plants established from seeds might have more stems/plant than those established from tubers. Conversely, semi-wild sites had more number of stems/plant than agricultural sites in the “highveld’ vegetation region. However, since semi-wild sites had been in cultivation longer than agricultural sites, the time difference may have biased the comparison.

When all types of sites were compared in the “lowveld” vegetation region, semi-wild and agricultural sites produced significantly more stems/plant than other sites and this shows that *P. sidoides* responds well in cultivation. However, in the “highveld’ vegetation region, unharvested control sites and semi-wild sites had higher number of stems/plant than wild-harvested and agricultural sites. The times since last cultivation of wild-harvested sites and times in cultivation of semi-wild and agricultural sites might have affected the analysis and hence the results obtained. Furthermore, in the “lowveld” vegetation region, agricultural sites had higher number of stems/plant than all other types of sites when sites were grouped according to site type and regardless of times since last harvest or times in cultivation (Figure 3.8). On the other hand, semi-wild and unharvested control sites had more stems/plant than agricultural and wild-harvested sites in the “highveld” vegetation region.

To adapt to the changing environment, plants produce a variety of secondary metabolites (Shijlen *et al*., 2004). Flavonoids are some of the secondary metabolites that are produced by plants and give them pigmentation (Shijlen *et al*., 2004). In *P. sidoides* plants, dark- red coloured tubers are preferred by the pelargonium industry (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008). Tuber recovery colour intensity varied across sites in wild-harvested sites from the “lowveld” vegetation region. Tuber recovery from sites that were last harvested 4 to 8 years ago was more dark-red coloured than tuber recovery from sites that were last harvested 3 years ago. The results indicate that tuber recovery colour intensifies with time. Furthermore, findings of the previous chapter confirmed that tuber recovery colour takes at least 8 years to get to the commercially preferred dark-red colouration (Chapter 2). This was expected because sites that were last harvested 4 to 8 years ago have experienced more environmental stress and hence an increase in their amounts of secondary metabolites. In the “highveld” vegetation region, tuber recovery colour was similar in all sites after 3 years since last harvest which was not surprising because sites that were last harvested 3 years ago in the “lowveld’ vegetation region also had similar tuber recovery colour. Comparisons on tuber colour between wild-harvested and unharvested control sites also produced significant outcomes. Generally, unharvested control sites were found to have darker-red coloured tubers than tuber recovery in wild-harvested sites; however, this was not significantly different to tuber recovery colour of plants from W I (Wesley I). This may indicate that tuber recovery colour requires at least 8 years to be dark-red coloured. Similarly, tubers from unharvested control sites were more dark-red coloured than tuber recovery from wild-harvested sites in the “highveld” vegetation region. Even after 3 years in cultivation, wild-harvested sites did not have dark-red coloured tuber regrowth.

Tuber regrowth colour was similar between semi-wild and agricultural sites in the “lowveld” vegetation region. These kind of results were obtained despite semi-wild sites being somehow closer to wild-harvested sites in management regime than agricultural sites and were thus expected to have darker tuber regrowth colour than agricultural sites. This is because some secondary metabolites have been hypothesized to be produced when plants experience water stress (Ojala, 2001). This means plants from semi-wild sites would have darker red coloured tuber regrowth than plants from agricultural sites as they received less water. Additionally, in semi-wild sites, plants experienced more competition from other plants compared to agricultural sites which would have caused more stress. This is because some authors have concluded that secondary metabolites can also be produced as an allelopathic response to the surrounding environment (Uritani, 1999; Urdangarin *et al*., 2004). However, in the “highveld” vegetation region, agricultural sites had darker coloured tuber regrowth than semi-wild sites.

When all types of sites were compared in the “lowveld” vegetation region, unharvested control and wild-harvested sites that were harvested 4 to 8 years ago had darker red coloured tubers than tubers from semi-wild, agricultural and wild-harvested sites that were last harvested 3 years ago. Likewise, tubers from unharvested control sites in the “highveld” vegetation region were more dark-red than tubers from wild-harvested, semi-wild and agricultural sites. In the same manner, grouping sites according to site type and regardless of their times since last harvest or times in cultivation in both regions gave significant results. Unharvested control sites had significantly darker-red coloured tubers than wild-harvested, semi-wild and agricultural sites. However, tuber recovery from wild-harvested sites was a darker red colouration than semi-wild and agricultural sites. The results indicate that tuber regrowth colour intensification in cultivated sites takes longer than in wild-harvested sites. One reason for this might be that under cultivation, secondary metabolites that are usually produced by plants in response to environmental stress are reduced (Schippmann *et al*., 2002). These results have negative implications for conservation of wild populations of *P. sidoides*. This is more so because tuber recovery seems to be impacted by harvest and therefore cultivation of *P. sidoides* maybe one option to conserve wild populations of *P*. *sidoides*.

3.5.3. Below-ground plant growth between “lowveld” and “highveld” vegetation regions according to site type

3.5.3.1. Below-ground plant performance

Significant differences were detected in tuber recovery size based on tuber recovery diameter and volume in wild-harvested sites between the “lowveld” and “highveld” vegetation regions. However, this trend was not detected when tuber recovery size was measured based on tuber recovery mass and length. Plants from the “lowveld” vegetation region had larger tuber recovery diameter and volume than plants from the “highveld” vegetation region. While these results indicate that wild-harvested plants from the “lowveld” vegetation region have larger tuber recovery mass, this may have been a result of variation in the times since last harvest between the regions. For instance, wild-harvested sites in the ‘lowveld” vegetation region varied much in the times since last harvest (e.g. sites were last harvested 3-8 years ago) and thus had more time to recover. On the other hand, in the “highveld” vegetation region, wild-harvested sites that were used for this study were last harvested 1-3 years ago. Therefore, there could have been an age bias in wild-harvested sites between the two regions which favoured the “lowveld” vegetation region to the “highveld” vegetation region. However, although tuber recovery length was not significantly different between the two regions, plants from the “highveld” vegetation region seemed to have larger tuber recovery length. This may indicate that harvesters fill up harvest holes post harvest in the “highveld” vegetation region. Furthermore, according to the Pelargonium industry personnel (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008), harvest holes are closed up post harvest and the same observation was made during this study in the “highveld’ vegetation region (*pers*. *obs*.). Filling up harvest holes post harvest can be expected to increase tuber recovery size, especially tuber recovery mass and length. This is more so because below-ground stem in other plants such as potatoes has been reported to elongate as mother tubers are planted deeper (Stalham *et al*., 2001).

Plants from semi-wild and agricultural sites from the “lowveld” vegetation region had significantly larger tuber regrowth size than plants from the “highveld” vegetation region. Tuber regrowth mass, diameter and volume were found to be larger in the “lowveld” vegetation region compared to “highveld’ vegetation region. However, this may have been caused by different times in cultivation of sites from the two regions. For instance, cultivated sites were established relatively a while ago in the “lowveld’ vegetation region compared to those in the “highveld” vegetation region and this might have given the former region an advantage. Plants from the two regions had similar tuber regrowth length.

Plant growth rates depend on factors such as habitat and environmental conditions (Tictin, 2004a). For example, outcrop habitats are characterized by harsh environmental conditions that limit plant growth (de Lange and Norton, 2004). Tuber size (tuber mass, length and volume) except for tuber diameter was significantly larger in unharvested control sites from the “lowveld” vegetation region compared to the “highveld” vegetation region. The “highveld” vegetation region is characterized by rocky areas and harsh environmental conditions typical of higher altitudes hence tuber size would be smaller.

3.5.3.2. Above-ground plant size

P. sidoides is widely distributed across a wide range of habitats with varying altitudes (Van der Walt and Vorster, 1988; Dreyer and Marais, 2000). The selective pressures for leaf growth rates and duration change with altitude probably due to declines in temperature and growing season (Geiger, 1965; Billings, 1974). Canopy area did not vary significantly between different types of sites from the two regions. Therefore canopy area in wild-harvested, semi-wild, agricultural and unharvested control sites from the “lowveld” and “highveld” regions was similar. The results imply that altitudinal aspects do not determine canopy size in *P. sidoides* plants. This is despite that increases in altitude changes many parameters of the environment which makes growth conditions more severe for plants at high altitude versus plants at low altitudes (Korner *et al*., 1989). This suggests that growth of *P*. *sidoides* plants growing at high altitudes may be negatively affected. Additionally, growing season for *P. sidoides* is shorter in the “highveld” vegetation region compared to the “lowveld’ vegetation region, therefore plants from the former region would have smaller canopy area. Furthermore, the “highveld” vegetation region is colder than the “lowveld’ vegetation region.

The number of stems/plant did not vary between wild-harvested and semi-wild sites. However, there were more stems/plant in the “lowveld” vegetation region on agricultural sites than in the “highveld” vegetation region. On the contrary, the unharvested control sites from the “highveld” had more stems/plant than those from the “lowveld” vegetation region.

Tuber recovery colour was found to be significantly different between regions in wild-harvested and semi-wild sites. Tuber recovery colour was more darker-red in the “lowveld’ vegetation region than in the “highveld’ vegetation region. The results suggest that tuber recovery colour is more intense in tuber recovery from the “lowveld” vegetation region. This may imply that the active ingredient in tuber recovery of plants last harvested 4 to 8 years ago is more concentrated than in tuber recovery of plants harvested 3 years ago. However, since wild-harvested sites from the “lowveld” vegetation region were last harvested up to 8 years ago, they had more time to recover and develop intense tuber recovery colour. Similarly, tuber regrowth colour in semi-wild sites was more intense in the “lowveld” vegetation region compared to the “highveld” vegetation region. Sites from the “lowveld” vegetation region were put in cultivation 3 years ago whereas in the “highveld” vegetation region it was 11/2 years ago. The difference in the times in cultivation between the regions could have put the “lowveld” vegetation region at an advantage. Tuber regrowth and tuber colour intensity was similar in agricultural sites from the two regions. Unharvested control plants from both regions also had similar tuber colour intensity.

3.6. CONCLUSION

The results of this study have revealed that tuber recovery size of previously wild-harvested plants is smaller compared to tuber size of unharvested plants even at 8 years since last harvest. Thus coupled with slow tuber recovery rates as shown in chapter 2 (10-15 years), extensive harvest of *P. sidoides* plants can negatively affect its wild populations should such harvest occur before 10-15 years has elasped. This simply means extensive harvest can only be sustainable if it occurs after 10-15 years (Chapter 2). Thus although *P. sidoides* seems to be a good resprouter, tuber recovery in wild-harvested sites is very slow for sustainable commercial harvest. On the other hand, owing to its wide distribution, it is unlikely that *P. sidoides* wild populations are facing immediate threat of ecological extinction due to harvest. Localized commercial extinction is however likely if repeat harvest is carried out before 10-15 years in previously wild-harvested sites. Although a too soon repeat harvest can negatively affect previously wild harvested *P. sidoides* populations, other researchers have argued that the greatest threat to wild populations of *P. sidoides* is not wild harvesting but habitat destruction (de Castro *et al.*, *in prep*.). To counteract this, cultivation of *P. sidoides* can be increased in Lesotho and South Africa to supply the trade demand. This is particularly so because this study has also shown that tuber regrowth biomass of cultivated plants is larger than tuber recovery biomass of wild-harvested plants even after 8 years since they were last harvested. This can be a viable alternative since tuber regrowth biomass of cultivated plants attained similar biomass to that of unharvested control plants after only 9 years (Chapter 2). This is as opposed to tuber recovery of wild harvested plants that only attains similar biomass to that of unharvested plants after 10-15 years. However tuber colour which appears to be the industry's requirement develops more slowly under cultivation. Hence more research is required on producing darker coloured tubers that are presumed to be high in the required medicinal compounds.

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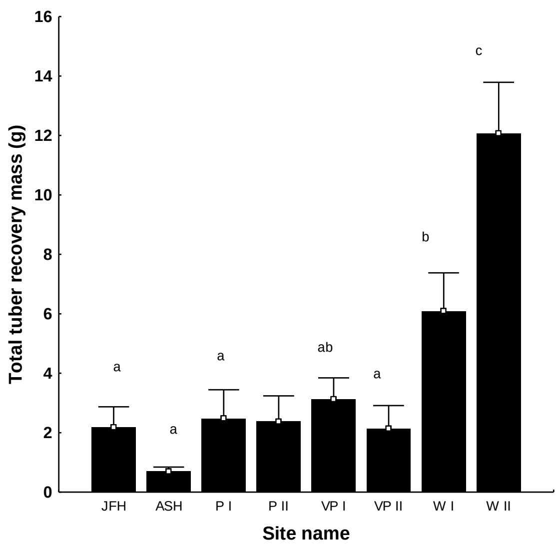
APPENDIX 1. Results on comparison of below-ground and above-ground plant size (using total tuber size values) in *Pelargonium sidoides* plants across different types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites) in the "lowveld" and "highveld" vegetation regions

3.4 RESULTS

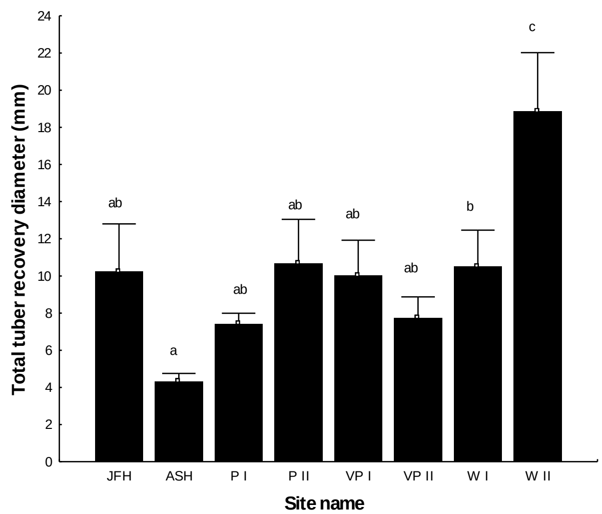
3.4.1 "Lowveld" vegetation region

3.4.1.1 Comparisons on tuber recovery size in wild harvested sites

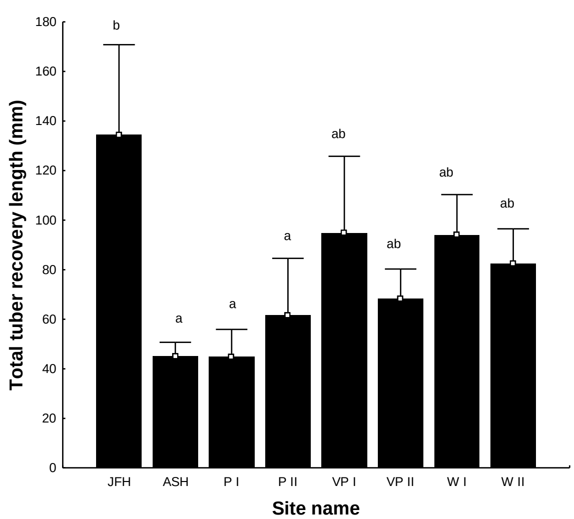
(A) ($F_{7,59}$ = 11.6338, P < 0.0001)



(B) ($F_{7,59}$ = 3.9481, P = 0.001)



(C) ($F_{7,59}$ = 1.8294, P = 0.096)



(D) ($F_{7,59}$ = 3.8296, P = 0.002)

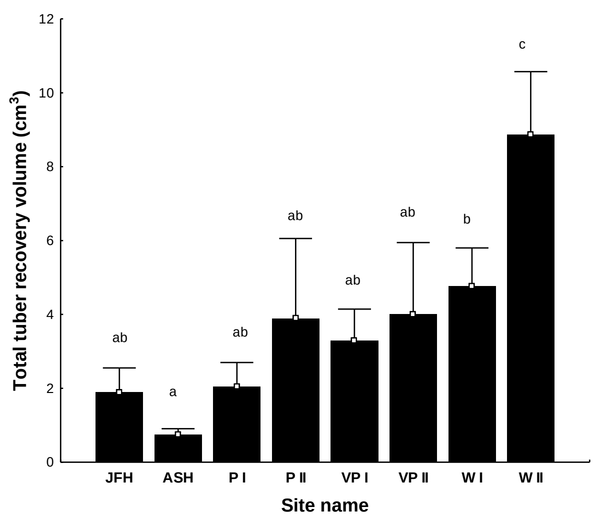
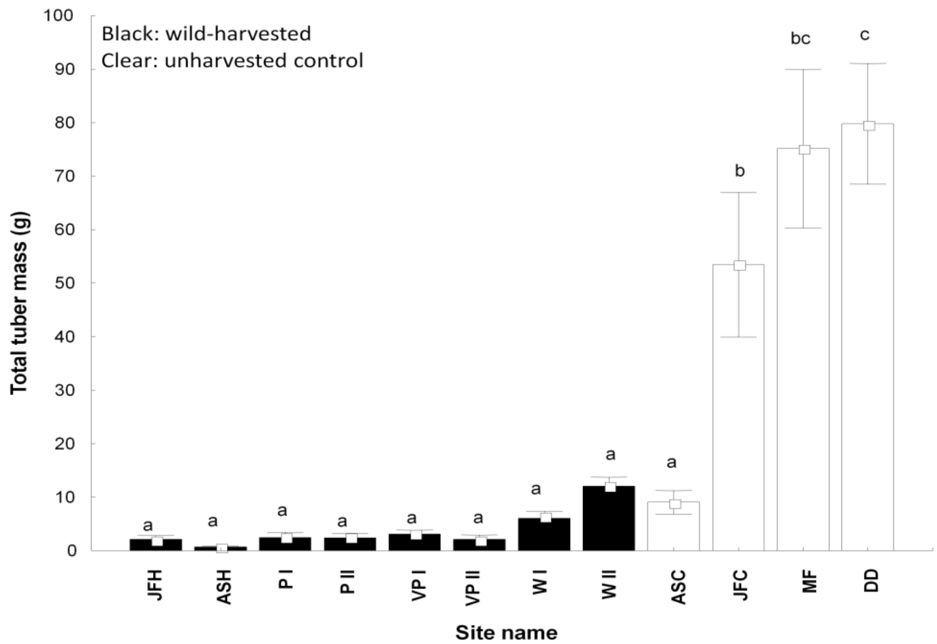


Figure 3.1. Comparisons of post-harvest tuber recovery growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides

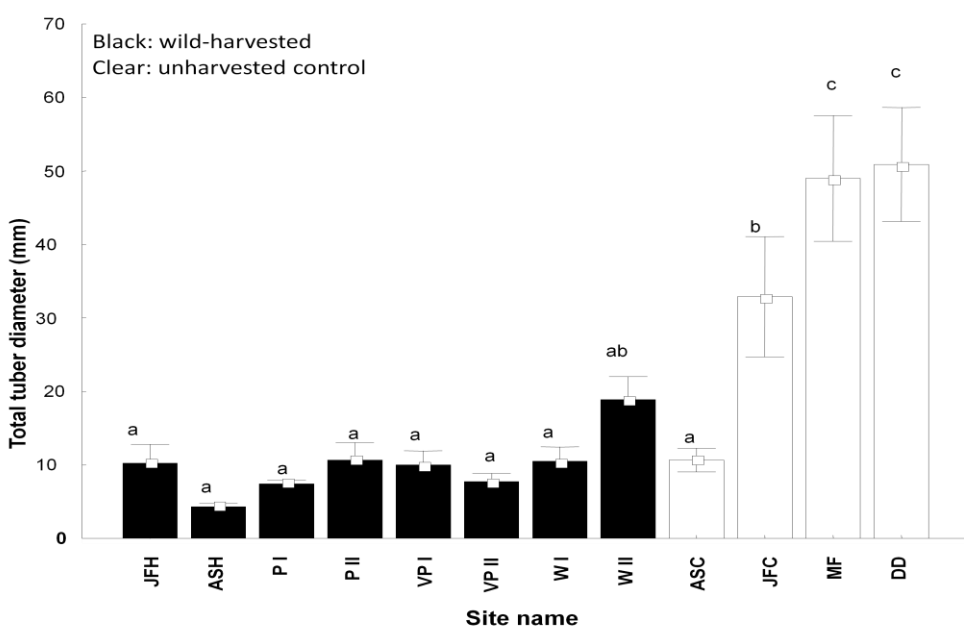
plants in wild-harvested sites of differing ages in the 'lowveld" vegetation region (JFH=Janine farm harvested (3 years), ASH= Airstrip harvested (3 years), P I= Peddie I (4 years), P II= Peddie II (4 years), VP I= Victoria Post I (5 years), VP II= Victoria Post II (5 years), W I= Wesley I (7 years) and W II= Wesley II (8 years)). Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.1.2 Comparisons on tuber growth in wild harvested and unharvested control sites

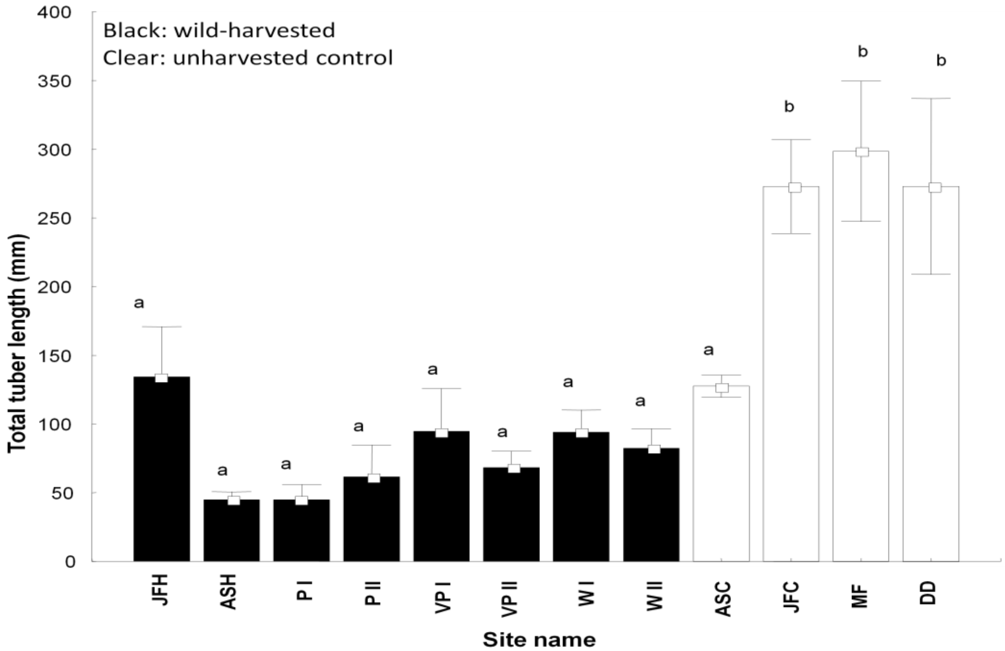
(A) ($F_{11,95}$ = 11.6672, P < 0.001)



(B) ($F_{11,95}$= 8.3441, P < 0.001)



(C) ($F_{11,95}$ = 7.2384, P < 0.001)



(D) ($F_{11,95}$ = 11.3529, P < 0.001)

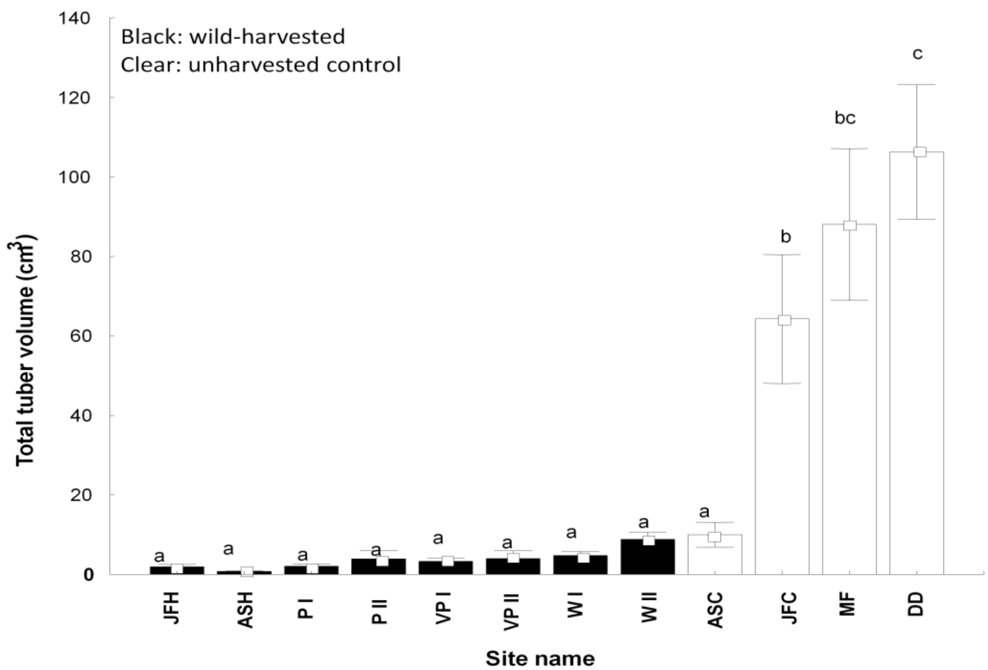
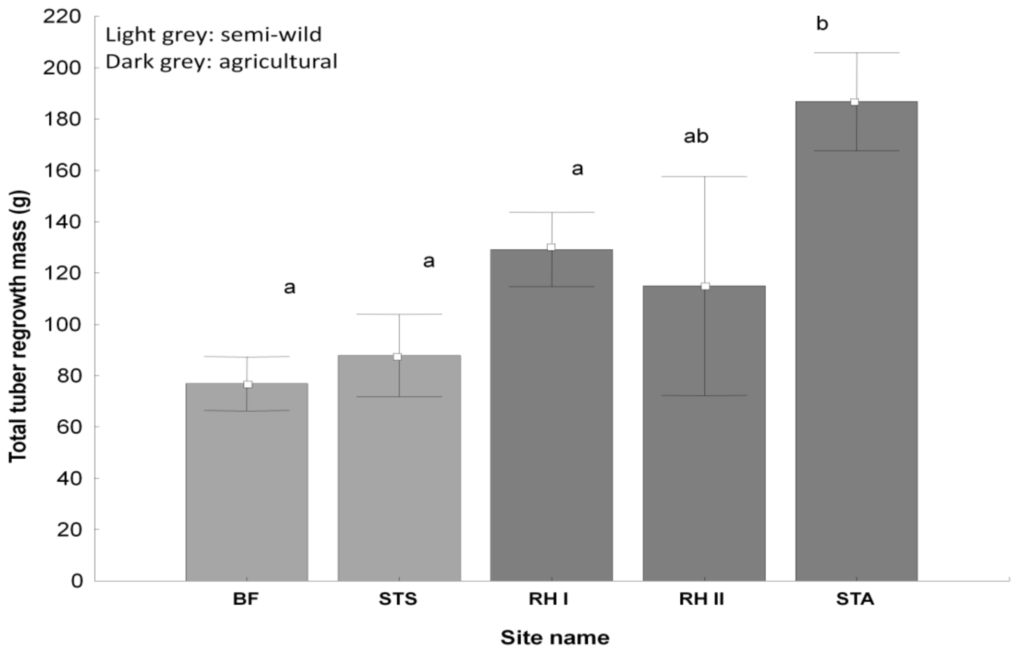


Figure 3.2. Comparisons of Pelargonium sidoides plant growth in wild-harvested ("tuber recovery", JFH=Janine farm harvested (3 years), ASH= Airstrip harvested (3 years), P I= Peddie I (4 years), P II= Peddie II (4 years), VP I= Victoria Post I (5 years), VP II= Victoria Post II (5 years), W I= Wesley I (7 years) and W II= Wesley II (8 years)).) and unharvested control plants ("tuber", (ASC= Aistrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift) in the 'lowveld" vegetation region. Error

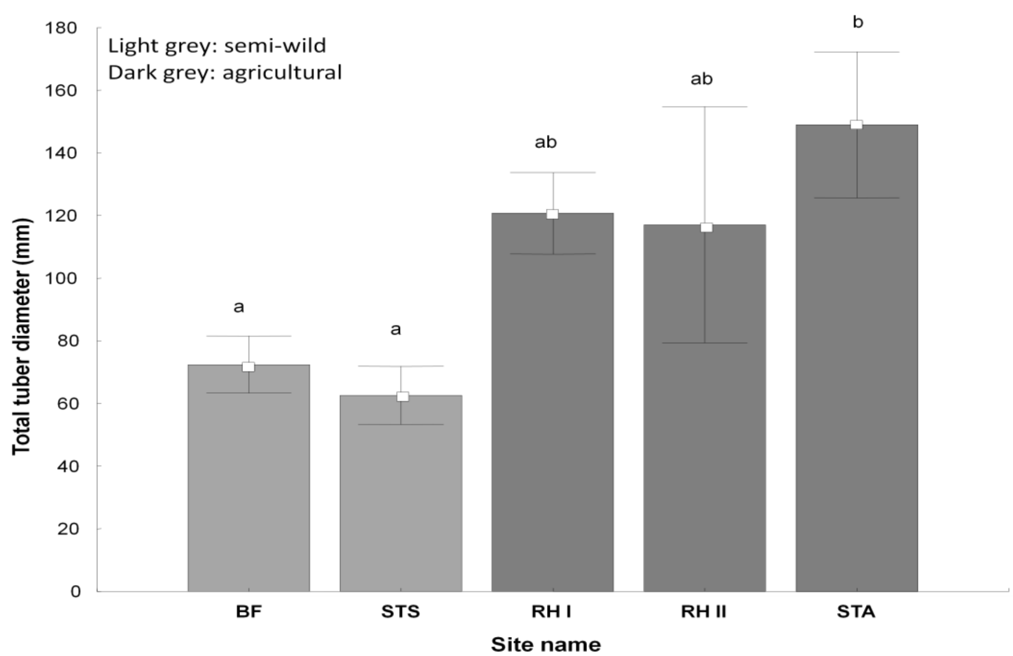
bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.1.3 Comparisons on tuber regrowth size in semi-wild and agricultural sites

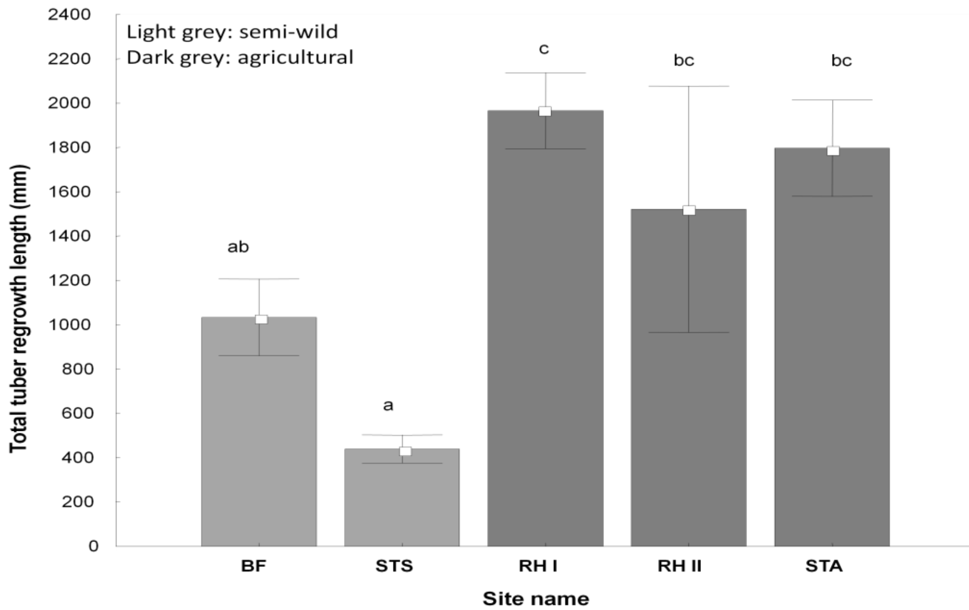
(A) ($F_{4,45}$ = 3.0375, *P* = 0.027)



(B) ($F_{4,45}$ = 2.5368, *P* = 0.053)



(C) ($F_{4,45}$ = 4. 1335, P= 0.006)



(D) ($F_{4,45}$= 7.6316, P < 0.001)

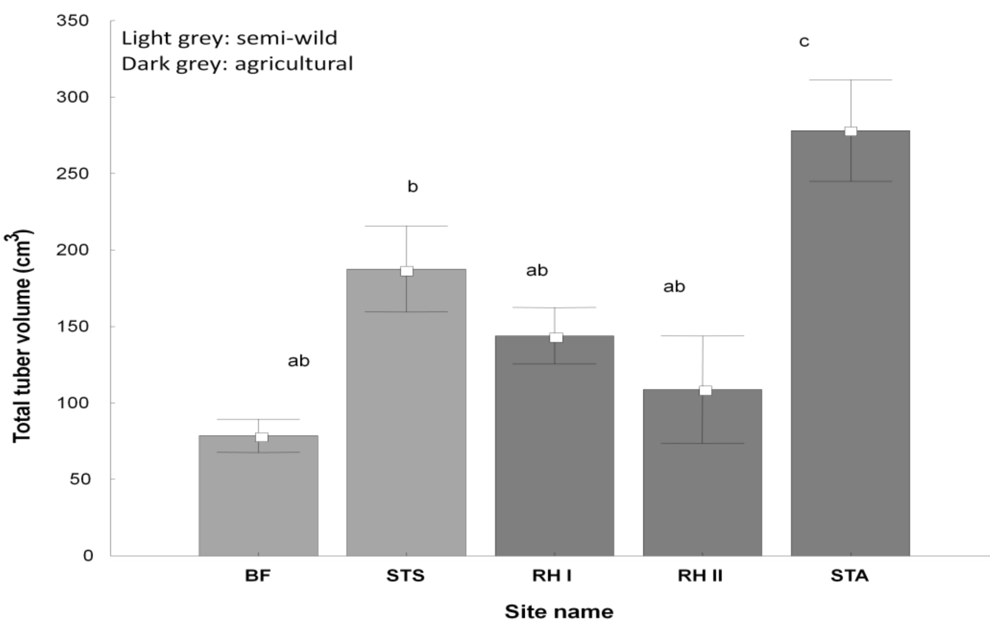
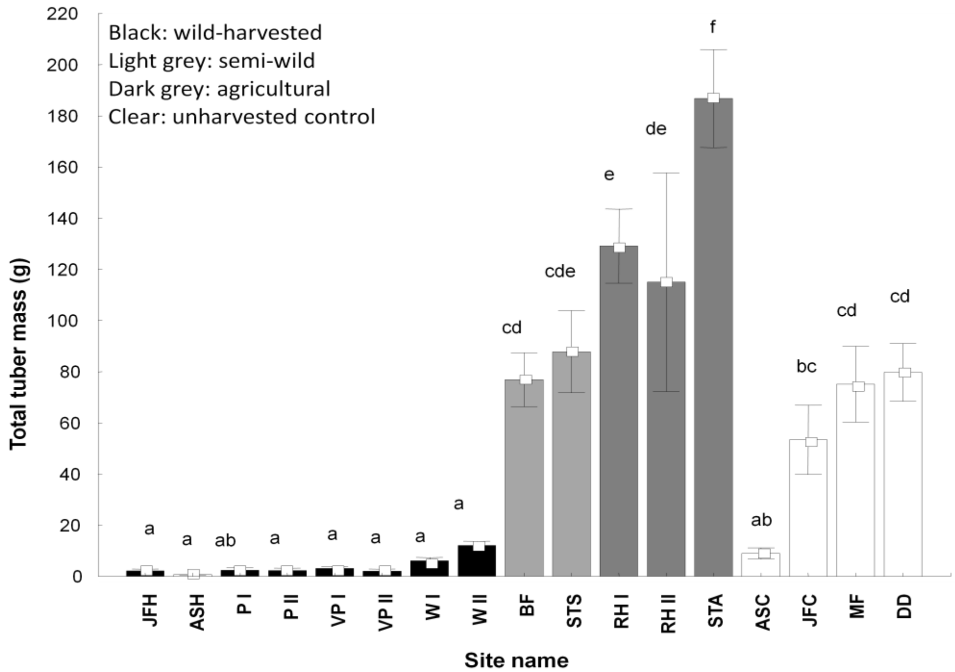


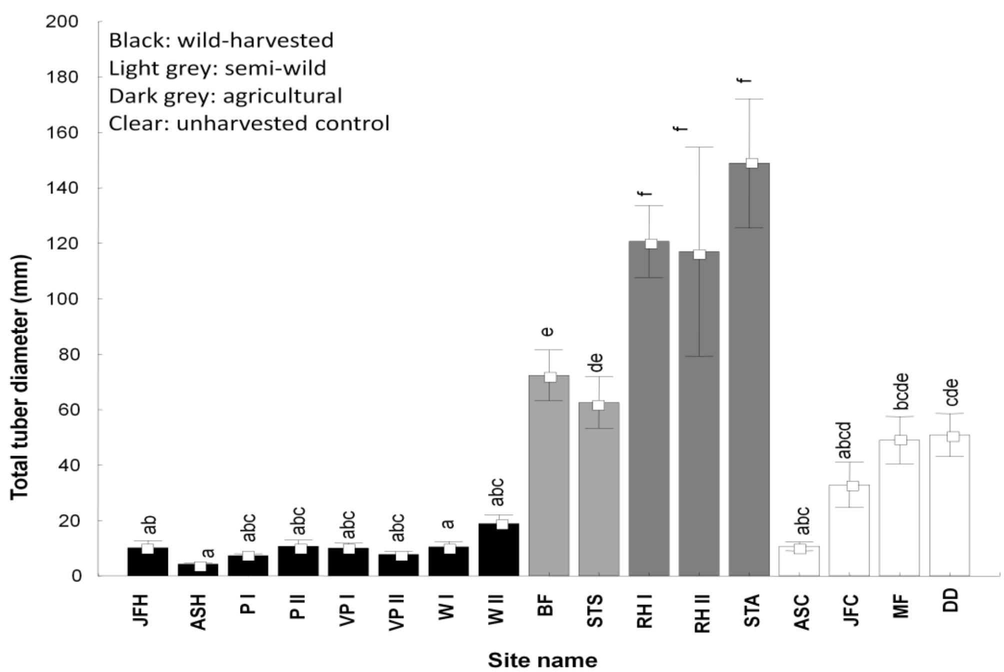
Figure 3.3. Comparisons of 'tuber regrowth" of Pelargonium sidoides plants in semi-wild (BF= Bold farm (2 years), STS= Stutterheim semi-wild (3 years)) and agricultural sites (RH I= Rhodes I (1 year), RH II= Rhodes II (2 years) and Stutterheim agricultural (4 years) of differing ages in the 'lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.1.4. Comparisons on tuber size across all types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

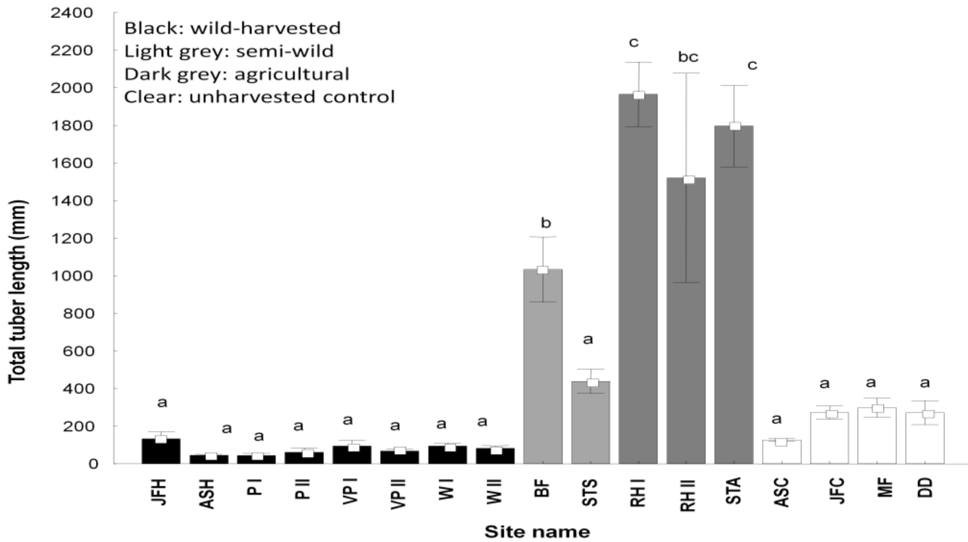
(A) ($F_{16,140}$= 11.9737, *P* < 0.001)



(B) ($F_{16,140}$= 10.7769, *P* < 0.001)



(C) ($F_{16,140}$= 13.4015, P < 0.001)



(D) ($F_{16,140}$= 17.8938, P < 0.001)

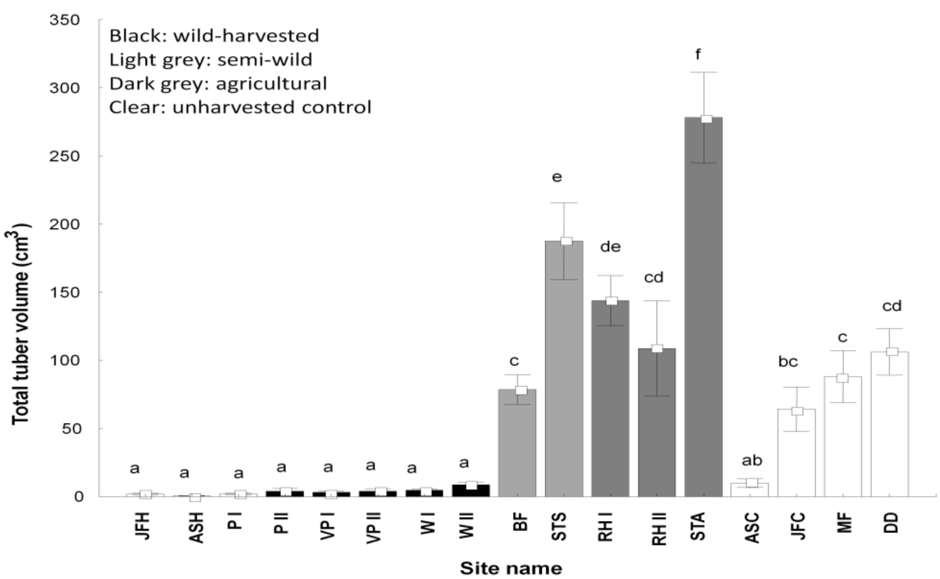
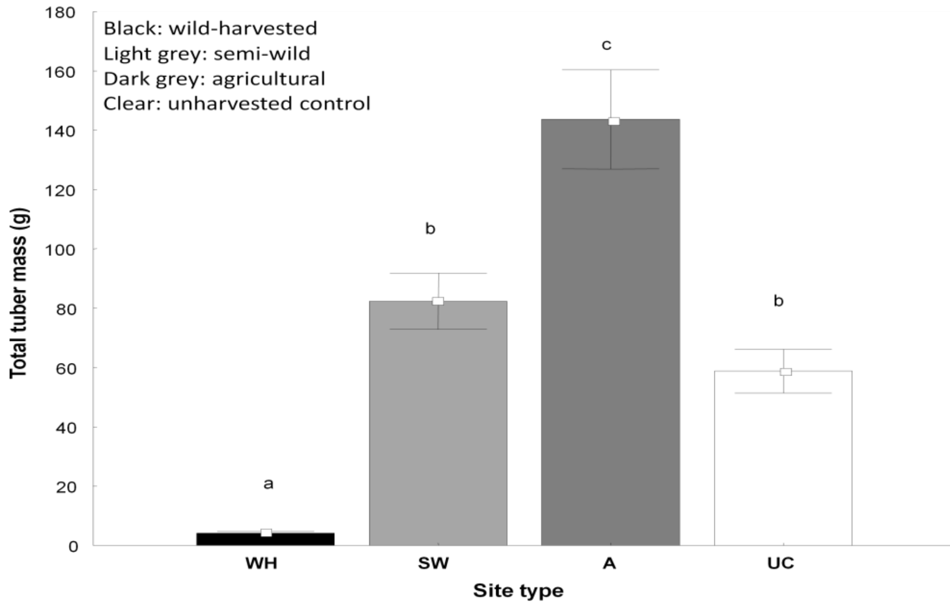


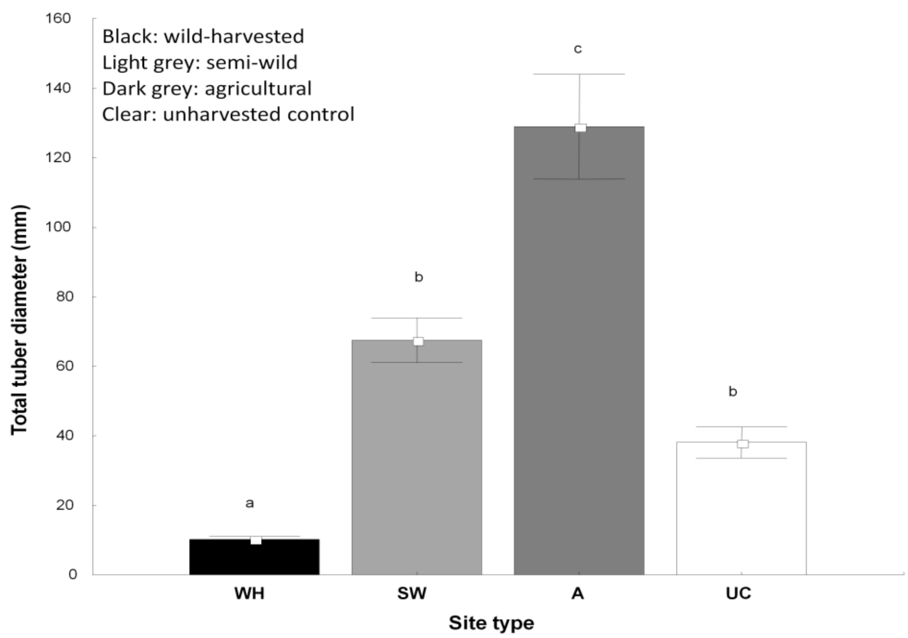
Figure 3.4. Comparisons of plant growth of Pelargonium sidoides in wild-harvested ("tuber recovery", JFH=Janine farm harvested (3 years), ASH= Airstrip harvested (3 years), P I= Peddie I (4 years), P II= Peddie II (4 years), VP I= Victoria Post I (5 years), VP II= Victoria Post II (5 years), W I= Wesley I (7 years) and W II= Wesley II (8 years)), semi-wild ("tuber regrowth", BF= Bold farm (2 years), STS= Stutterheim semi-wild (3 years)) and agricultural sites ('tuber regrowth", RH I= Rhodes I (1 years), RH II= Rhodes II (2 years) and Stutterheim agricultural (4 years)) and unharvested control sites ("tuber", ASC= Aistrip control, JFC= Janine farm control, MF= McMaster farm and DD= Double-Drift) in the 'lowveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.1.5 Comparisons on tuber size when sites are grouped according to site type (wild-harvested- WH, semi-wild- SW, agricultural- A and unharvested control- UC sites)

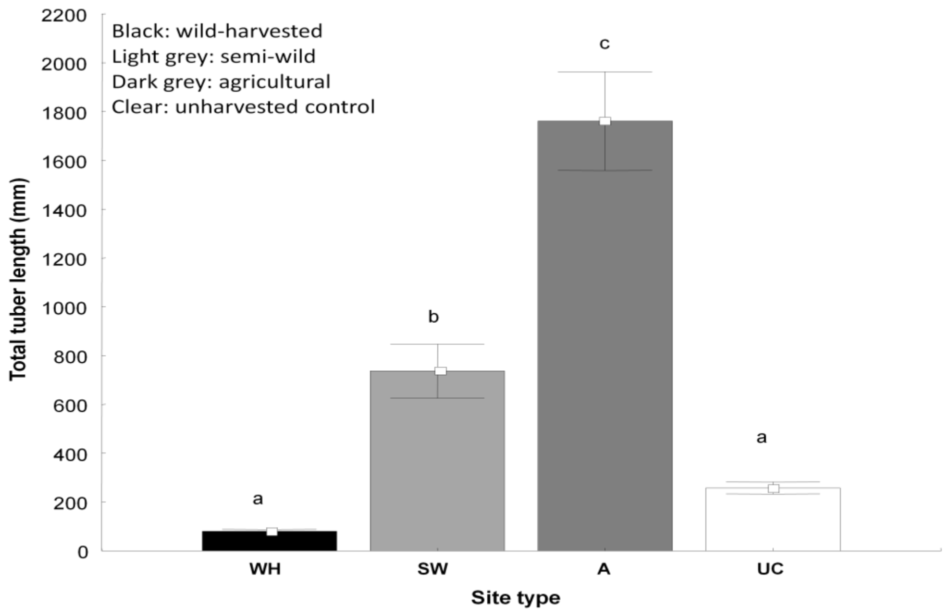
(A) ($F_{3,153}$= 53.9228, P < 0.001)



(B) ($F_{3,153}$= 56.3870, P < 0.001)



(C) ($F_{3,153}$= 69.8286, P < 0.001)



D ($F_{3,153}$= 49.7779, P < 0.001)

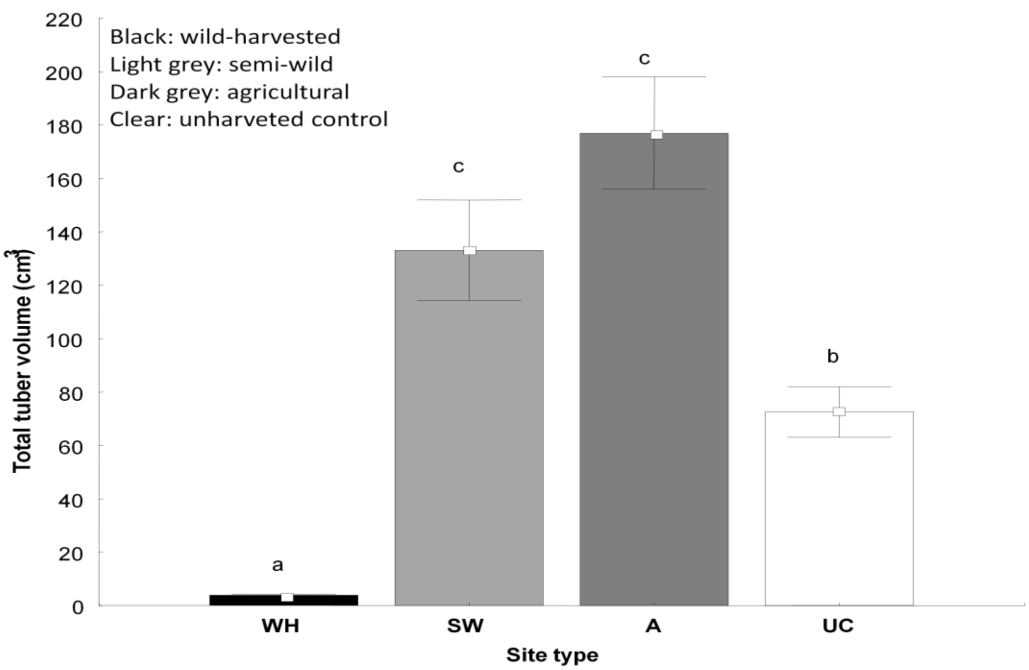


Figure 3.5. Comparisons of tuber growth of P. sidoidies plants in wild-harvested (WH), semi-wild (SW), agricultural (A) and unharvested control (UC) sites in the "lowveld" vegetation region. (A=mass, B= diameter, C= length and D= volume). Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2 “Highveld” vegetation region

3.4.2.1 Comparisons on tuber recovery size in wild-harvested sites

(A) ($F_{5,15}$= 3.8049, *P* = 0.020) **(B)** ($F_{5,15}$= 1.4947, *P* = 0.250)

C ($F_{5,45}$= 1.6438, *P*= 0.2088) **D** ($F_{5,15}$= 4.7276, *P* = 0.010)

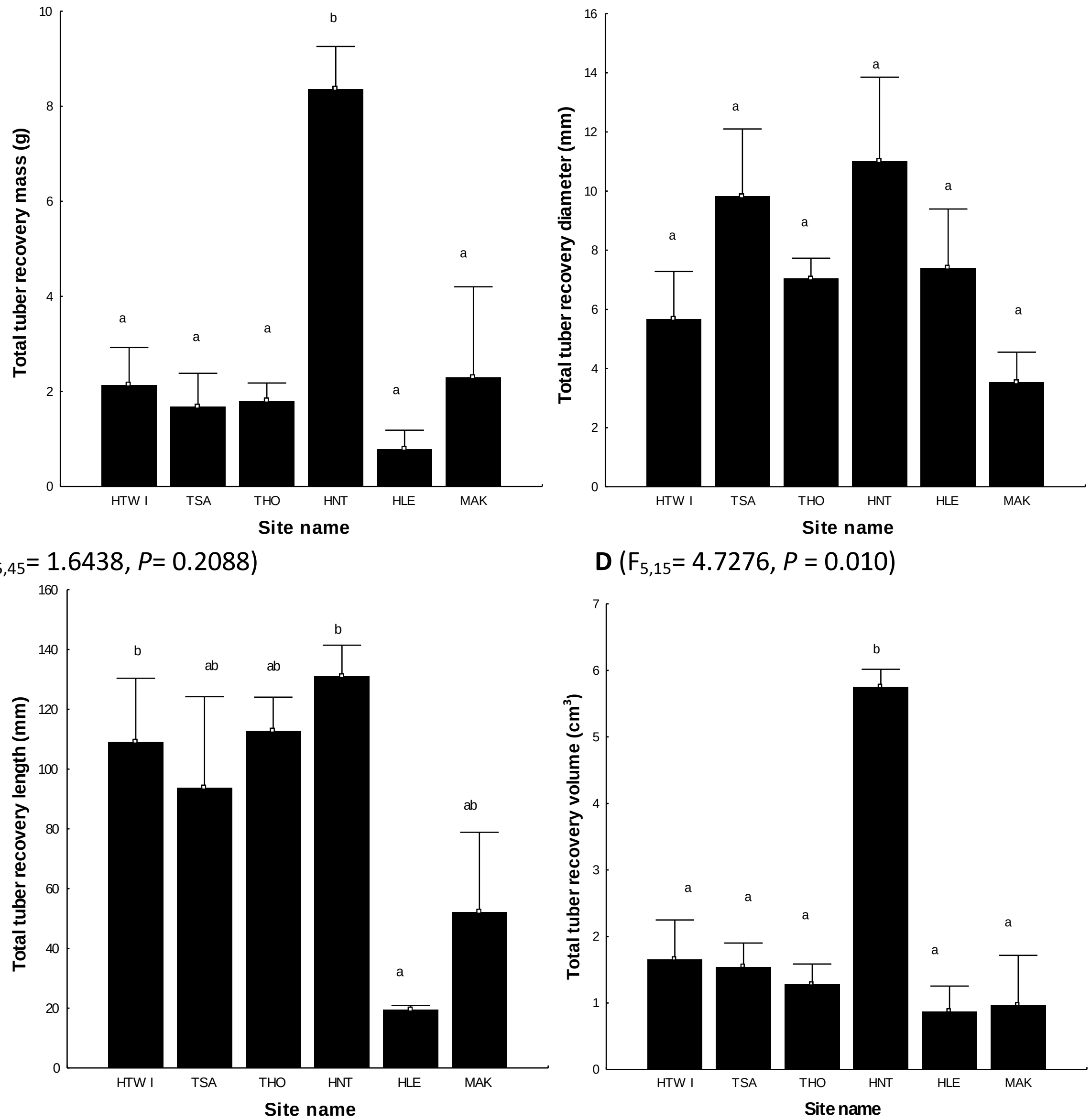
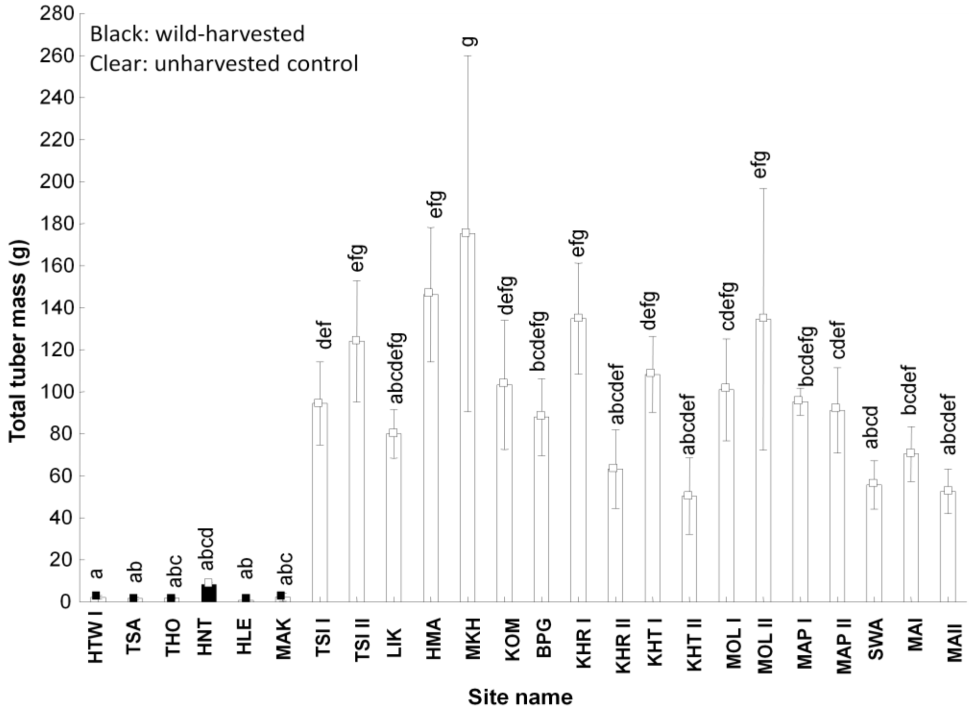


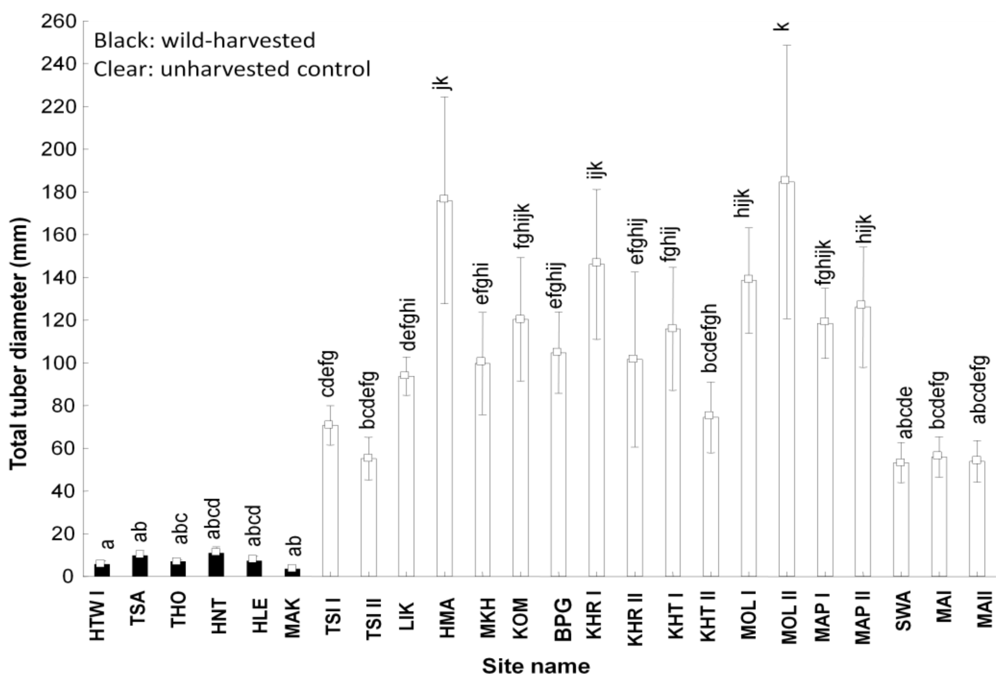
Figure 3.13. Comparisons of post-harvest tuber recovery size (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in wild-harvested sites of differing ages in the “highveld” vegetation region (HTW I= Ha Tlhaku wild (2 years), TSA= Tsatsane (2 years), THO= Thoteng (1 year), HNT= Ha Nthunya (1 year), HLE= Ha Lebelonyane (3 years), MAK= Makhoakhoeng (3 years)). Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher’s LSD, P < 0.05).

3.4.2.2 Comparisons on tuber size in wild-harvested and unharvested control sites

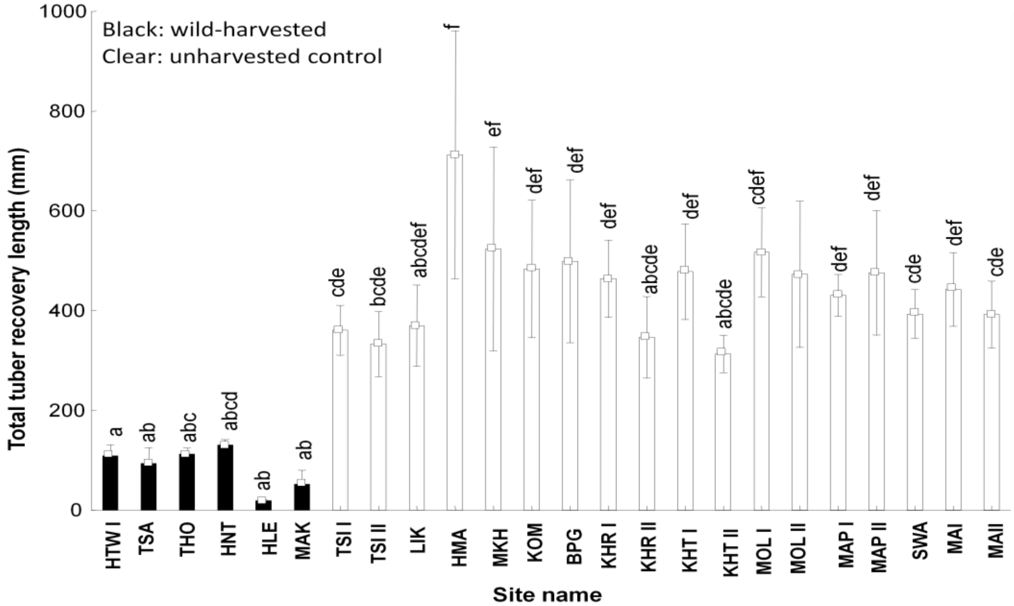
(A) ($F_{23,98}$= 2.5240, P = 0.001)



(B) ($F_{23,98}$= 5.0428, P < 0.001)



(C) ($F_{23,98}$= 2.3371, *P* = 0.002)



(D) ($F_{23,98}$= 3.3275, *P*= 0.0001)

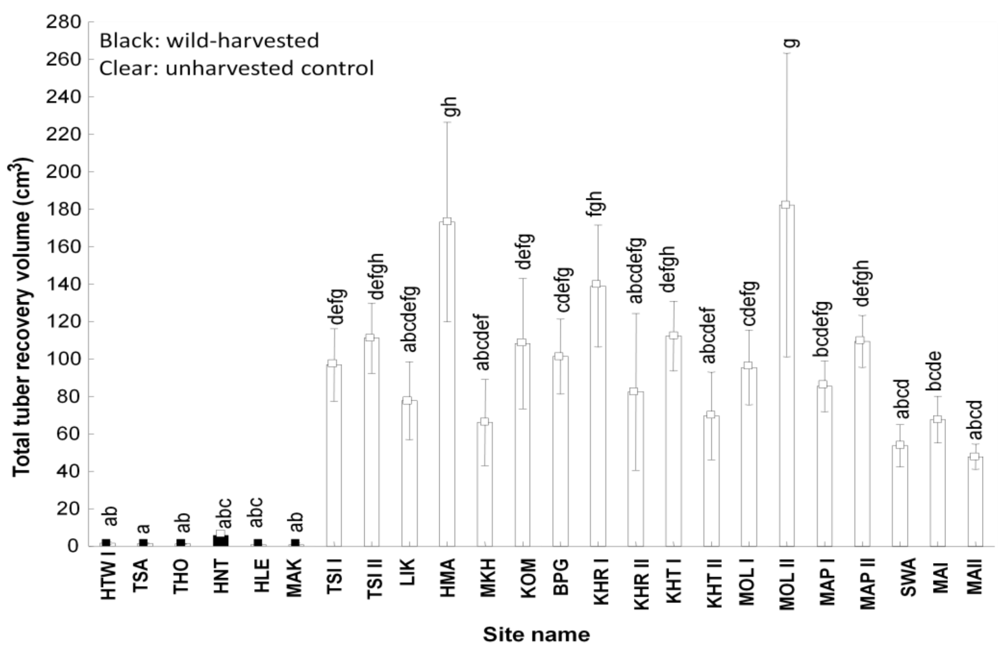
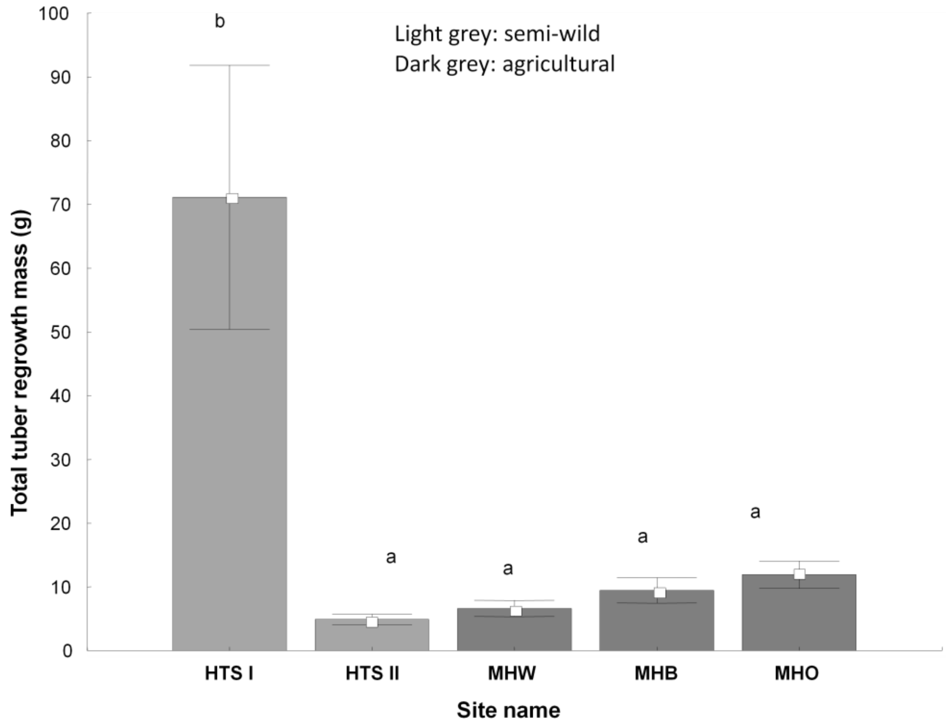


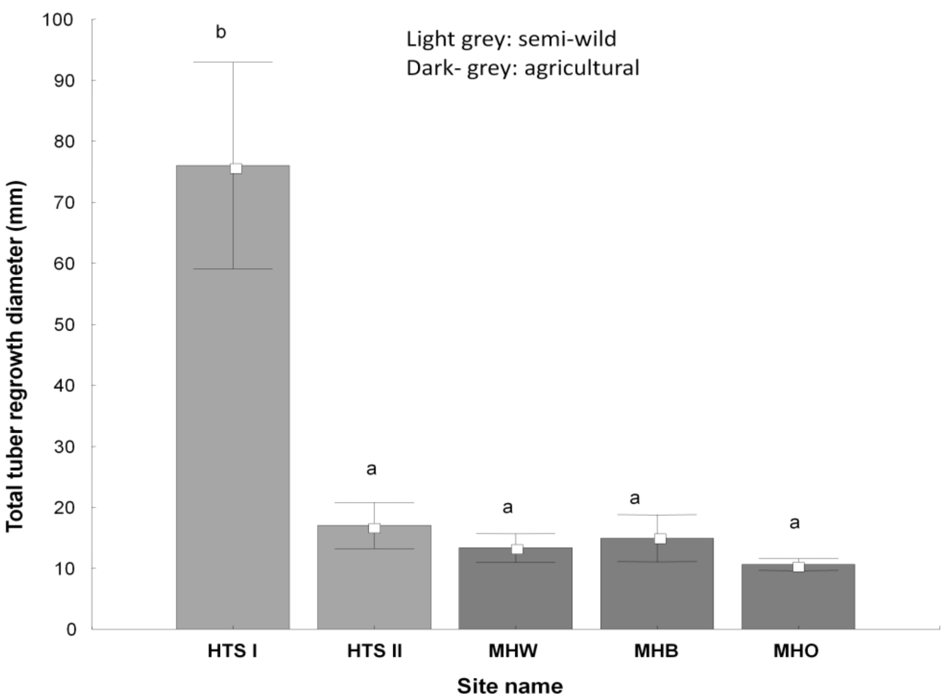
Figure 3.14. Comparisons tuber recovery and tuber size of Pelargonium sidoides in wild-harvested sites of differing ages (HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng) and unharvested control sites (TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II= Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II) in the 'highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2.3 Comparisons on tuber regrowth size in semi-wild and agricultural sites

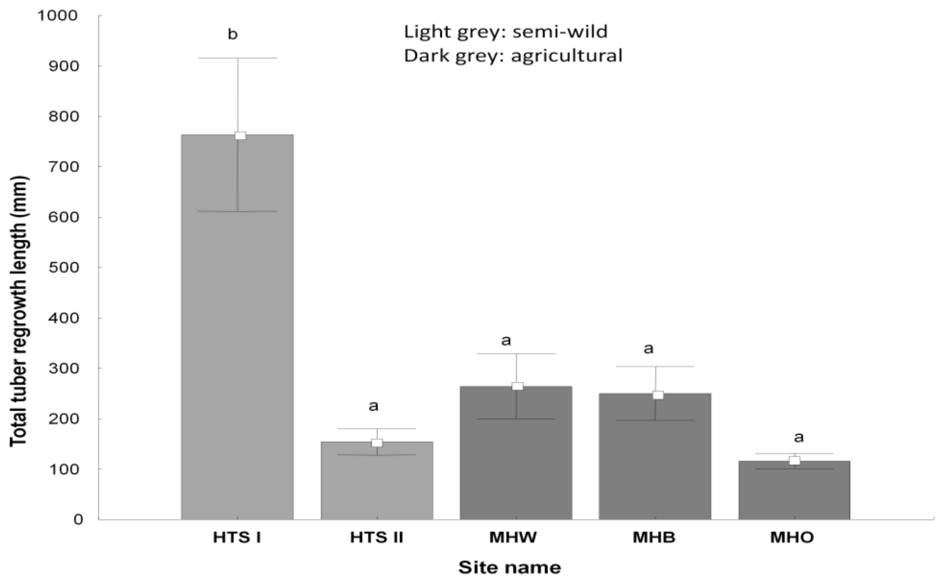
(A) ($F_{4,40}$= 7.1151, P < 0.001)



(B) ($F_{4,40}$= 9.7481, P < 0.001)



(C) ($F_{4.40}$= 8.8950, P < 0.001)



(D) ($F_{4.40}$= 8.9689, P < 0.001)

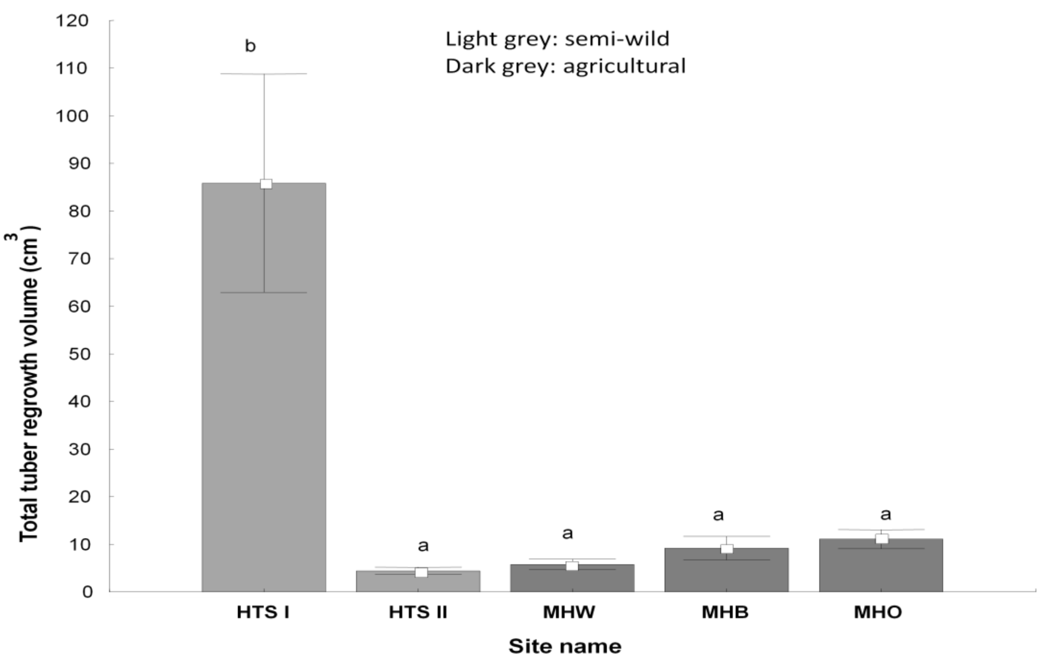
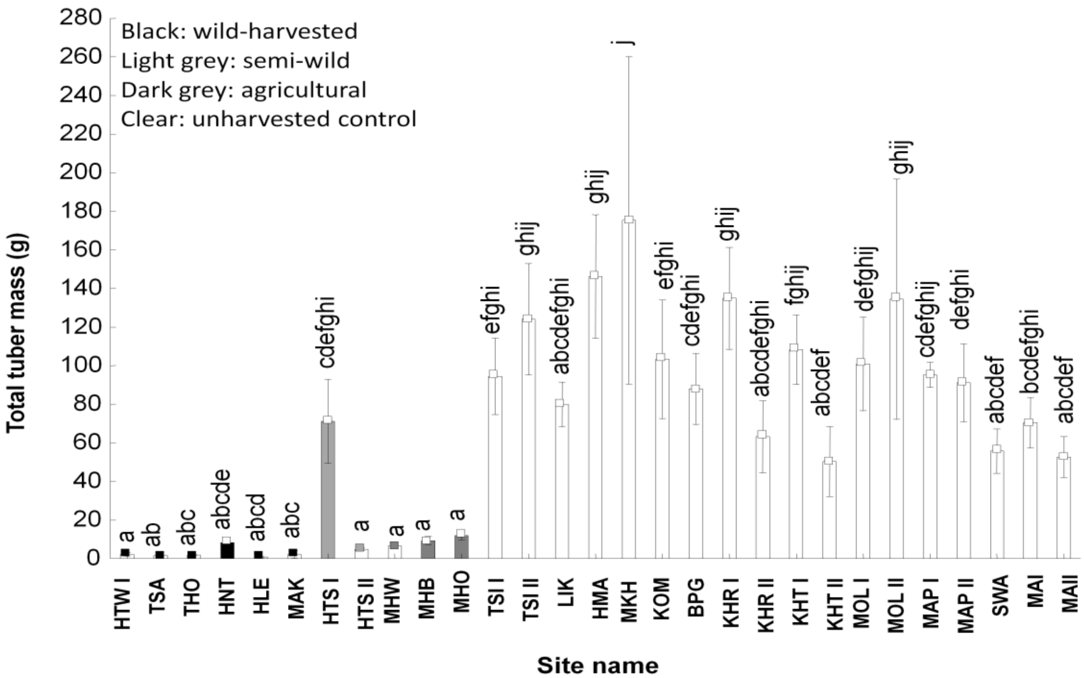


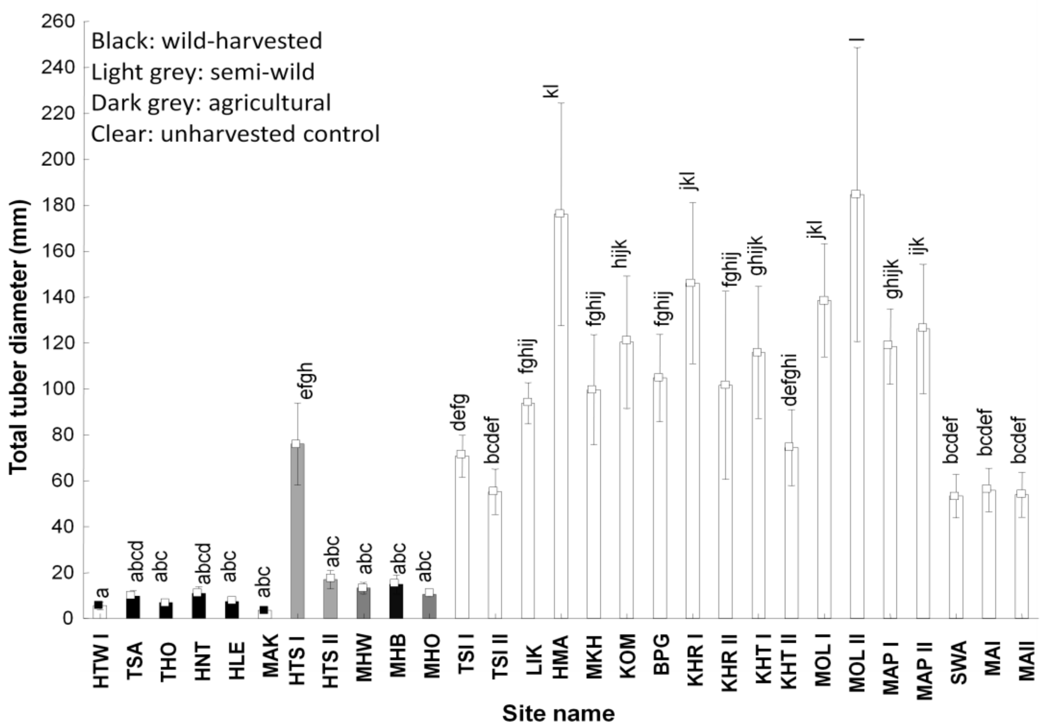
Figure 3.15. Comparisons of 'tuber regrowth" of Pelargonium sidoides plants in semi-wild (BF= Bold farm, STS= Stutterheim semi-wild and agricultural sites (HTS I= Ha Tlhaku I- semi-wild, HTS II= Ha Tlhaku II- semi-wild, MHW= Mohale's Hoek white- agricultural, MHB= Mohale's Hoek black- agricultural, MHO= Mohale's Hoek open-agricultural) of differing ages in the 'highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2.4 Comparisons on tuber size across all types of sites (wild-harvested, semi-wild, agricultural and unharvested control sites)

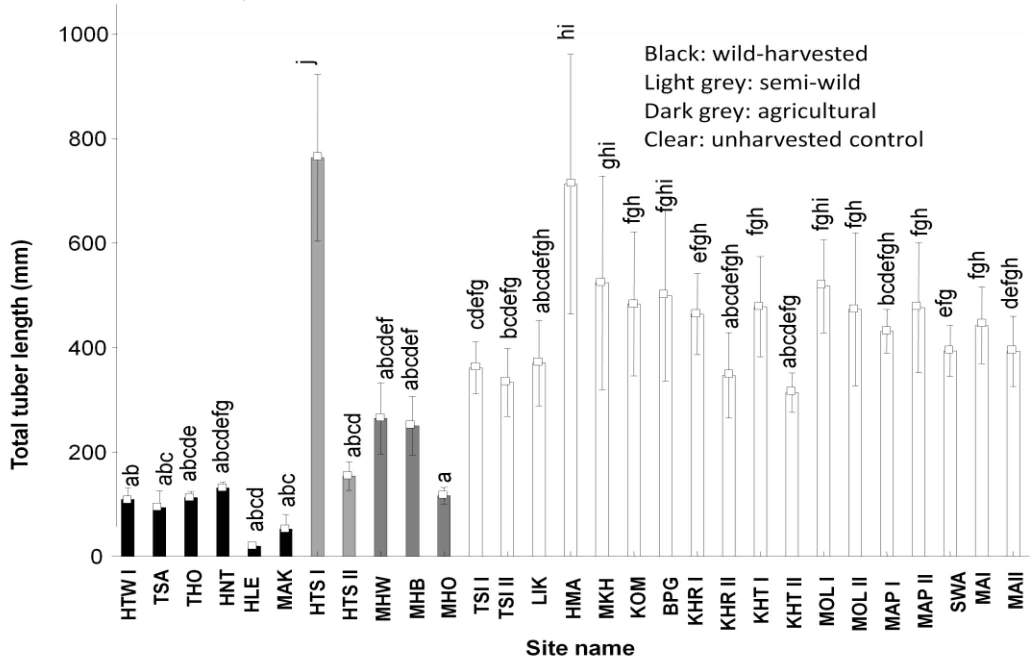
(A) ($F_{28,138}$= 4.0690, P < 0.001)



(B) ($F_{28,138}$= 7.2356. P < 0.001)



(C) ($F_{28,138}$= 3.3979, P < 0.001)



(D) ($F_{28,138}$= 5.0869, P < 0.001)

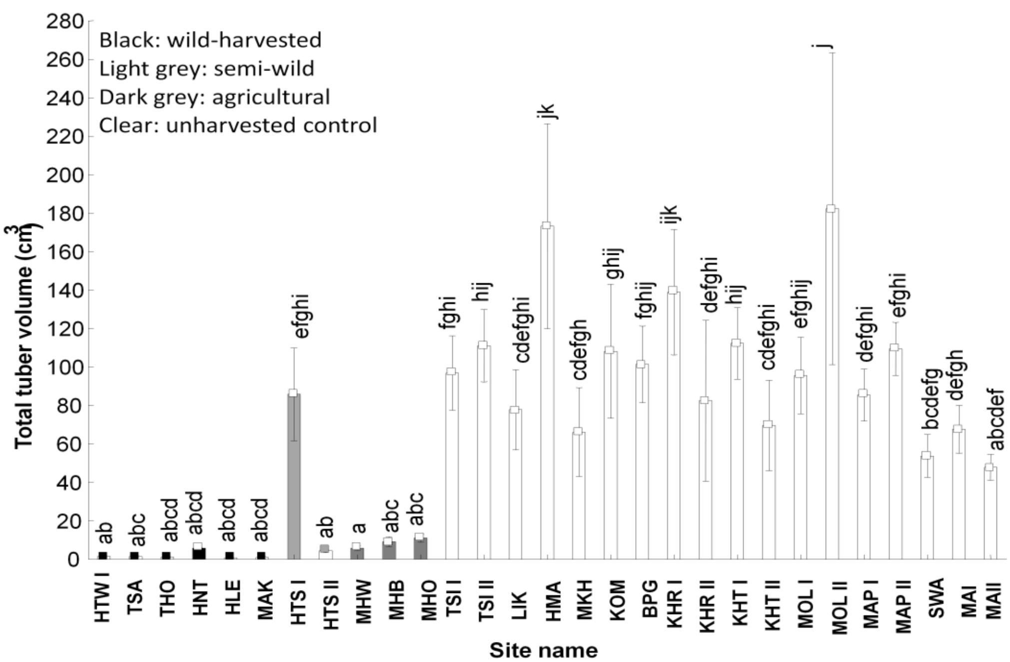
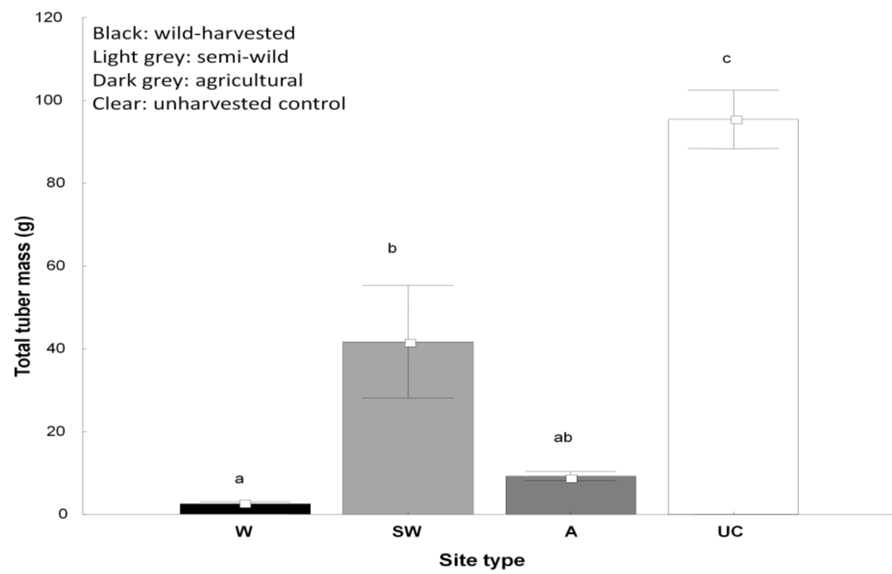


Figure 3.16. Comparisons of tuber recovery, tuber regrowth and tuber size (A= tuber recovery, tuber regrowth and tuber mass, B= tuber recovery, tuber regrowth and tuber diameter, C= tuber recovery, tuber regrowth and tuber length, D= tuber recovery, tuber regrowth and tuber volume) of Pelargonium sidoides plants in wild-harvested (HTW I= Ha Tlhaku wild, TSA= Tsatsane, THO= Thoteng, HNT= Ha Nthunya, HLE= Ha Lebelonyane, MAK= Makhoakhoeng), semi-wild (HTS I= Ha Tlhaku I, HTS II= Ha Tlhaku II and agricultural sites (MHW= Mohale's Hoek white- MHB= Mohale's Hoek black, MHO= Mohale's Hoek open) and unharvested control sites (TSI I= Tsiame I, TSI II= Tsiame II, LIK= Likhohloaneng, HMA= Ha Matsa, MKH= Makhoareng, KOM= Koma-koma, BPG= Basotho Pony Garden, KHR I= Katse I, KHR II=

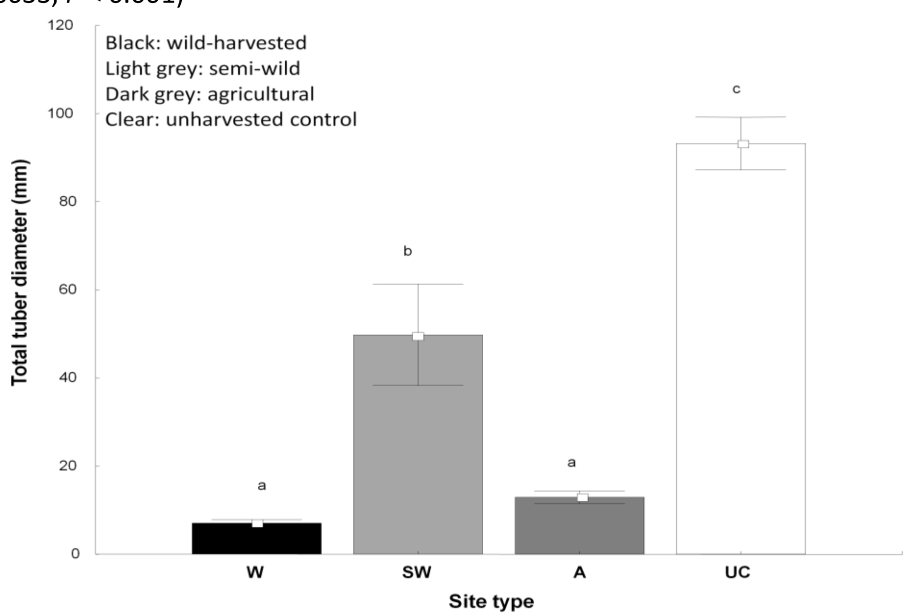
Katse II, KHT I= Ha Theko I, KHT II= Ha Theko II, MOL I= Molumong I, MOL II= Molumong II, MAP I= Mapholaneng I, MAP II= Mapholaneng II, SWA= Swaartkop, MAI= Mampier I, MAII= Mampier II) in the "highveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.2.5 Comparisons on tuber size when sites are grouped according to site type (wild-harvested- WH, semi-wild- SW, agricultural- A and unharvested control- UC sites)

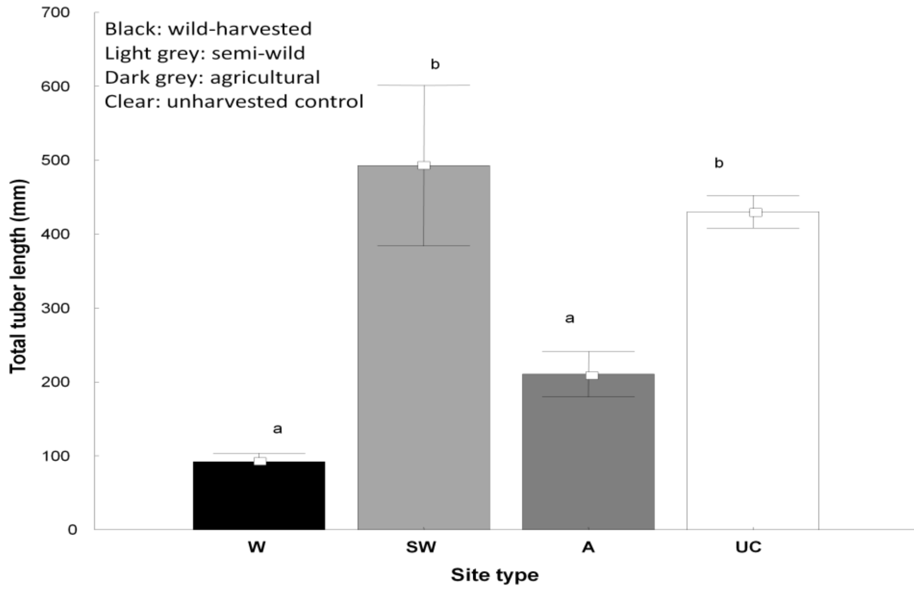
(A) ($F_{3,163}$= 23.8318, P < 0.001)



(B) ($F_{3,163}$= 27.6633, P < 0.001)



(C) ($F_{3,163}$= 15.5571, *P* < 0.001)



(D) ($F_{3.163}$= 25.9306, *P* < 0.001)

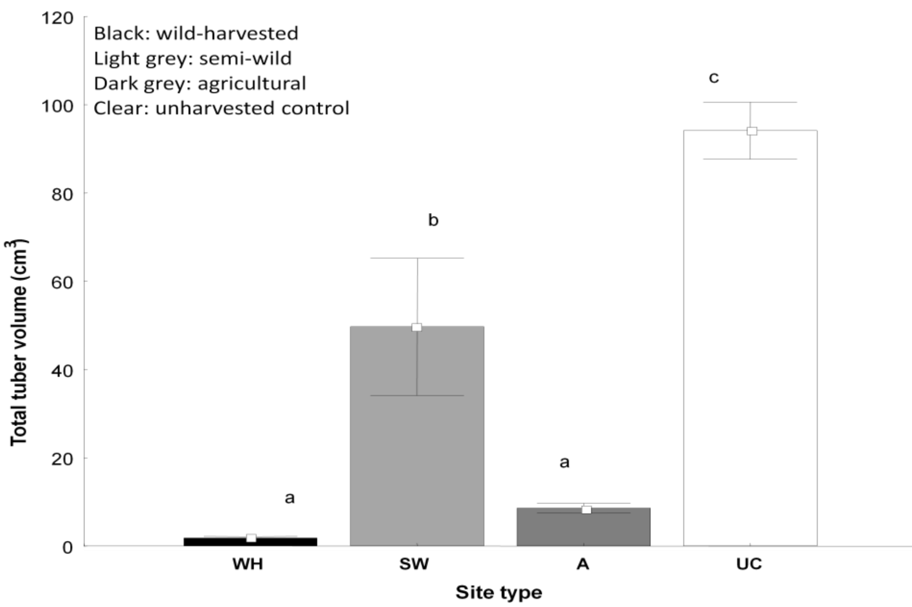


Figure 3.17. Comparisons of tuber recovery, tuber regrowth and tuber size (A= tuber recovery, tuber regrowth and tuber mass, B= tuber recovery, tuber regrowth and tuber diameter, C= tuber recovery, tuber regrowth and tuber length, D= tuber recovery, tuber regrowth and tuber volume) of Pelargonium sidoidies in wild-harvested (WH), semi-wild (SW), agricultural (A) and unharvested control (UC) sites in the "higveld" vegetation region. Error bars represent standard error of a mean. Bars marked with different letters are significantly different (Fisher's LSD, P < 0.05).

3.4.3.1.1. Comparisons on tuber recovery size in wild-harvested sites from "lowveld" and "highveld" vegetation regions

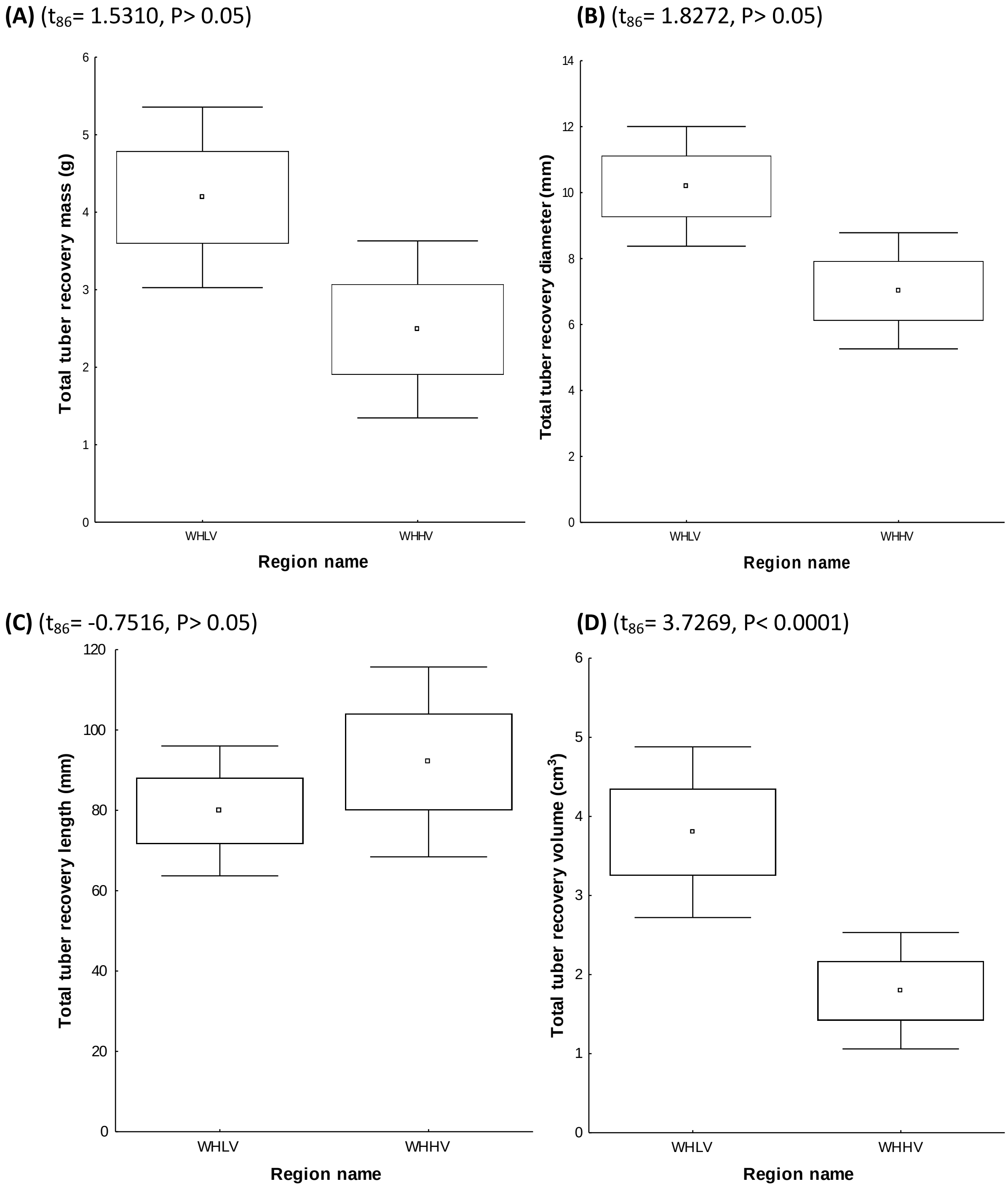


Figure 3.25. Comparisons of post-harvest tuber recovery growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in wild-harvested sites from the "lowveld" (WHLV) and "highveld" (WHHV) vegetation regions. Error bars represent standard error of a mean. Significant differences detected using using student t-tests.

3.4.3.1.2. Comparisons on tuber regrowth size in semi-wild sites from "lowveld" and "highveld" vegetation regions

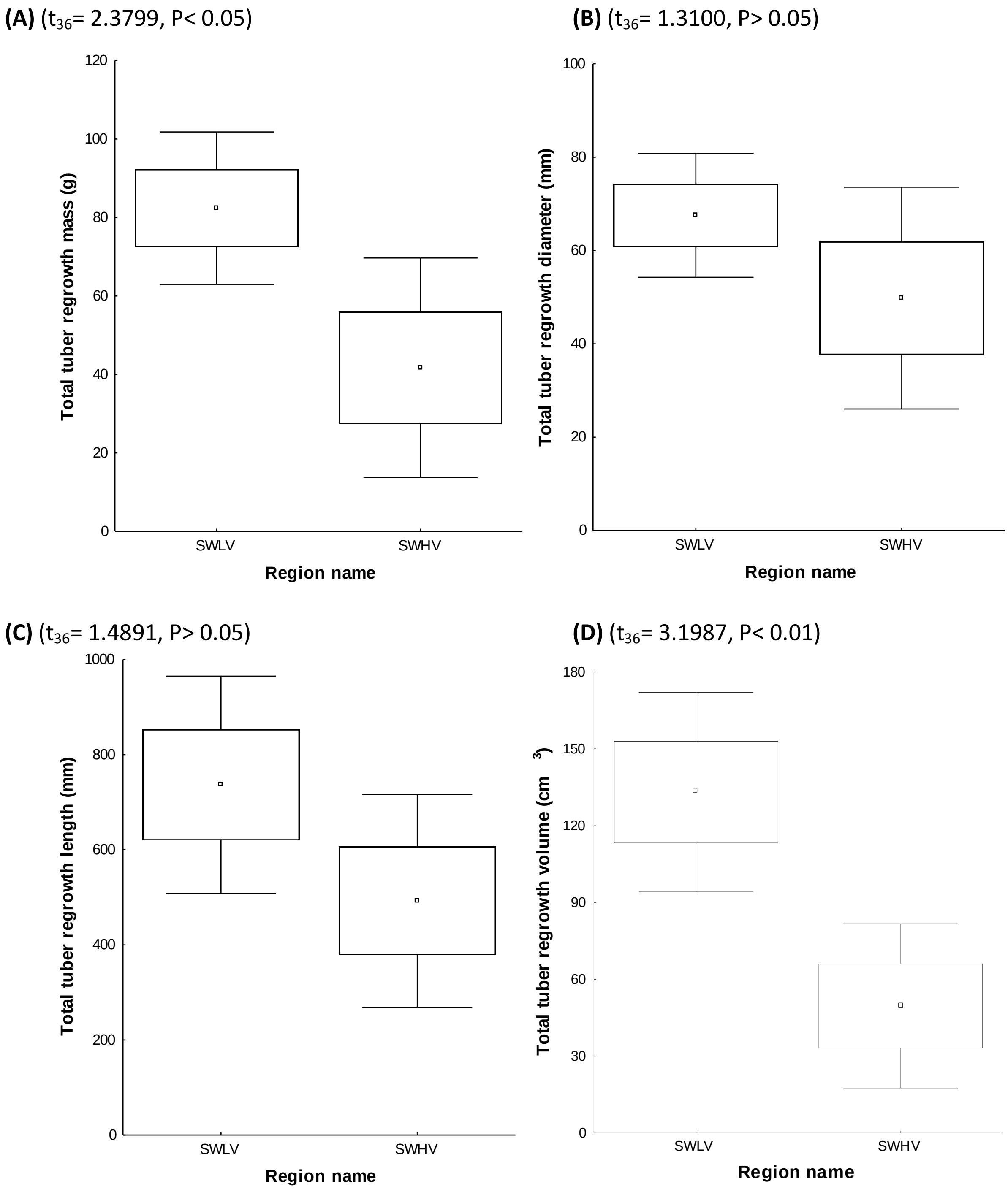
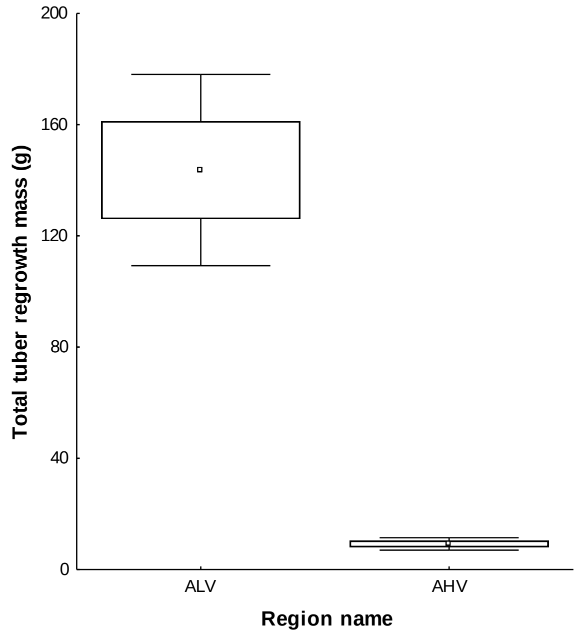


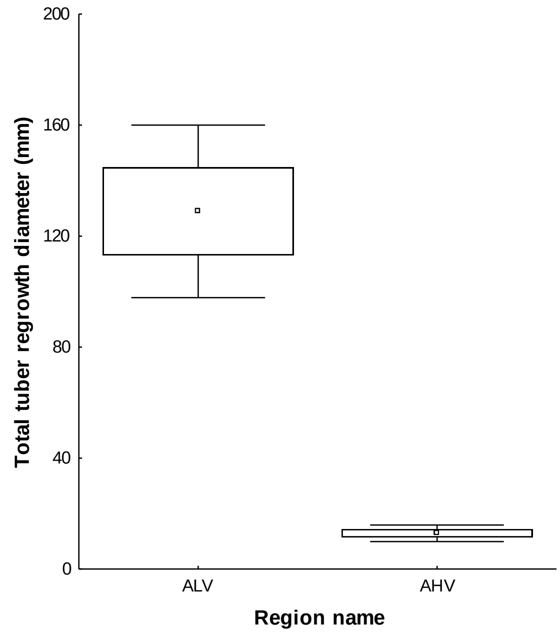
Figure 3.26. Comparisons of tuber regrowth growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in semi-wild sites from the "lowveld" (SWLV) and "highveld" (SWHV) vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

3.4.3.1.3. Comparisons on tuber regrowth size in agricultural sites sites from “lowveld” and “highveld” vegetation regions

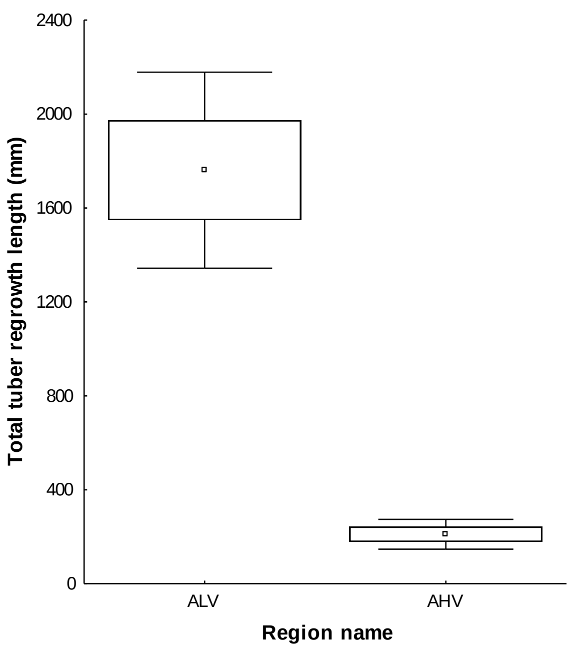
(A) (t_{55}= 7.2449, P< 0.0001)



(B) (t_{55}= 6.9064, P< 0.0001)



(C) (t_{55}= 6.8406, P< 0.0001)



(D) (t_{55}= 7.2027, P< 0.0001)

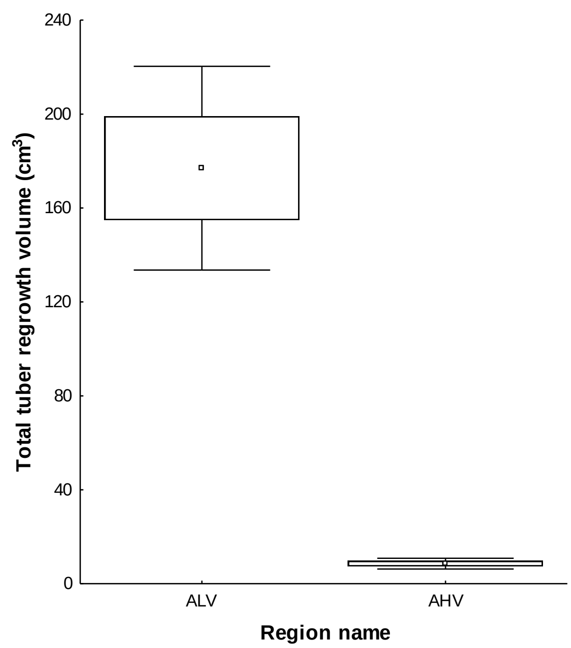
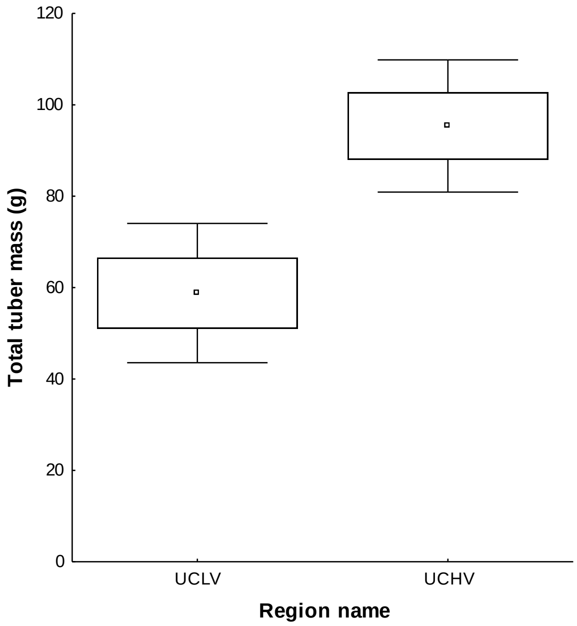


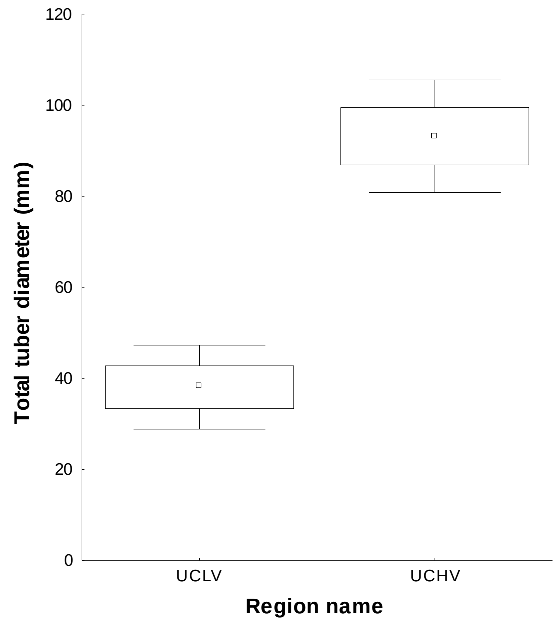
Figure 3.27. Comparisons of tuber regrowth growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in agricultural sites from the “lowveld” (ALV) and “highveld” (AHV) vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

3.4.3.1.4. Comparisons on tuber size in unharvested control sites from "lowveld" and "highveld" vegetation regions

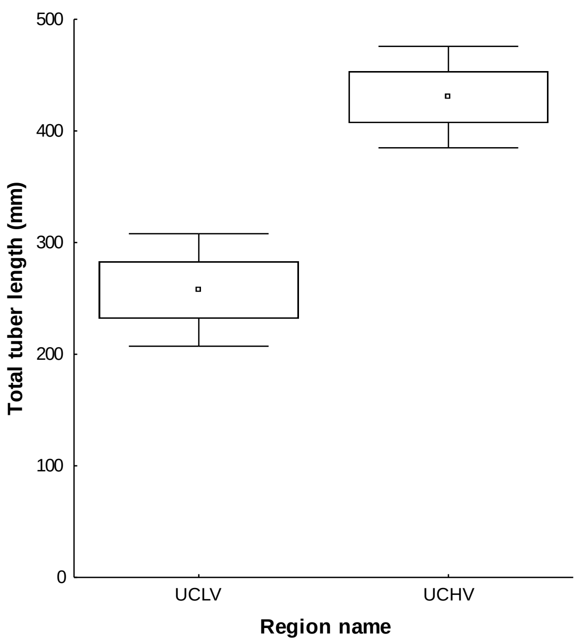
(A) (t_{140}= -2.8765, P= 0.05)



(B) (t_{140}= -5.2676, P< 0.05)



(C) (t_{140}= -4.2901, P< 0.05)



(D) (t_{140}= - 1.7290, P> 0.05)

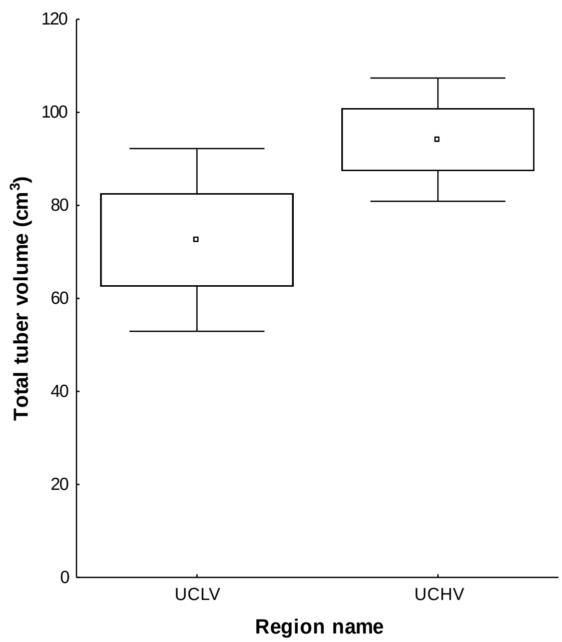


Figure 3.28. Comparisons of tuber growth (A=tuber recovery mass, B= tuber recovery diameter, C= tuber recovery length and D= tuber recovery volume) of Pelargonium sidoides plants in unharvested control sites from the "lowveld" (UCLV) and "highveld" (UCHV) vegetation regions. Error bars represent standard error of a mean. Significant differences were detected using student t-tests.

Chapter 4

Sustainable harvesting methods and harvesting guidelines for *Pelargonium sidoides*

4.1. ABSTRACT

Following the successful commercialization of *P. sidoides* as a medicinal plant, the number of plant gatherers intending to supply local and international markets and generate incomes have increased. Consequently, unsustainable wild harvesting of the resource has occurred in various parts of the Eastern Cape and Lesotho to meet the growing trade demand. Although various studies have investigated the impacts of such harvesting operations on *P. sidoides* wild populations, these studies have not provided suitable recommendations to ensure sustainable harvest of *P. sidoides* from the wild. This study therefore investigated factors which affect sustainable harvesting of *P. sidoides* using linear and non-linear regression models. The effects of depth of harvest hole, mother tuber size (biomass), canopy area and altitude on tuber recovery biomass, tuber recovery colour and number of stems/plant was explored. Furthermore, prospects of using canopy size as a surrogate for tuber size were established. These relationships were determined for previously wild-harvested sites in the "lowveld" and "highveld" vegetation regions. Additionally, the relationships were explored when data from the two regions was combined. Although results obtained for the effects of depth of harvest holes were inconsistent in the "lowveld" vegetation region, a positive trend was revealed implying that filling these holes post harvest can lead to greater tuber recovery biomass. In the "lowveld" vegetation region, when a relationship between depth of harvest hole and tuber recovery biomass was determined, significant relationships were found at the site level for four of the eight study sites (r^2= 0.57, P < 0.05, df= 8, r^2= 0.58, P< 0.05, df = 7, r^2= 0.82, P < 0.05, df = 5, r^2= 0.57, P < 0.05, df = 9). However, at regional level, no significant relationships were found despite there being a positive exponential trend. Similarly, no significant relationships were found in the "highveld" vegetation region, whether at site or regional level. Furthermore, in the "lowveld" vegetation region, the effects of mother tuber size on tuber recovery biomass and colour were only significant and pronounced at regional level. An increase in mother tuber biomass resulted in increasing tuber recovery biomass and colour score (intensity) (r^2= 0.80, P < 0.05, df = 7, r^2= 0.72, P < 0.05, df = 7). Similarly, canopy area affected tuber recovery biomass significantly at regional level in the "lowveld" (r^2= 0.81, P < 0.05, df = 7). The size of the mother tuber was found to have no significant effect on the number of stems/plant. Lastly, canopy area increased significantly with tuber biomass, implying that the size of a canopy can be used as a surrogate for tuber size (r^2= 0.57, P < 0.05, df = 7). No significant relationships were evident however between all these variables in the "highveld" vegetation region, either at site or regional level, probably due to limited sites and little variability in the times since last harvest. Similarly, relationships between most variables were not significant when data from the two regions was combined. The results of this study indicate that for sustainable wild harvest of *P. sidoides*, harvest operations should entail effective closure of harvest holes with soil. Additionally, plants with bigger canopies should be targeted when harvesting *P. sidoides* in previously harvested and new harvest areas. However, further research into sustainable harvest methods for *P. sidoides* is recommended, and direct longer term monitoring of selected sites would be useful.

4.2. INTRODUCTION

Sustainable harvest is suggested as the most important conservation strategy for most wild harvested species and their habitats, with the idea that non-destructive harvests will maintain population, species and ecosystem diversity (Schippmann *et. al*., 2002). Sustainable harvest refers to the activities that involve the extraction of a natural resource in a manner that does not deplete it and similar levels of exploitation can continue (Struhsaker, 1998). This means harvest rates should not exceed the capacity of populations to replace individuals that were removed through harvest (Hall and Bawa, 1993). While sustainable harvest of plants is important, factors such as lack of information on sustainable harvest practices, land-use rights and lack of legislative guidance are some of the major challenges for sustainable wild harvesting of medicinal plants (Peters, 1994). Many authors have suggested various options for the sustainable harvest of medicinal plants. These options include public participation, ecological studies of the species involved and creation of enabling legislative environment (Struhsaker, 1998; Peres *et. al*., 2003; Rock *et. al*., 2004). This means that to achieve sustainable harvest of medicinal plants, the focus should not only be on how to carry out the actual harvesting such as which tools to use, but should also include perceptions of the people that rely on the resource such as harvesters and traditional healers. Public participation in conservation of medicinal plants can be in the form of access and benefit sharing (ABS) agreements. For example, Steward and Cole (2005) established that implementation of ABS agreements improved the sustainable harvest of Devils claw. Currently ABS agreements have been developed for *Pelargonium sidoides* in Lesotho (R. Nts'ohi, Lesotho Department of Environment [DoE], *pers. comm*., 2010) and South Africa (P. Mosana, South African Department of Environmental Affairs [DEA], *in litt*., 2010) however, it is yet to be seen if they will help achieve sustainable harvest of the resource.

Public participation may be important in resource conservation but it should not be the only focus for sustainable harvest of medicinal plants. Interventions such as identifying the ecological impacts of harvesting as well as post harvest recovery rates have to be implemented (Struhsaker, 1998; Peres *et. al*., 2003; Rock *et. al*., 2004; Ticktin, 2004). Furthermore, factors such as growth form and harvest methods should be investigated as they may also determine how medicinal plants should be harvested. For instance, for *Neopicrorhiza scrophulariiflora*, selective collection of mature rhizomes and replanting of younger ones has been suggested as the best option to achieve sustainable wild harvest. However for *Nardostachys grandiflora* with slow recovery rates, even selective harvesting is not an option unless a long harvest interval is employed (Ghimire *et. al*., 2005). Thus the conservation of long-lived plants can present a dilemma to conservation officials (Raimondo and Donaldson, 2003).

Insights into harvesting of Devil's claw can also contribute to sustainable harvest of *P. sidodies*. Firstly, when harvesting Devil's claw, harvesters are encouraged not to harvest the primary tuber, but rather to dig around it and replant it if it has been removed. However, this is not always done (Fell 2002; Raimondo *et. al*., 2003). A primary tuber (main tuber attached to the stem) or a "mother" tuber is considered by Devil's claw harvesters as a persistent primary tuber from which all the rest of the tubers grow from (secondary tubers) (Stewart and Cole, 2005). Harvesters are probably encouraged not to harvest the primary tuber as it is thought to have more assimilates and moisture than the rest of the tubers. These assimilates ensure emergence of the plant in the next growing season if conditions are unfavourable (Strohbach and Cole 2007). A similar harvesting strategy maybe adopted for *P. sidoides* to ensure long term survival of wild populations. It should be noted though that these plants do not experience the same environmental conditions as their distribution range differs.

Secondly, harvesters of Devil's claw are advised to minimize soil disturbance during harvesting by using a digging stick to first loosen the soil rather than a spade. A spade is only used when covering harvest holes. Additionally, harvesters gradually loosen the soil around the plant working in a semi-circle away from the plant then remove the loosened soil by hand. Thus while minimizing soil disturbance, the remainder of the plant is left untouched whereby only secondary tubers will be collected (Strohbach and Cole, 2007). Harvesting using a digging stick has also been reported for collection of *Dichelostemma capitatum* (Anderson and Rowney, 1999). Although a digging stick has been used traditionally in Lesotho to collect medicinal plants and is currently used to collect *P. sidoides* (M. Letsie, local chief of Ha Tlhaku, Quthing, *pers. comm*., 2009), it may not be practical to use it for commercial *P. sidoides* harvest in the Eastern Cape as soils are sometimes hard where it occurs (*pers. obs*.). During field work for this study, it was easier to loosen the soil with a digging fork or steel pick-axe than with a spade and this questions the viability of using a spade by some harvesters.

Currently, there are no clear national harvesting guidelines for *P. sidoides* although the Pelargonium industry argues otherwise (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008; R. Gowar, Gowar Enterprises, *in litt*., 2009; D. Newton, TRAFFIC East/Southern Africa, *pers. comm*., 2011). *P. sidoides* has been harvested for commercial purposes since 2001 to supply the international market (Newton *et al*., *in prep*.) and unsustainable harvesting methods have been reported (Vlok, 2003, 2005; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008; Newton *et al*., *in prep*.; chapter 3, section 3.4). These harvesting methods have major implications for the conservation of *P. sidoides* wild populations more so because local population declines have been reported in some harvest sites in Lesotho and South Africa (Vlok, 2003, 2005; Newton *et al*., *in prep.*) and *P. sidoides* was estimated to have long tuber recovery rates (Chapters 2 and 3).

The Pelargonium industry personnel argue that they adhere to sustainable harvest standards by providing training on harvest methods to harvesters of *P. sidoides* before any commercial harvest commences (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; K. Paulsen, BZH, *pers. comm*., 2008; R. Gowar, Gowar Enterprises, *in litt*., 2009; D. Newton, TRAFFIC East/Southern Africa, *pers. comm*., 2011). In Lesotho, harvesters employed by one trader are provided with training on harvesting techniques, cultivation and environmental management of the surrounding habitat. Before any harvesting operation commences, public gatherings are held in the villages where the company wants to harvest. At these public gatherings, the Lesotho DoE, local chiefs and members of the local council are represented to monitor how the training proceeds (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008*; pers. obs*). Other than to offer training, potential bio-prospectors in Lesotho are required to carry out public participation consultations prior to commencement of their projects so that concerned and affected parties can voice their concerns (R. Nts'ohi, Lesotho DoE*, pers. comm*., 2010).

The harvesting guidelines provided include (1) collecting what is required and leaving behind some tubers, (2) Minimal disturbance of surrounding soil, (3) closure of harvest holes and (4) watering the replanted tubers. After tubers have been collected and having left some behind, one of these is cut into three parts of about +/- 2cm. Cut one (with some roots still attached) is replanted at the site, cut two is harvested while the remaining cut three (together with stems and leaves) is taken as parent stock for establishment of home gardens (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2007). This harvesting method suggests that not all the tubers are collected instead a certain proportion is taken. But this might not be the case when the actual harvesting occurs in the wild especially because the soils are often hard and the terrain is rugged. Thus one can question the practicality of this harvesting method. Rather, and with inadequate monitoring, what might happen is that harvesters obtain as much as they can find from one plant, replant cut one and move to the next plant.

The home gardens were established so that after about 3 years, the tubers can be harvested (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2007). Although the expectation from the traders in Lesotho is to be able to obtain tubers from the home gardens, this might not be attainable. This is because only relatively few harvesters managed to start home gardens meaning there will not be enough cultivated resource to supply the market. Other than quantity limitations, the Pelargonium industry also faces the problem of having to wait a long time for the tubers to be dark-red and to have attained enough biomass. This is because tuber colour development from pale to dark-red was found to require at least 8 years whereas tuber regrowth biomass needed at least 9 years to reach similar biomass to that of unharvested control plants (Chapter 2 and 3).

Other harvesting guidelines include harvesting mature tubers which are dark-red and not young tubers that are pale-coloured (H. Nieuwoudt, Managing Director of Bophelo Natural Products *pers. comm.,* 2008; U. Feiter, Managing Director of Parceval, *per. comm*., 2008). However, before harvesting, harvesters cannot tell how large the tubers are before uprooting the plant because such guidance is not available. Thus, it becomes difficult to adhere to this guideline and as such young plants will be uprooted.

Lastly, harvesting in Lesotho does not occur all year round but is restricted to a 7 month period starting from September and ending in March. In the remaining 5 months of the year, no harvesting occurs to give the plants an opportunity to recover (H. Nieuwoudt, Managing Director of Bophelo Natural Products *pers. comm.,* 2008, *pers. comm*.). Conversly, it is also possible that the rest period is more of a growing season constraint because often snow covers the landscape and plants disappear from sight, than a sustainability strategy. The above training procedure is also given to different communities in the Eastern Cape but it could not be established as to whether harvesters are encouraged to establish home gardens and if all relevant stakeholders are represented during the training. Harvesting can occur throughout the year in the Eastern Cape as long as there is enough rainfall but the period October to May is preferred (K. Paulsen, Managing Director of BZH, *pers. comm*., 2008; R. Gowar, Managing Director of Gowar Enterprises, *in litt*., 2009; D. Newton, TRAFFIC East/Southern Africa, *pers. comm*., 2011). This is probably possible as winters are mild therefore the plants are visible throughout the year. If plants are harvested throughout the year, this may lead to repeat harvest in one site and as such plants do not get an opportunity to accumulate enough reserves and this can affect their ability to flower optimally in the next growing season (and to regrow tubers).

Furthermore, the harvesting guidelines in the Eastern Cape are intended for conservation authorities, permit holders and harvesters (D. Newton, TRAFFIC East/Southern Africa, *pers. comm*., 2011). Conservation authorities are tasked with carrying out field visits prior to harvesting to assess whether *P. sidoides* is abundant for harvesting in a given locality and also doing spot checks to monitor harvesting operations. For permit holders, they are requested to record all their harvesters' details such as names and such records should be submitted to conservation authorities (K. Paulsen, Managing Director of BZH, *pers. comm*., 2008; R. Gowar, Managing Director of Gowar Enterprises, *in litt*., 2009; D. Newton, TRAFFIC East/Southern Africa, *pers. comm*., 2011). Importantly, permit holders are responsible for training their harvesters, ensuring that harvesting only occurs in areas stipulated in their permits and recording quantities of the resource harvested.

Except for guidance on which tubers to collect from any one plant, watering and season of harvest, the harvesting guidelines for *P. sidoides* provided by the Pelargonium industry are insufficient. For instance, the guidelines do not specify harvest frequency and harvest interval for harvested sites. Furthermore it is not clear which harvesting tools are recommended and how plants should be uprooted in the field. The fact that the harvesting guidelines provided by the Pelargonium industry do not have this important information may explain why training on sustainable harvest methods that they provide does not seem to have any positive impact on tuber recovery of *P. sidoides* following harvest (Chapter 3). Thus the aim of this study was to investigate factors that affect tuber recovery of *P. sidoides* plants and recommend sustainable harvesting options that will maximize tuber recovery post harvest.

4.3. MATERIALS AND METHODS

Refer to Chapter 2, section 2.3.1, 2.3.2 and 2.3.3.

4.3.3. Data analysis

To investigate factors that affect *P. sidoides* "tuber recovery" biomass and colour, linear and non-linear regression models were used to determine relationships between variables. Tuber colour PCC codes were quantified as explained in chapter 2.

The relationships were established per site where each plant represented a data point and per region where each site represented a site. "Tuber recovery" (wild-harvested sites), "tuber regrowth" (semi-wild and agricultural sites) and "tuber" (unharvested control sites) data were used in the analyses and summarized as explained below.

- Mean "tuber recovery": This was obtained by getting the average "tuber recovery" mass value for each plant. Each plant represented a data point in the regression graphs.
- Mean of mean "tuber recovery": It was obtained by getting the average of mean of "tuber recovery" mass obtained for each plant as explained above to represent each site. Each site represented a data point in the regression graphs.
- Mean of total "tuber recovery": This was obtained by getting the average of total "tuber recovery" mass obtained for each plant to represent a site (total "tuber recovery" mass values were calculated by getting a sum of "tuber recovery" mass values for each plant. They were not

used in the analysis for this chapter at site level. Each site represented a data point in the regression graphs.

To establish factors that influence tuber recovery biomass and colour, the following relationships were determined:

- Depth of soil covering mother tuber post harvest (x) and tuber recovery mass (y)
- Mother tuber mass (x) and “tuber recovery” mass (y)
- Mother tuber mass (x) and “tuber recovery” colour (y)
- Canopy area (x) and “tuber recovery mass” (y)
- Altitude (x) and “tuber recovery” (y)

Since the number of stems recovering out of a cut tuber can also measure tuber recovery, the following relationships were explored:

- Mother tuber mass (x) and number of stems (y)
- Mother tuber diameter (x) and number of stems (y)

In order to investigate whether canopy size can be used as a surrogate for tuber biomass, relationships between the following were determined:

- Tuber mass (x) and canopy area (y)

There were an inadequate number of semi-wild and agricultural sites from the “lowveld” and “highveld” vegetation regions; so it was not possible to obtain clear relationships between time in cultivation and colour per region. Therefore at regional level, the available semi-wild and agricultural sites were combined to investigate various relationships. However, when the data from the “lowveld” and “highveld” vegetation regions were combined, semi-wild and agricultural sites were each analyzed separately as the number of sites per site type increased. During this study, only two wild-harvested sites were sampled in the “highveld” vegetation region therefore it was not possible to get relationships between variables at regional level. It was only possible to investigate relationships at site level. The data from the Lesotho NDF wild-harvested sites could not be used to get some relationships because it was not possible to estimate some measurements such as canopy width from the photographs.

Micro-Soft excel 2007 analysis tool package was used to conduct the analysis.

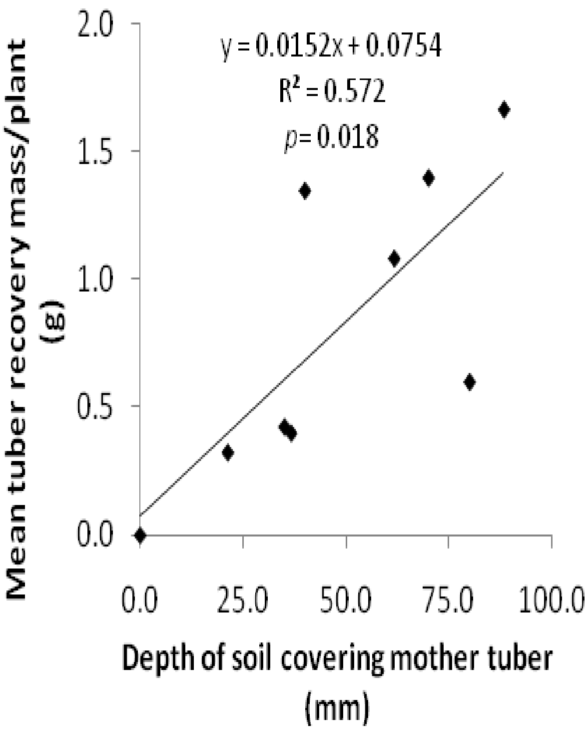
4.5. RESULTS

4.5.1. "Lowveld" vegetation region

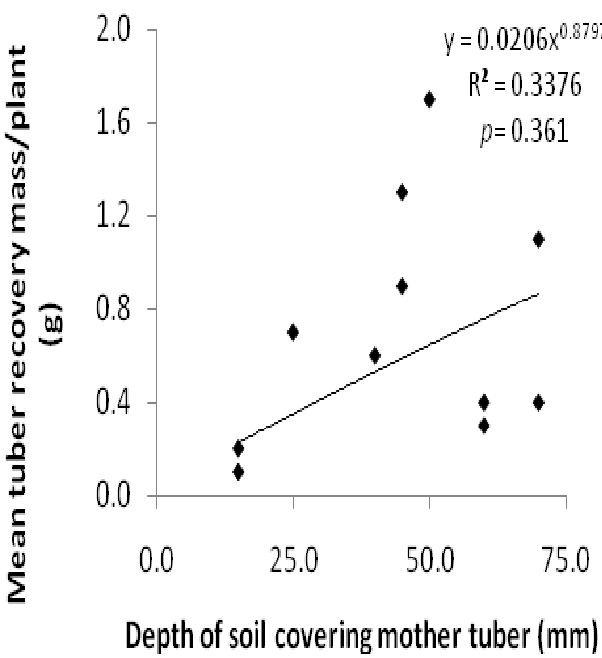
4.5.1.1. The effect of soil depth above the mother tuber on tuber recovery biomass per site

How well the mother tuber is covered with soil post harvest was expected to affect tuber recovery biomass. Therefore relationship between the depth of soil covering the mother tuber and tuber recovery biomass was investigated. The results that were obtained varied. For instance, there was a positive significant relationship between these variables in only four of the eight sampled wild-harvested sites ($P < 0.05$) (Figure 4.1A, D, F, H). However, significant relationship between the variables at other four sites was not found ($P > 0.05$) (Figure 4.1B, C, E, G). But even at these sites, a positive linear trend was observed.

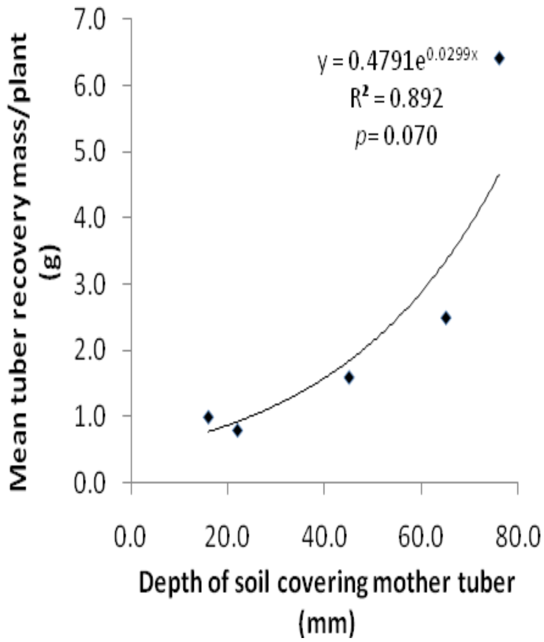
(A)



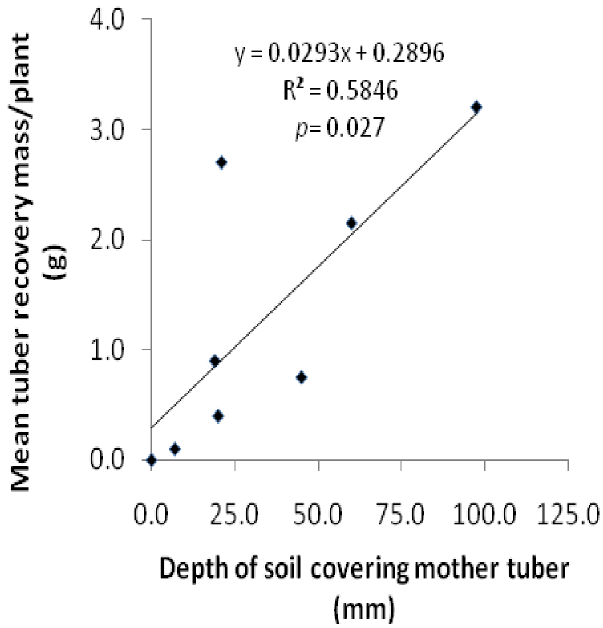
(B)



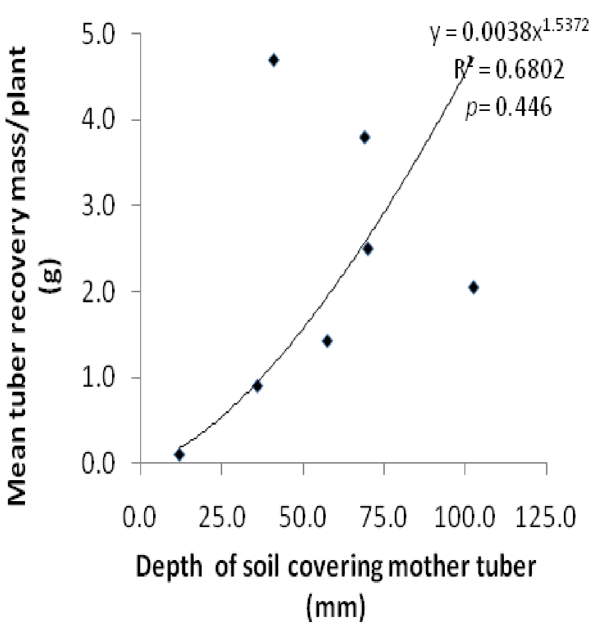
(C)


y = 0.4791e^0.0299x
R² = 0.892
p= 0.070
Mean tuber recovery mass/plant (g)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
20.0
40.0
60.0
80.0
Depth of soil covering mother tuber (mm)

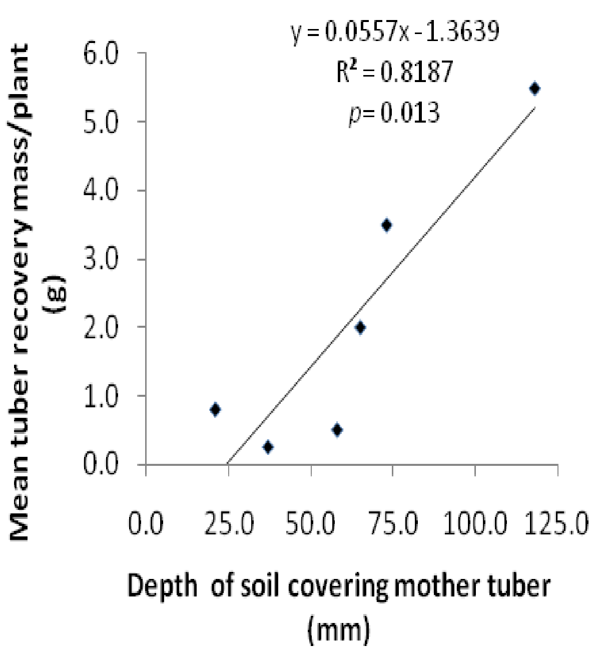
(D)


y = 0.0293x + 0.2896
R² = 0.5846
p= 0.027
Mean tuber recovery mass/plant (g)
4.0
3.0
2.0
1.0
0.0
0.0
25.0
50.0
75.0
100.0
125.0
Depth of soil covering mother tuber (mm)

(E)


y = 0.0038x^1.5372
R² = 0.6802
p= 0.446
Mean tuber recovery mass/plant (g)
5.0
4.0
3.0
2.0
1.0
0.0
0.0
25.0
50.0
75.0
100.0
125.0
Depth of soil covering mother tuber (mm)

(F)


y = 0.0557x - 1.3639
R² = 0.8187
p= 0.013
Mean tuber recovery mass/plant (g)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
25.0
50.0
75.0
100.0
125.0
Depth of soil covering mother tuber (mm)

(G) **(H)**

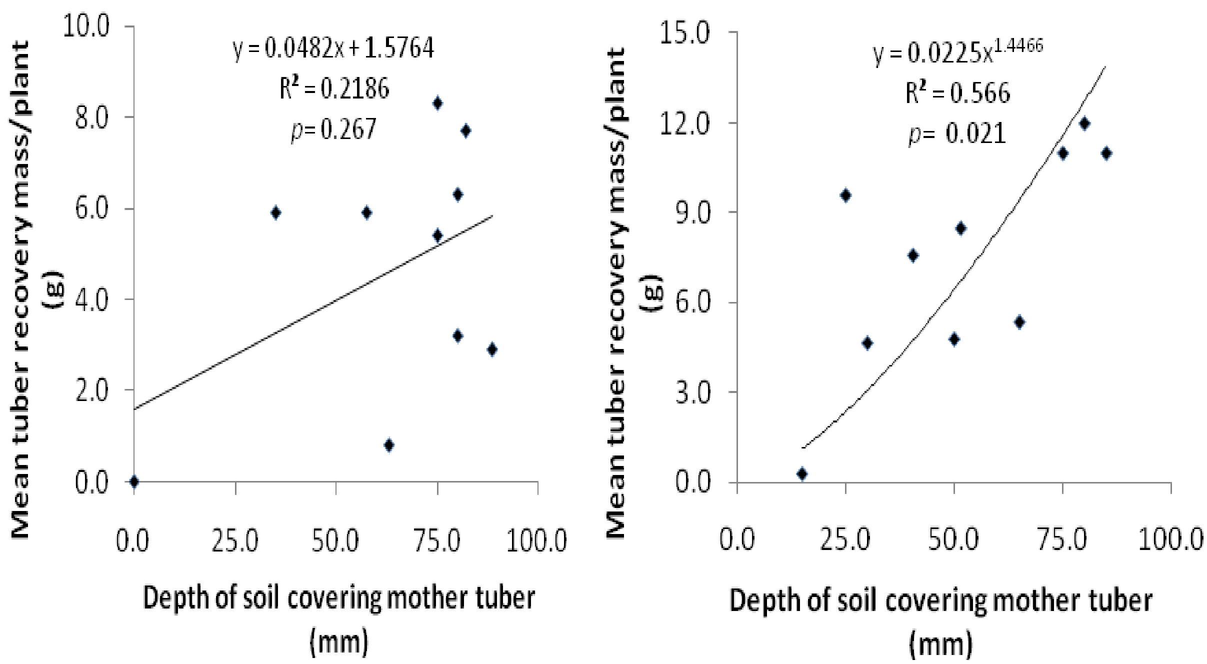
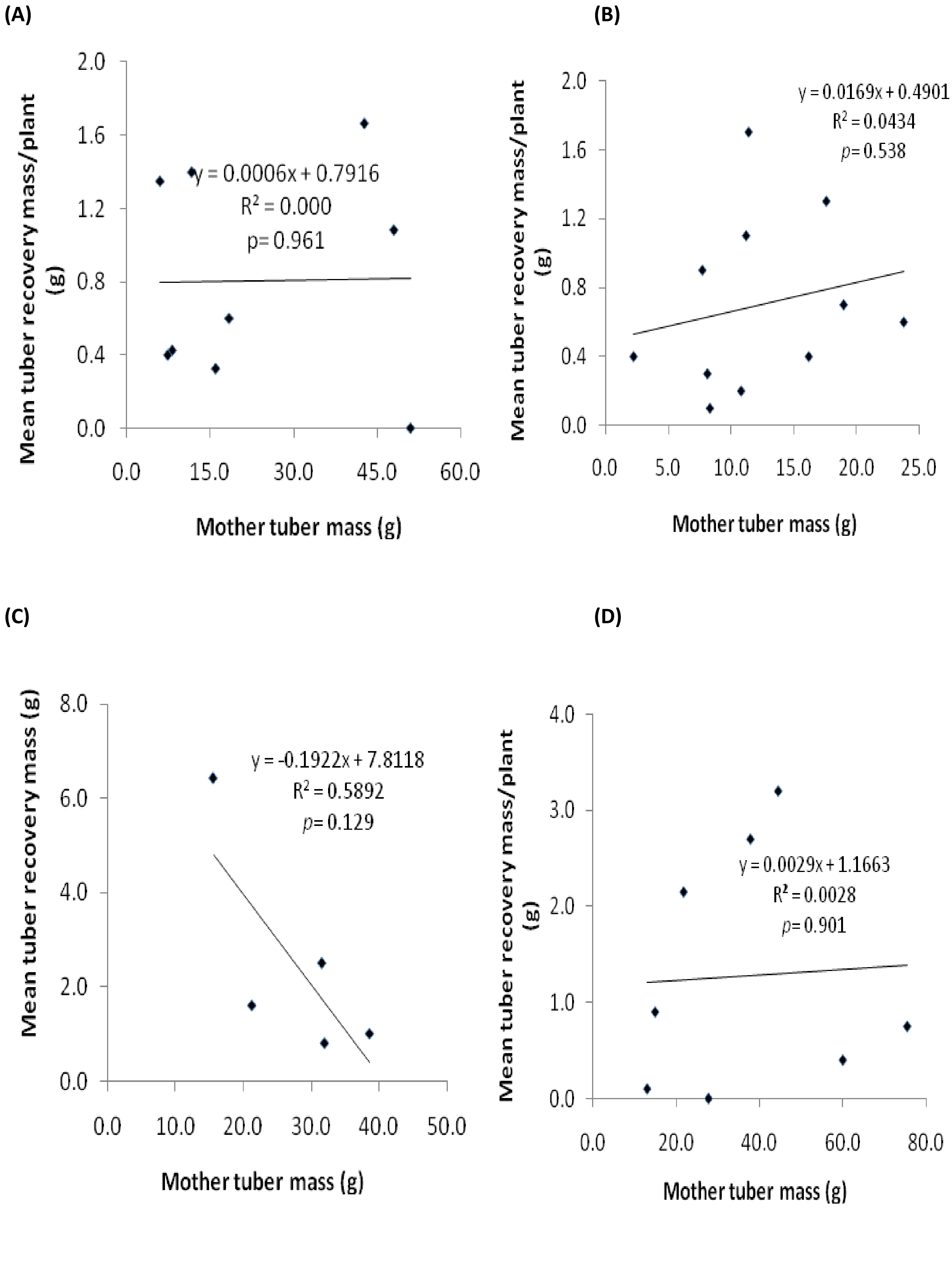


Figure 4.1. The relationship between depth of soil covering mother tuber (mm) and tuber recovery mass (g) in the "lowveld" vegetation region. A= JFH (n = 9), B= ASH (n = 11), C= PI (n = 5), D= PII (n = 8), E= VPI (n = 7), F= VPII (n = 6), G= WI (n = 10), H= WII (n = 10). Each individual data point represents a plant.

4.5.1.2. The effect of mother tuber biomass on tuber recovery biomass per site

Large mother tubers have enough assimilates for successful resprouting hence their size (biomass) might affect tuber recovery biomass. However, when relationships between mother tuber mass and tuber recovery mass were investigated, no significant relationships were found ($P > 0.05$) (Figure 4.2A, B, C, D, E, F, G, H). Thus these results suggest that mother tuber biomass does not determine tuber recovery biomass. However, absence of significant relationships may have been due to little variation at site level as plants were considered to have been last harvested at the same time.


(A)
Mean tuber recovery mass/plant (g)
y = 0.0006x + 0.7916
R2 = 0.000
p= 0.961
Mother tuber mass (g)
0.0 15.0 30.0 45.0 60.0
0.0 0.4 0.8 1.2 1.6 2.0
(B)
Mean tuber recovery mass/plant (g)
y = 0.0169x + 0.4901
R2 = 0.0434
p= 0.538
Mother tuber mass (g)
0.0 5.0 10.0 15.0 20.0 25.0
0.0 0.4 0.8 1.2 1.6 2.0
(C)
Mean tuber recovery mass (g)
y = -0.1922x + 7.8118
R2 = 0.5892
p= 0.129
Mother tuber mass (g)
0.0 10.0 20.0 30.0 40.0 50.0
0.0 2.0 4.0 6.0 8.0
(D)
Mean tuber recovery mass/plant (g)
y = 0.0029x + 1.1663
R2 = 0.0028
p= 0.901
Mother tuber mass (g)
0.0 20.0 40.0 60.0 80.0
0.0 1.0 2.0 3.0 4.0

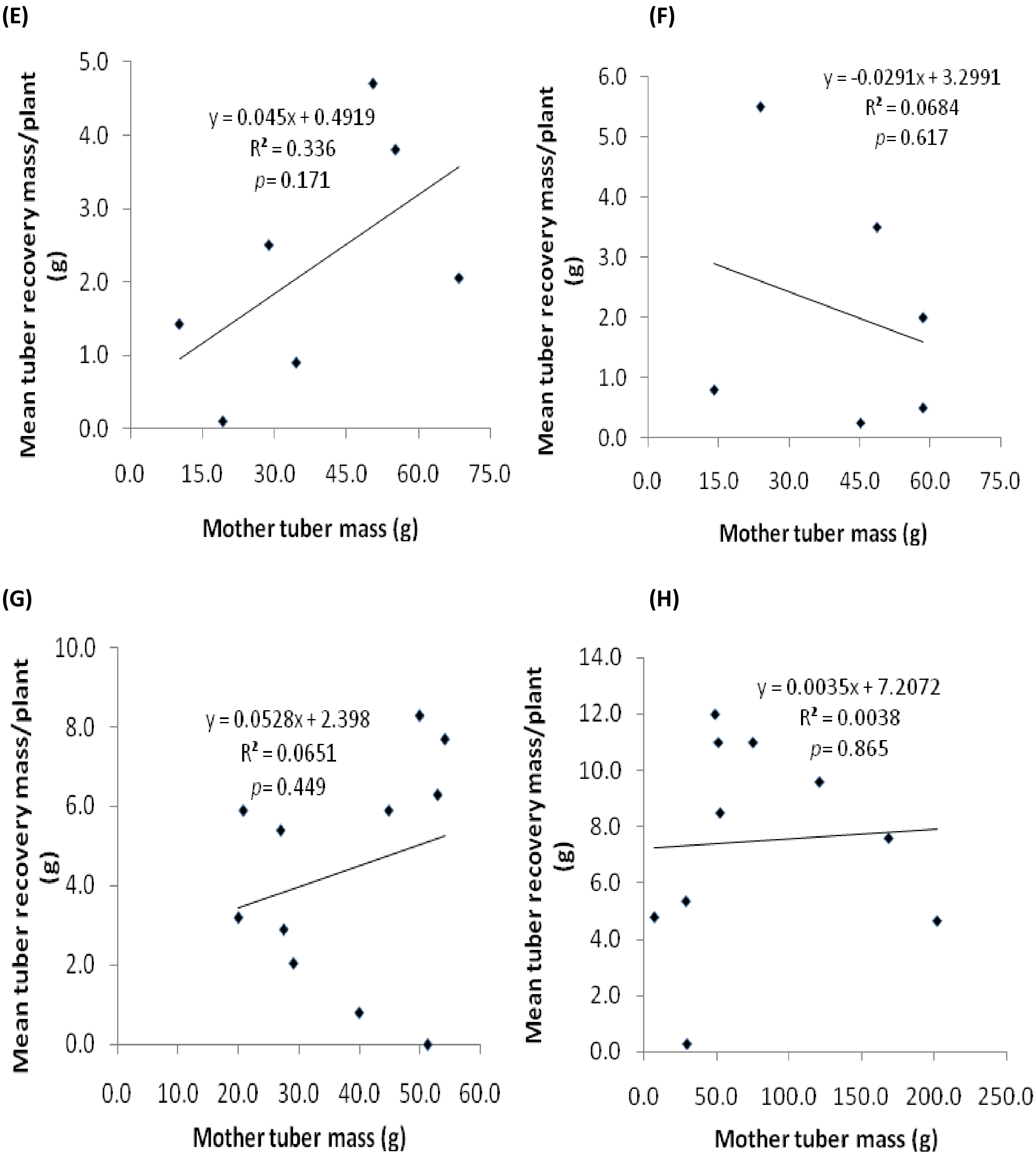
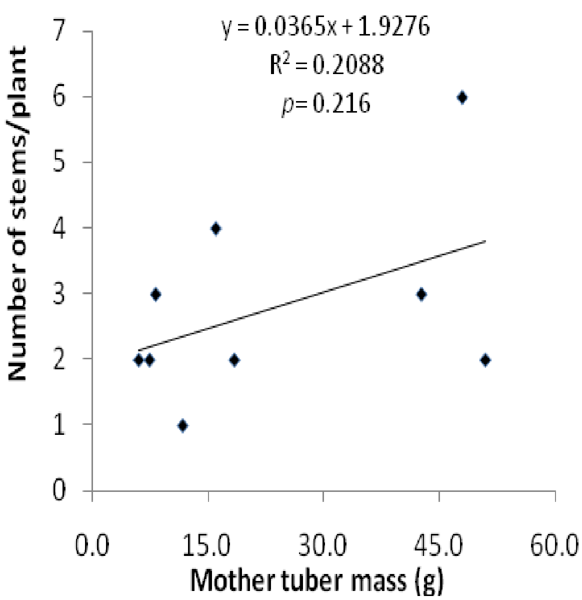


Figure 4.2. The relationship between mother tuber mass and tuber recovery in the "lowveld" vegetation region. A= JFH (n = 9), B= ASH (n = 11), C= PI (n = 5), D= PII (n = 8), E= VPI (n = 7), F= VPII (n = 6), G= WI (n = 10), H= WII (n = 10). Each individual data point represents a plant.

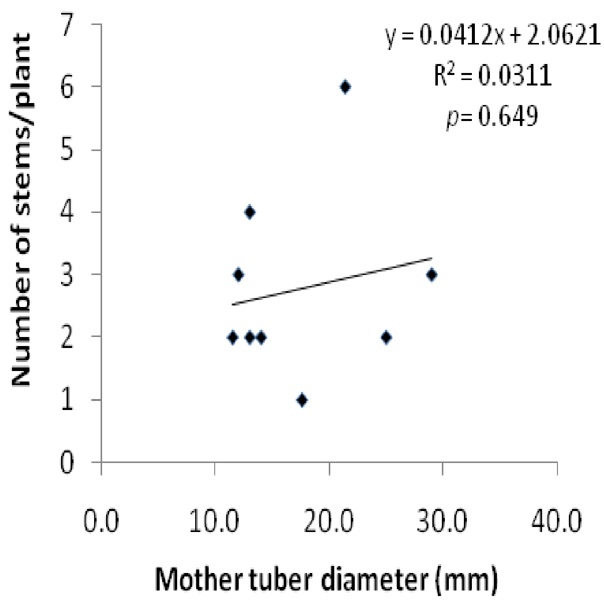
4.5.1.3. The effect of mother tuber size (mass and diameter) on number of stems per site

It was expected that the bigger (mass and diameter) the mother tuber, the higher the likelihood of it recovering successfully by having more stems as opposed to smaller mother tubers. This is because bigger mother tubers have more food reserves to support resprouting. Additionally, if a mother tuber has a large diameter, it is expected that it has a larger surface area for more resprouts to develop as opposed to a smaller one. However, no significant relationship was found between mother tuber size and the number of stems whether mother tuber mass or diameter was used ($P > 0.05$) (Figure 4.3A, B, C, D, E, F, G, H). On the other hand, there was little variation in times since last harvest at site level.

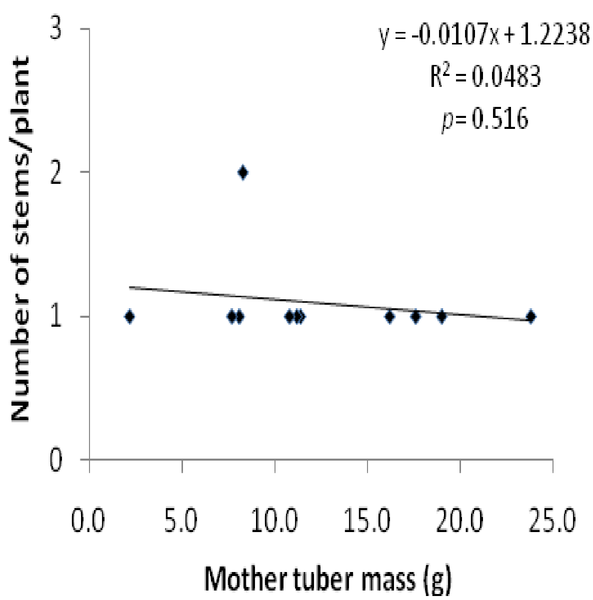
A (i)



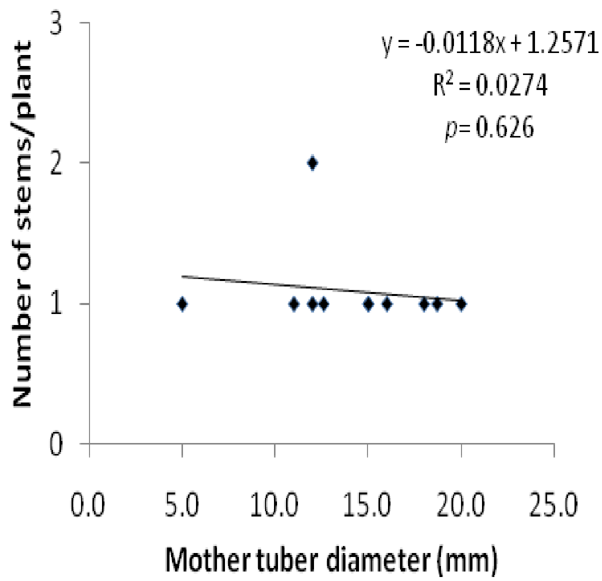
A (ii)



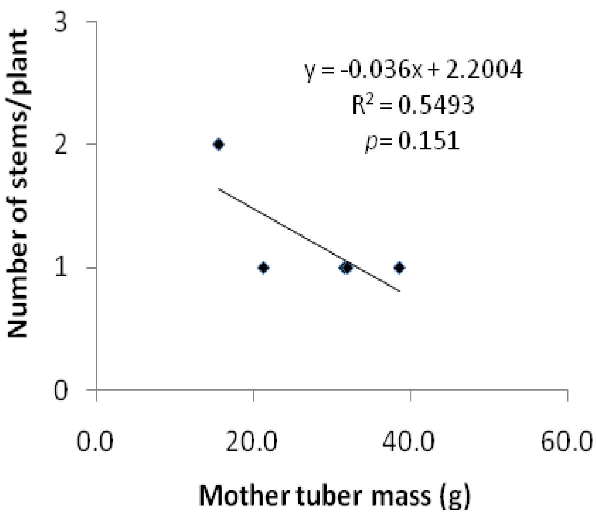
B (i)



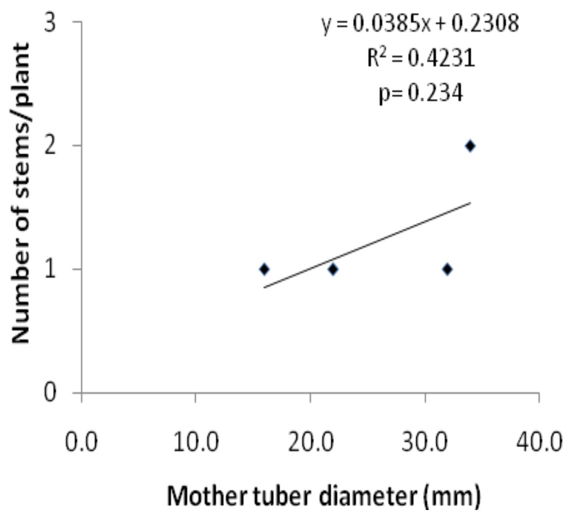
B (ii)



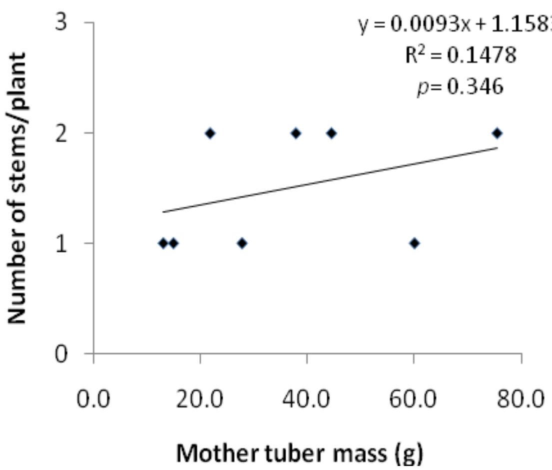
C (i)



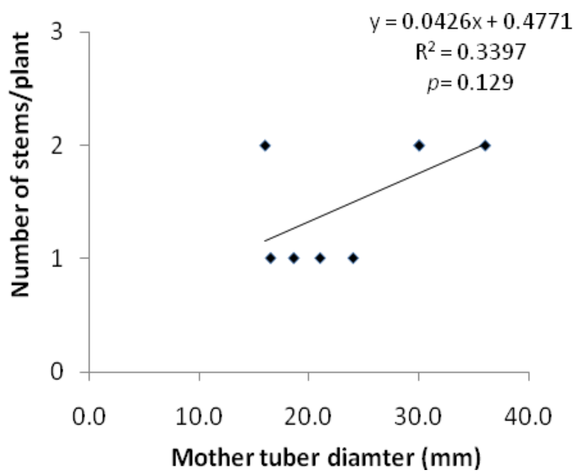
C (ii)



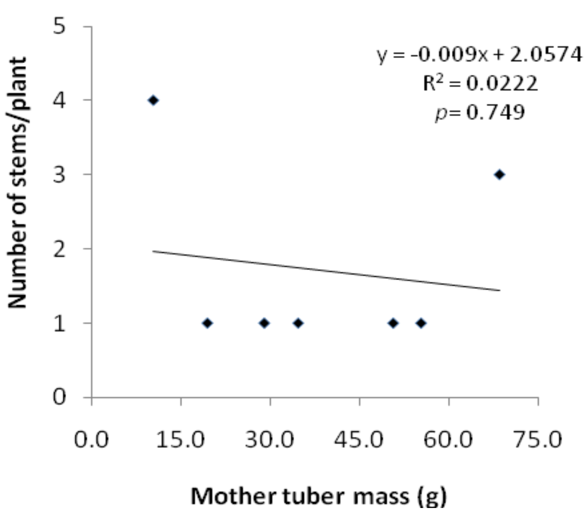
D (i)



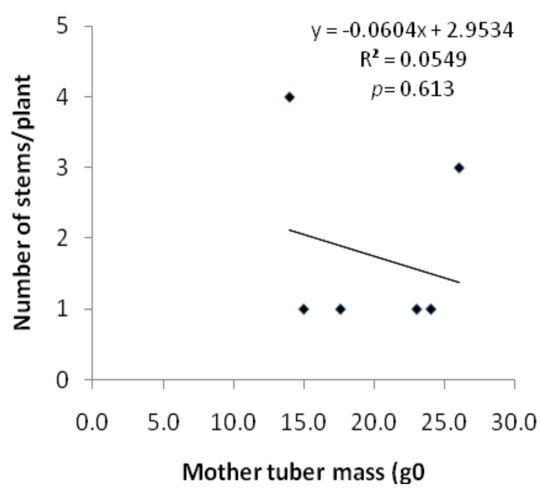
D (ii)



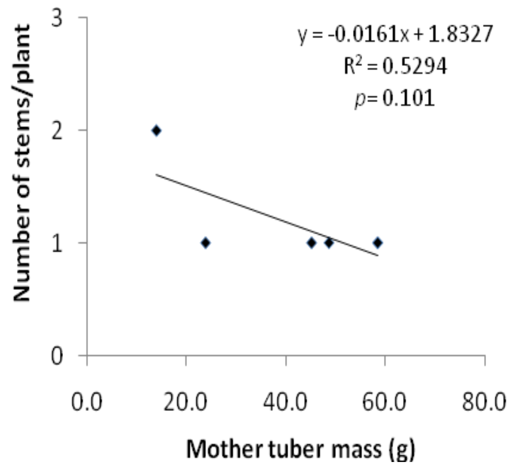
E (i)



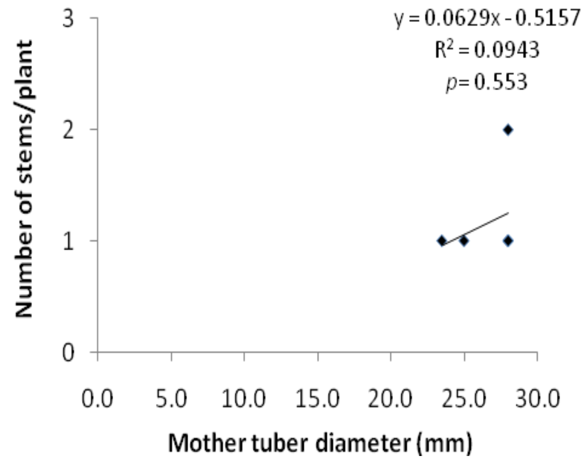
E (ii)



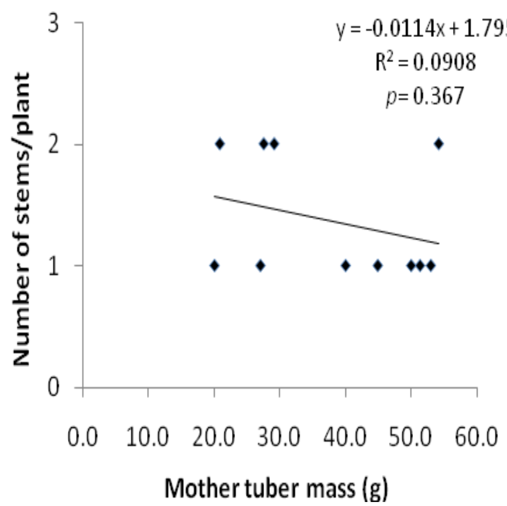
F (i)



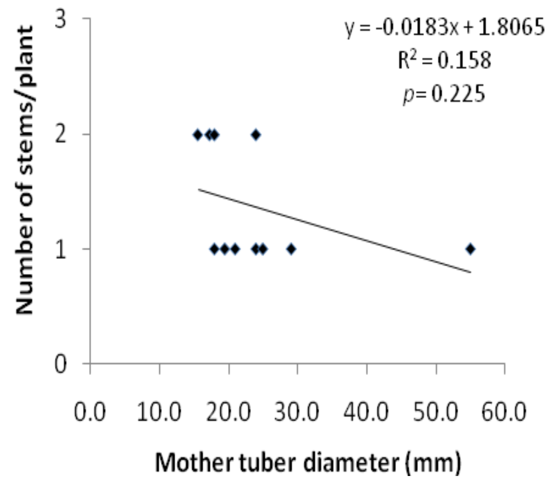
F (ii)



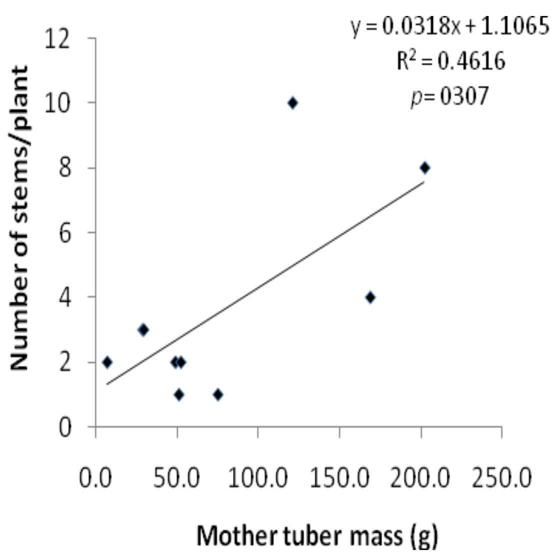
G (i)



G (ii)



H (i)



H (ii)

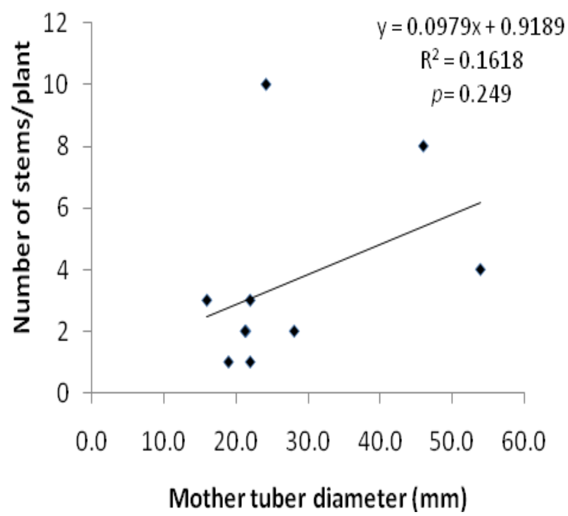
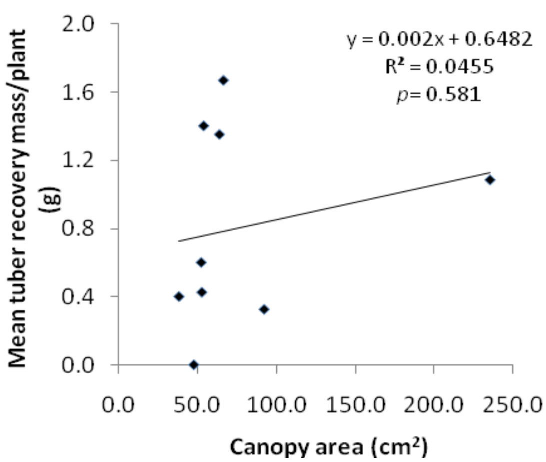


Figure 4.3. The relationship between mother tuber mass, mother tuber diameter and number of stems in the "lowveld" vegetation region. A= JFH (n = 9), B= ASH (n = 11), C= PI (n = 5), D= PII (n = 8), E= VPI (n = 7), F= VPII (n = 6), G= WI (n = 10), H= WII (n= 10). Each individual data point represents a plant. (i) Mass, (ii) Diameter.

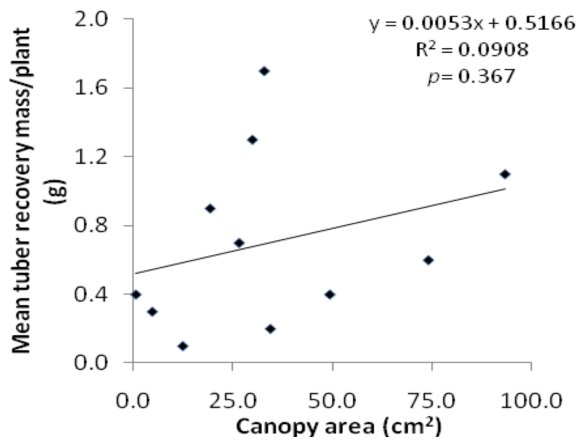
4.5.1.4. The effect of canopy area on tuber recovery biomass per site

Harvesting of *P. sidoides* involves removal of leaves which are responsible for photosynthesis. Thus removal of leaves during harvesting may affect tuber recovery biomass. In order to investigate this, the relationship between canopy area and tuber recovery biomass was explored. Generally, no significant relationship was obtained at six sites ($P > 0.05$) (Figure 4.4A, B, D, E, F, H), however there was a positive significant relationship between canopy area and tuber recovery mass at only 2 sites ($P < 0.05$) (Figure 4.4C, G). Even at the two sites where significant relationships were found, the slopes were different suggesting that there is no real pattern.

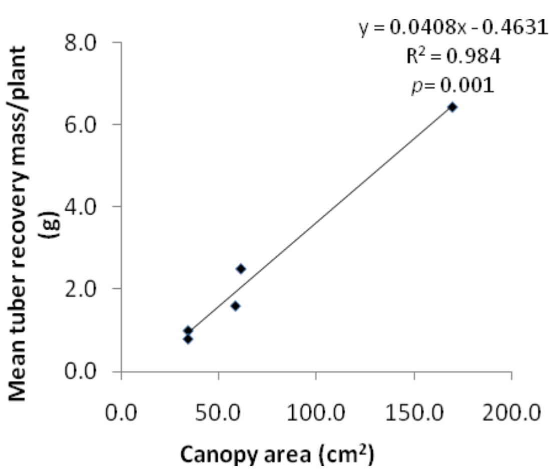
(A)



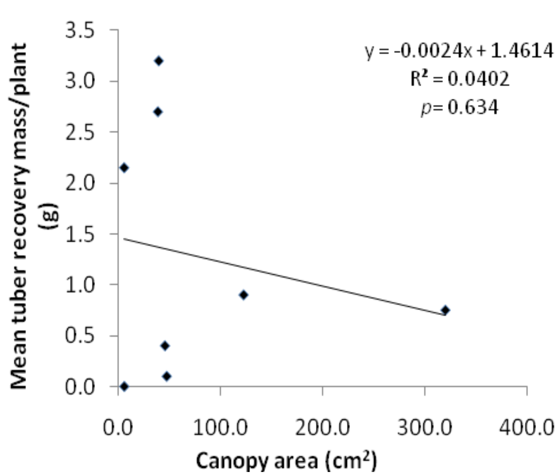
(B)



(C)



(D)



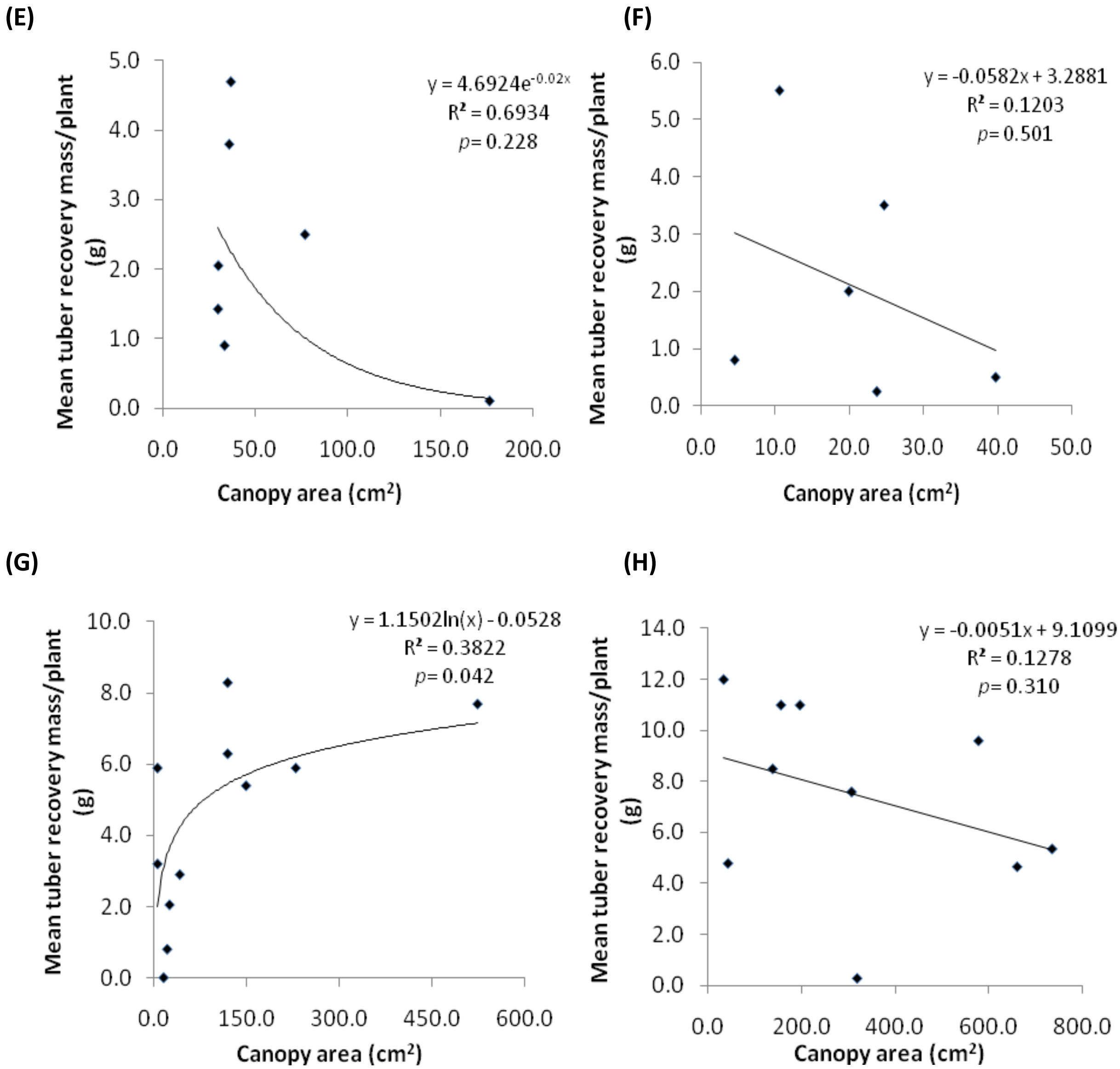


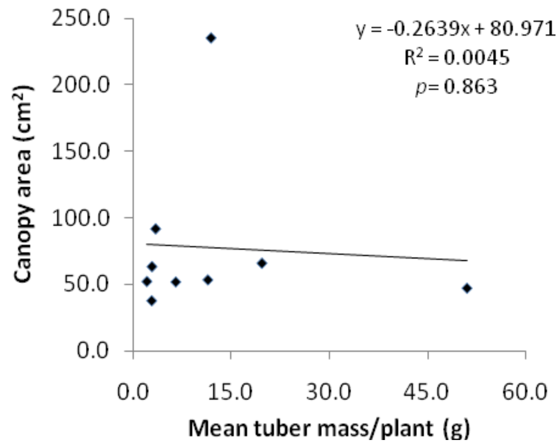
Figure 4.4. The effect of canopy area on tuber recovery in the "lowveld" vegetation region. A= JFH (n = 9), B= ASH (n = 11), C= PI (n = 5), D= PII (n = 8), E= VPI (n = 7), F= VPII (n = 6), G= WI (n = 10), H= WII (n = 10). Each individual data point represents a plant.

4.5.1.5. The effect of tuber biomass on canopy area per site

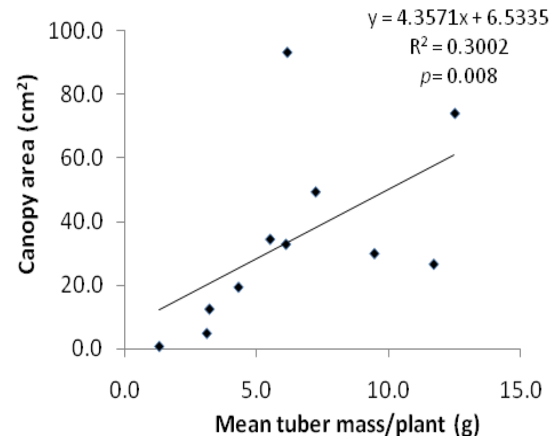
During harvesting, it is not possible to tell how big the tubers are before uprooting the plants. This has negative implications for the sustainable use of *P. sidoides* as young plants with pale coloured tubers are uprooted but not collected. Therefore in order to solve this problem, relationships between total tuber mass and canopy area were explored. No significant relationship was however found between tuber mass and canopy area in seven of the eight sites ($P > 0.05$) (Figure 4.5A, C, D, E, F, G, h). On the other hand, a significant relationship was found between the two variables at ASH ($P < 0.05$) (Figure 4.5B).

However, since at each site slopes of the trendlines were different, this implies that there is no real relationship.

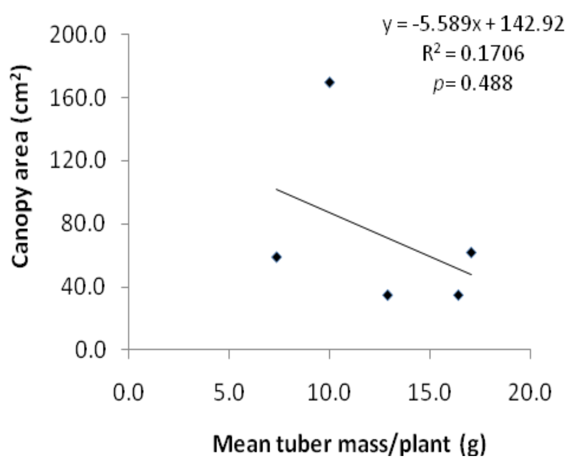
(A)



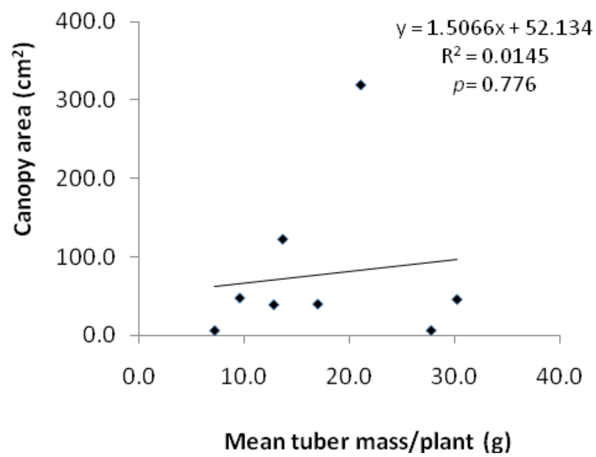
(B)



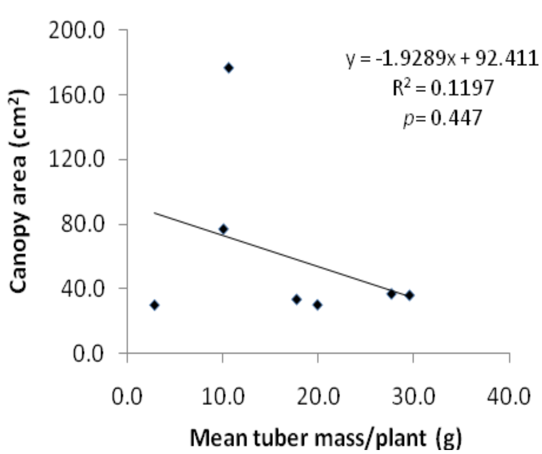
(C)



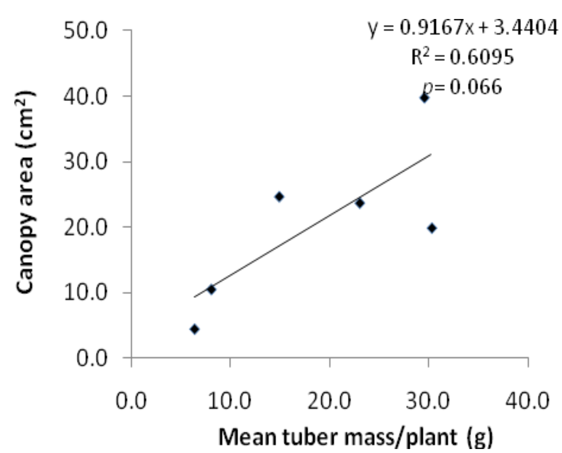
(D)



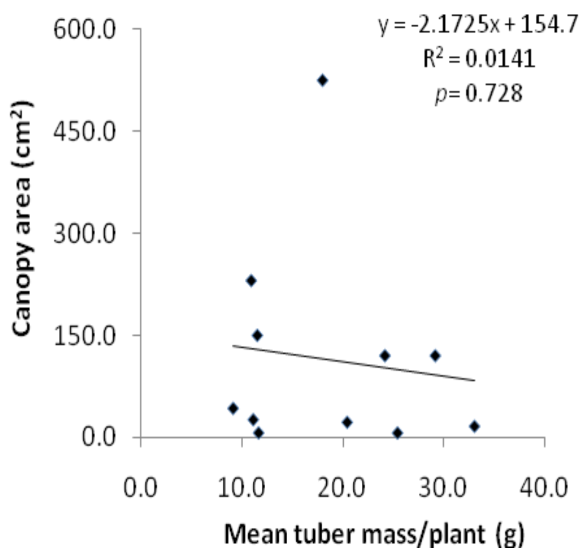
(E)



(F)



(G)



(H)

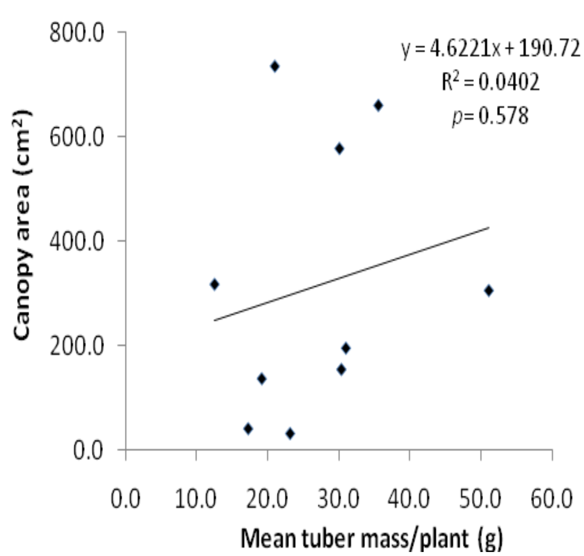


Figure 4.5. The relationship between tuber mass and canopy area in the "lowveld" vegetation region. A= JFH (n = 9), B= ASH (n = 11), C= PI (n = 5), D= PII (n = 8), E= VPI (n = 7), F= VPII (n = 6), G= WI (n = 10), H= WII (n = 10). Each individual data point represents a plant.

4.5.1.6. The effect of depth of soil covering mother tuber post harvest on tuber recovery biomass per region

The effect of depth of soil covering mother tuber on tuber recovery mass was investigated. There was no significant relationship between these variables (*P* >0.05) (Figure 4.6A, B). A positive exponential trend was however detected. This suggests that if there were more sites, the relationship would have been more pronounced and perhaps significant. This is because at regional level each site represented a data point and this decreased the number of points to run the regression.

(A) (B)

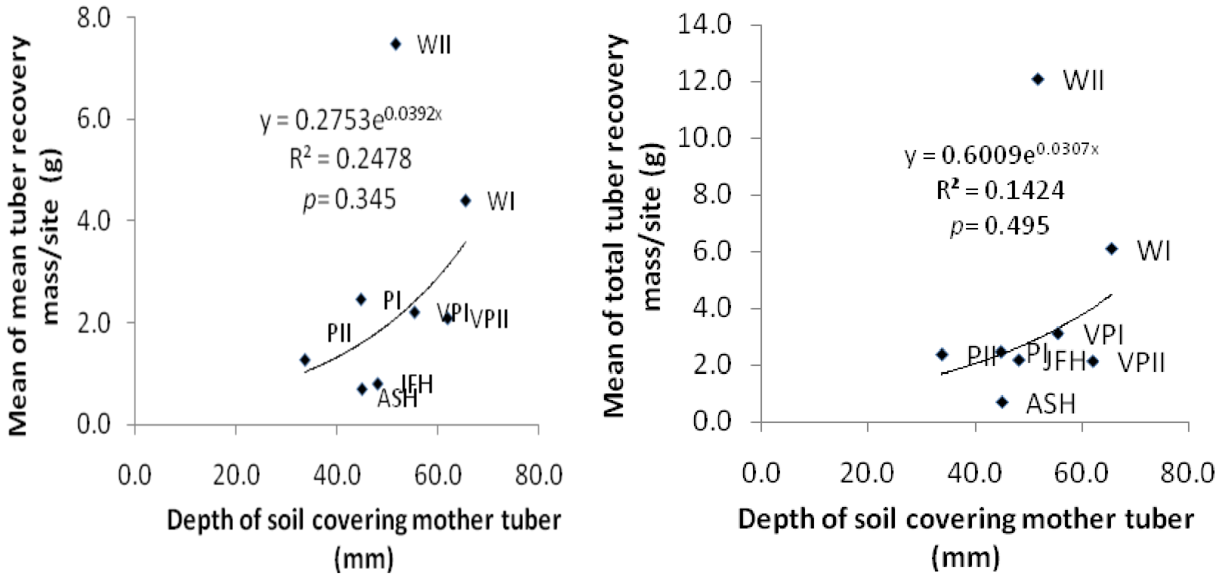


Figure 4.6. The relationship between depth of harvest hole and tuber recovery mass in the "lowveld" vegetation region (n = 8). ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.7. The effect of mother tuber biomass on tuber recovery biomass per region

The effect of mother tuber biomass on tuber recovery biomass was investigated. A positive significant relationship was established ($P < 0.05$) (Figure 4.7A, B) indicating that as mother tuber mass increases, tuber recovery mass also increases.

(A) (B)

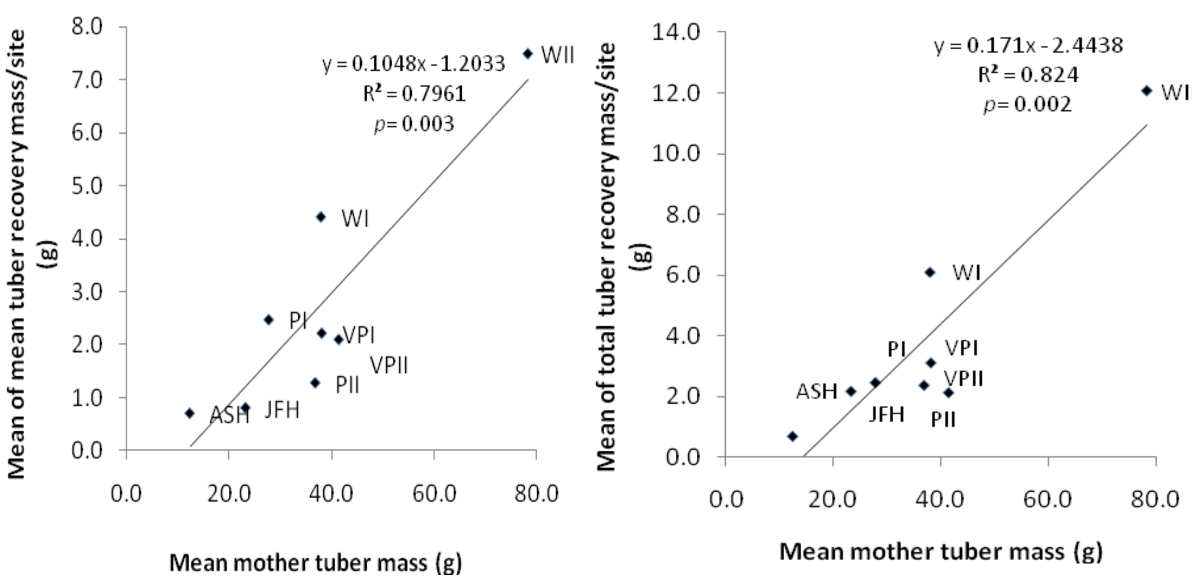


Figure 4.7. The relationship between mother tuber mass and tuber recovery mass in the "lowveld" vegetation region (n = 8). ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.8. The effect of mother tuber size (biomass and diameter) on number of stems per region

When relationships between mother tuber size (mass and diameter) and number of stems were investigated, no significant relationship was found ($P > 0.05$) (Figure 4.8A, B). However, a linear positive trend was detected. Although the relationship between mother tuber mass and tuber recovery mass was found not to be significant at 95% confidence interval, it was however significant at 90% confidence interval (Figure 4.8A). This implies that with more study sites (hence more data points), a significant result may have been possible.

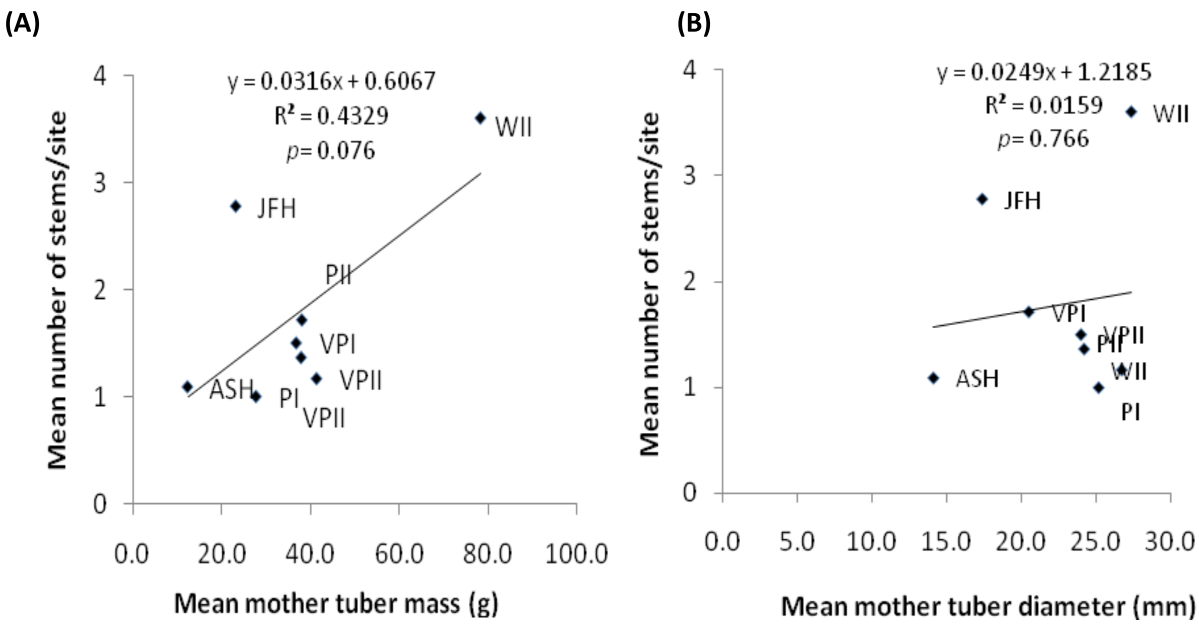


Figure 4.8. The relationship between mother tuber mass and number of stems in the "lowveld" vegetation region (n = 8). ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.9. The effect of mother tuber biomass on tuber recovery colour per region

P. sidoides tubers are damaged by harvest and therefore production of secondary metabolites can be initiated as a defense mechanism. Hence there is a possibility that there will be increased pigmentation in its tissues implying tuber recovery intensification. Therefore, a relationship between mother tuber biomass and tuber recovery colour was explored. A positive significant relationship was found between mother tuber mass and tuber recovery colour score ($P < 0.05$) (Figure 4.9). This suggests that as mother tubers get larger, their recovering tubers develop more intense colour.

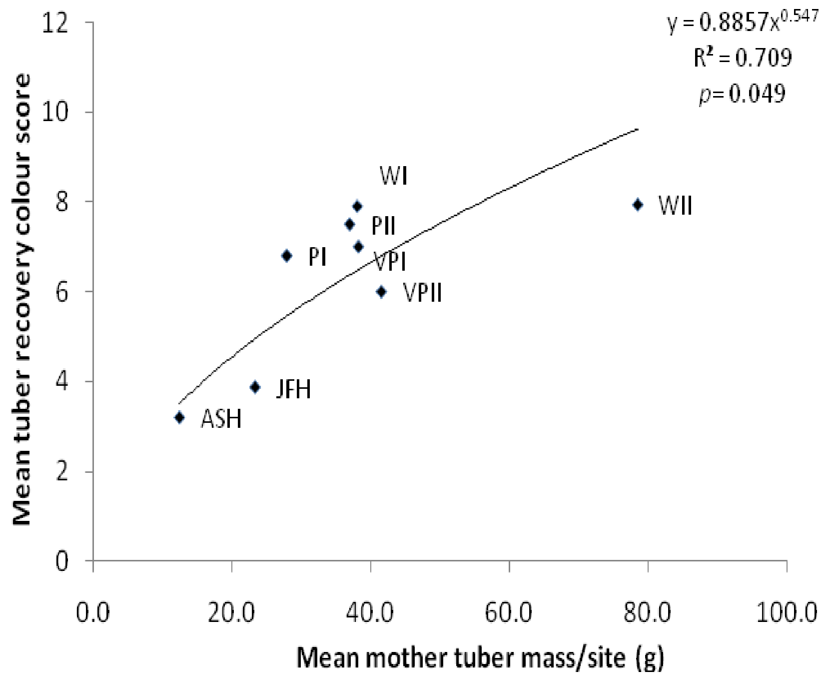
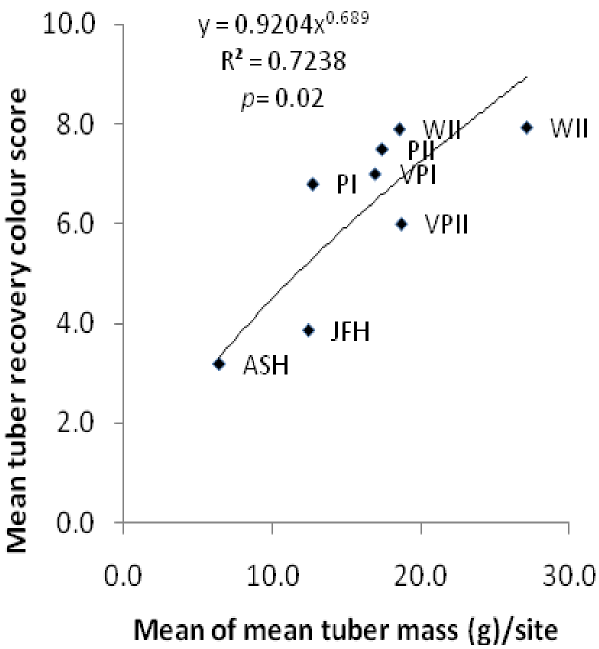


Figure 4.9. The relationship between mother tuber mass and tuber recovery colour score in the "lowveld" vegetation region (n = 8). ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II. Each data point represents a site. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.10. The effect of tuber biomass size on tuber recovery colour per region

In order to maximize tuber colour intensity, factors that influence it have to be established. For that reason a relationship between tuber mass and tuber recovery colour was determined. There was a positive significant relationship between the two variables when mean of mean tuber recovery mass values were used ($P < 0.05$) (Figure 4.10A). When mean of total tuber recovery mass values were used, there was no significant relationship although an increasing positive trend was seen ($P > 0.05$) (Figure 4.10B).

(A)



(B)

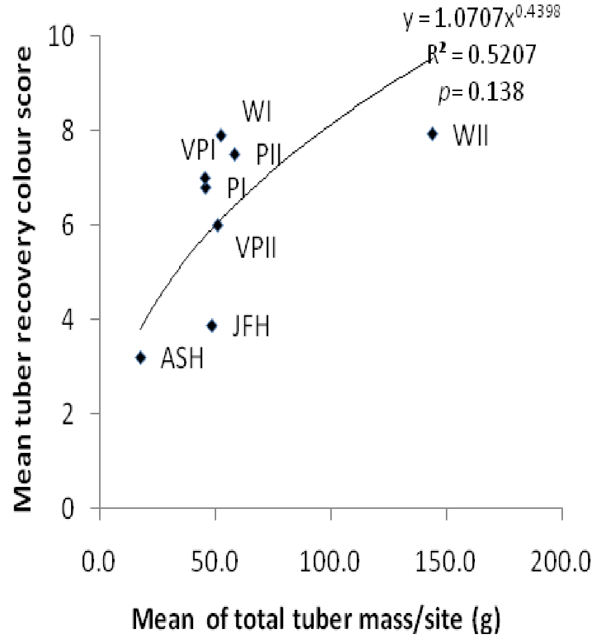


Figure 4.10. The relationship between tuber mass and tuber recovery colour score in the "lowveld" vegetation region (n = 8). ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II. Each data point represents a site. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.11. The effect of canopy area on tuber recovery biomass per region

Plants with large canopies are expected to have a large surface area for photosynthesis and hence production of more carbohydrates for the rest of the plant. Thus the logic was that since tuber recovery depends on photosynthates produced by the canopy, its biomass might be dependent on canopy area. There was a positive significant relationship between canopy area and tuber recovery biomass at regional level ($P < 0.05$) (Figure 4.11A, B). This suggests that plants with bigger canopies contribute to more tuber recovery biomass.

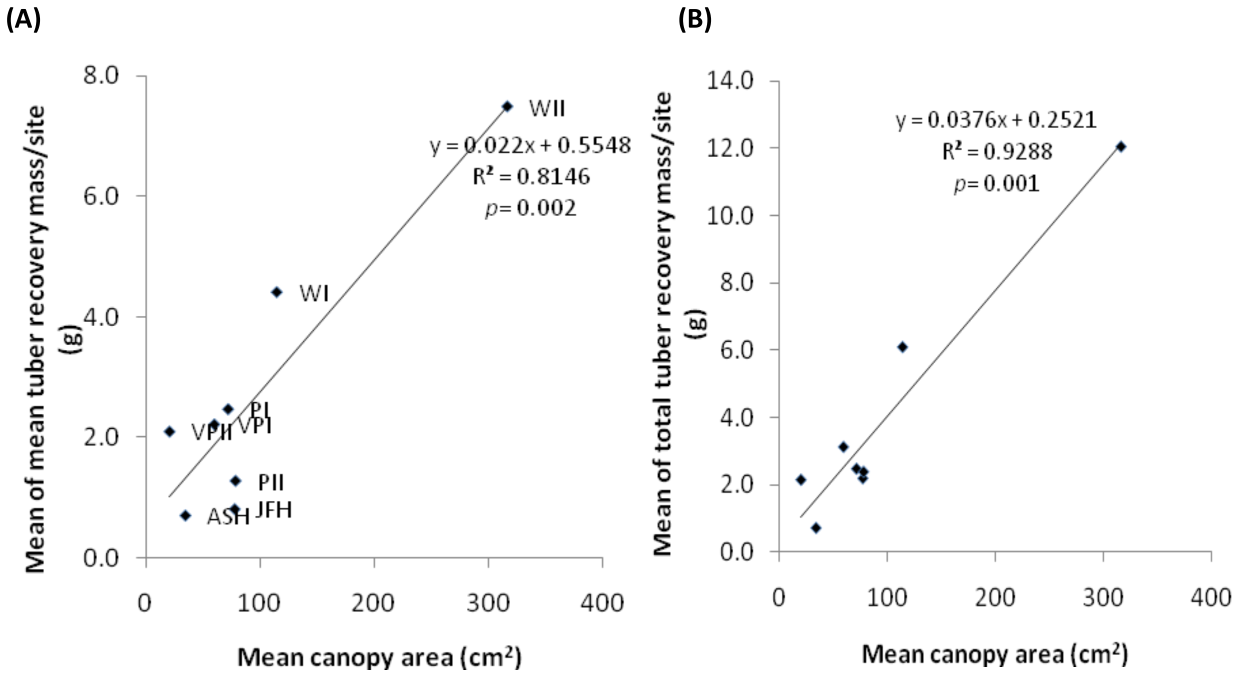


Figure 4.11. The relationship between canopy area and tuber recovery mass in the lowveld vegetation region (n = 8). Each data point represents a site (ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) but data labels could not be added as points are too close to each other. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.12. The effect of tuber biomass on canopy area per region

Harvesters are instructed to harvest mature *P. sidodies* plants. Therefore larger plants with bigger canopies are usually targeted by harvesters as they are assumed to have larger tubers. In order to test this, relationships between tuber mass and canopy area were investigated. A positive significant relationship was found between tuber mass and canopy area ($P < 0.05$) (Figure 4.12A, B). Thus as tuber biomass increases, canopy area also increases.

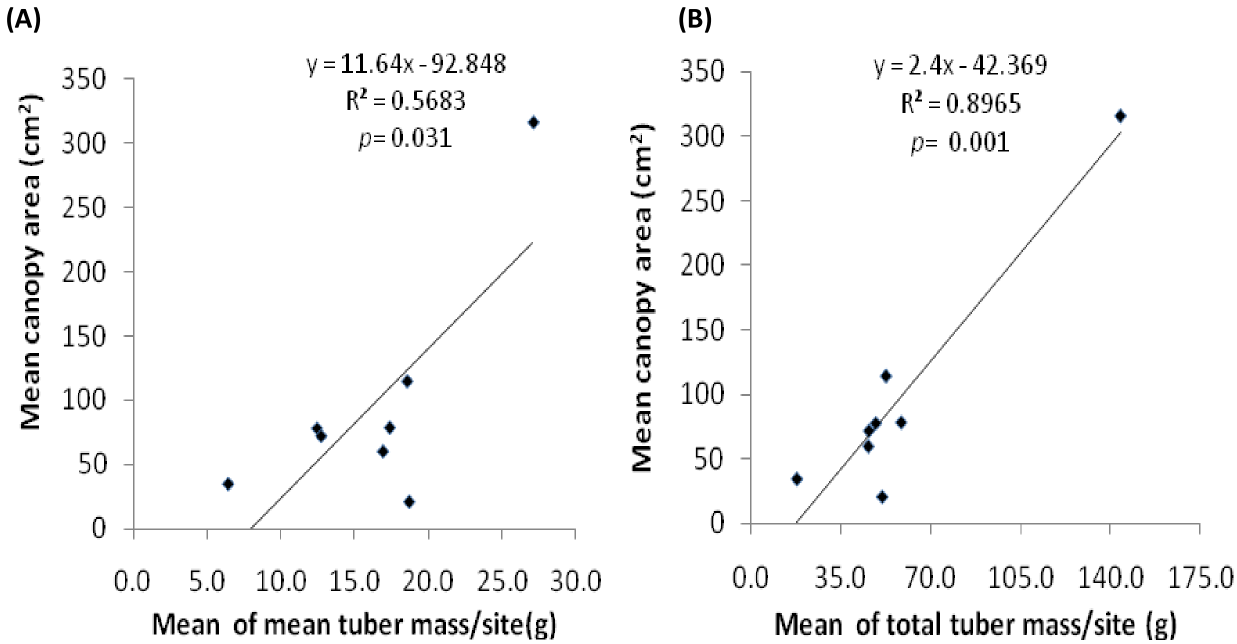
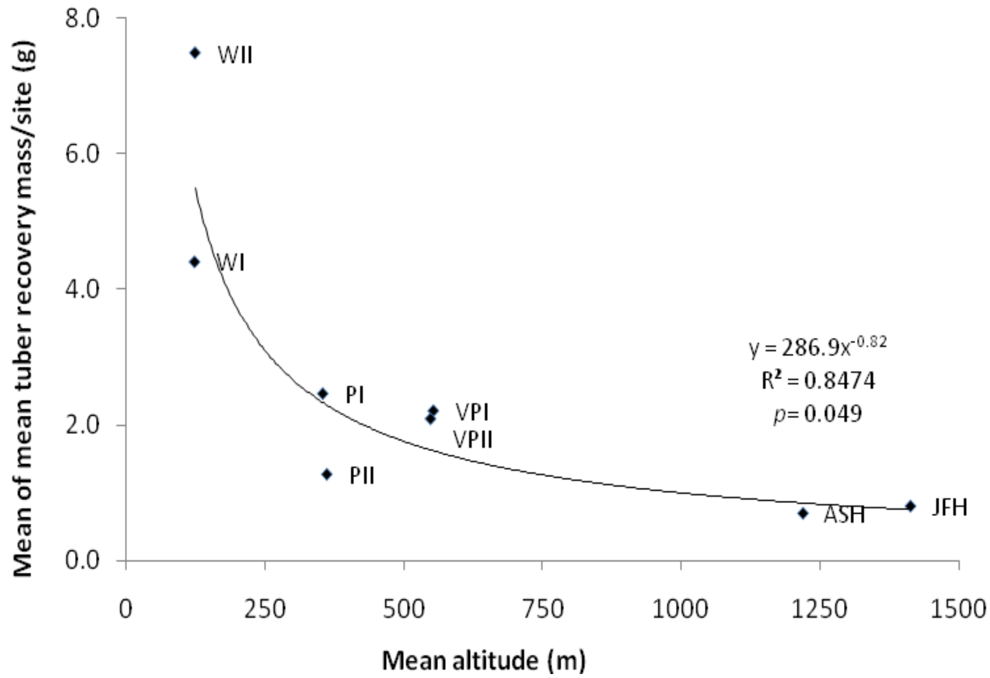


Figure 4.12. The relationship between tuber mass and canopy area in the lowveld vegetation region (n = 8). Each data point represents a site (ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) but data labels could not be added as points are too close to each other. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.1.13. The effect of altitude on tuber recovery biomass per region

Altitude is known to affect plant growth. *P. sidoides* occurs across a wide range of habitats with varying altitudes. Therefore in order to assess the effects of altitude on tuber recovery, relationship between this variable and tuber recovery mass was explored. Altitude was found to have a significant relationship with tuber recovery mass only when mean of mean tuber recovery mass values were used ($P < 0.05$) (Figure 4.13A). Sites at lowest altitudes were found to have more tuber recovery biomass as opposed to those found in higher altitudes. When mean of total tuber recovery values were used, there was no significant relationship ($P > 0.05$) although a high R^2 value was obtained (Figure 4.13B) suggesting that increasing study sites would have yielded a significant relationship.

(A)



(B)

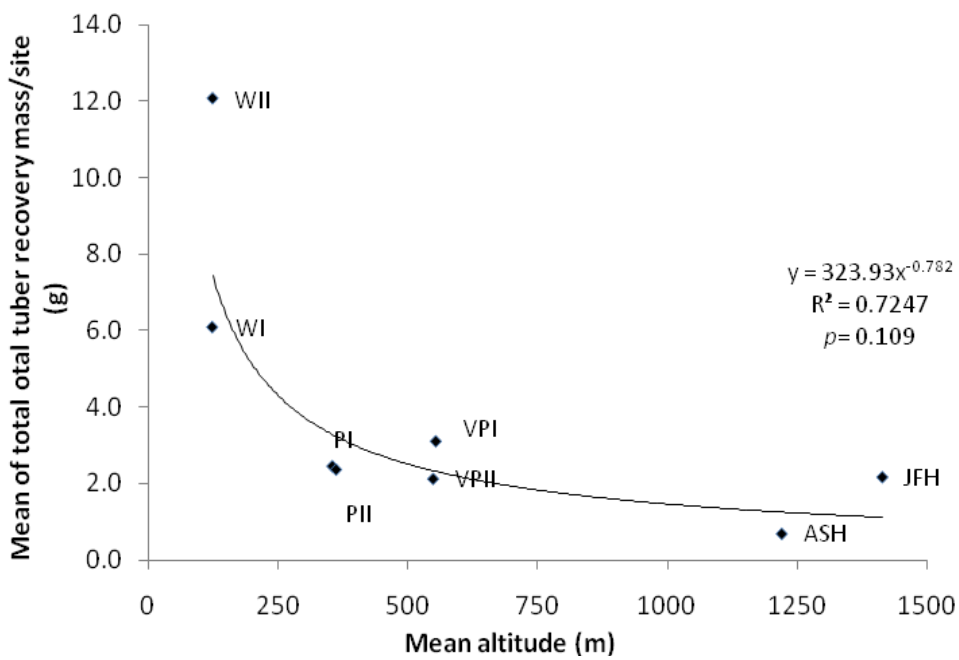


Figure 4.13. The relationship between altitude and tuber recovery mass in the lowveld vegetation region (n = 8). Each data point represents a site (ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) but data labels could not be added as points are too close to each other. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass.

4.5.2. “Highveld” vegetation region

4.5.2.1. The effect of depth of soil covering mother tuber on tuber recovery biomass per site

Closure of holes after harvest ensures that remaining parts of the plant are covered with soil and are not exposed to factors such as trampling by livestock. Therefore, it was expected that how well the mother tuber is buried after harvest may affect tuber recovery biomass. Thus the effect of depth of soil covering the mother tuber on tuber recovery biomass was investigated. However, there was no significant relationship between the variables (P > 0.050 (Figure 4.14A, B). Although there was no significant relationship found, a linear trend was observed at HTW I (Ha Tlhaku) (Figure 4.14A).

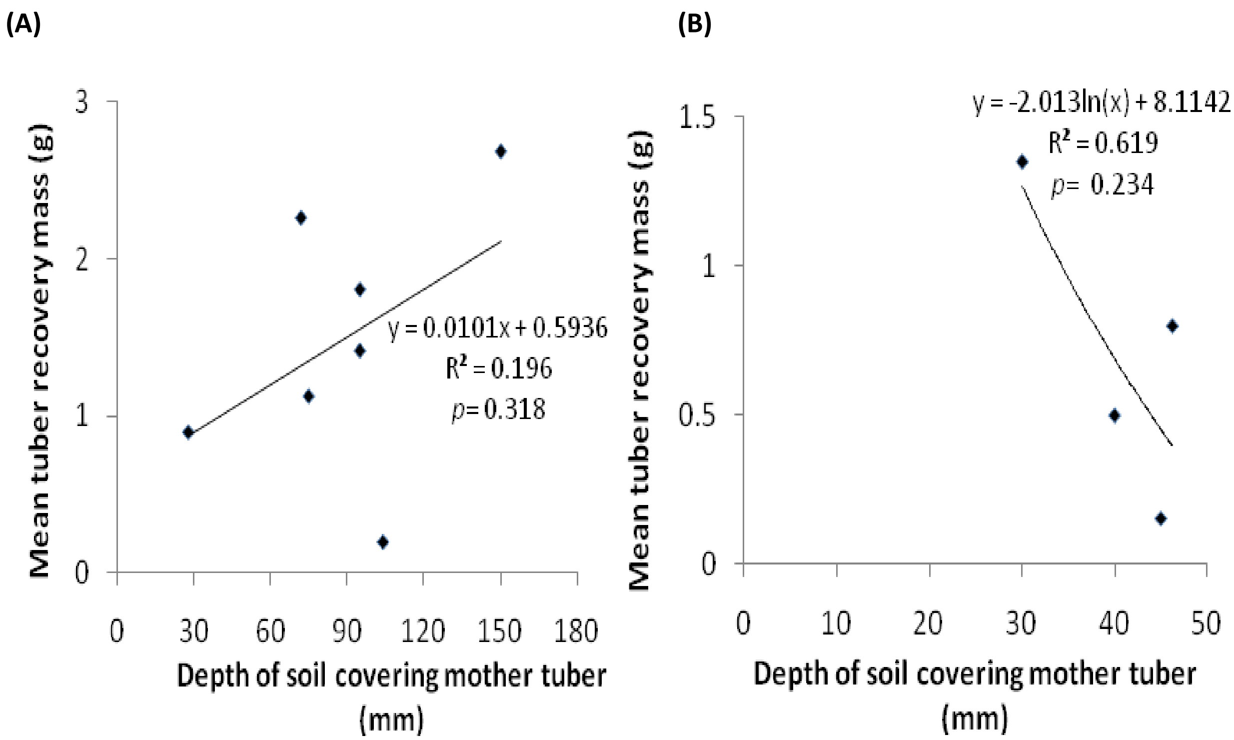


Figure 4.14. The relationship between depth of harvest hole and tuber recovery per site in the highveld vegetation region. A= HTW I (n = 7), B= TSA (n = 4).

4.5.2.2. The effect of mother tuber biomass on tuber recovery biomass per site

For successful resprouting, enough assimilates are required from the mother tuber. Therefore, a relationship between mother tuber mass and tuber recovery mass was explored. There was no significant relationship however between mother tuber mass and tuber recovery mass at the two sites (P > 0.05) (Figure 4.15 A and B). Additionally an inverse relationship was detected which might be attributed to too low sample size per site.

(A) (B)

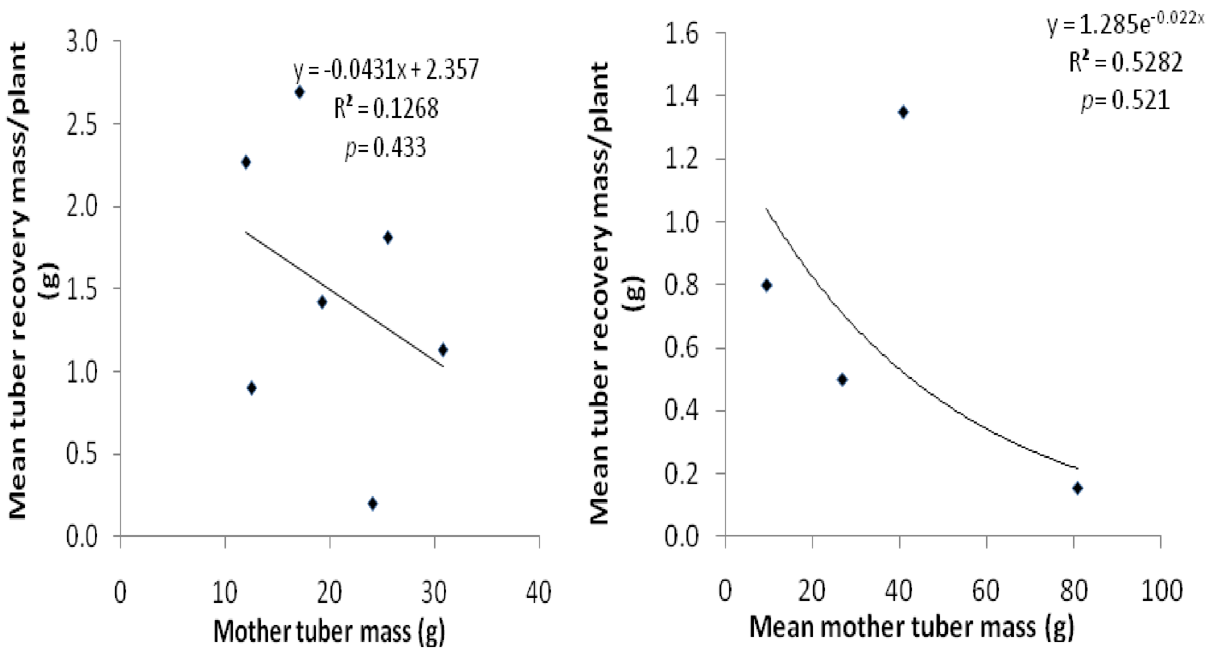


Figure 4.15. The relationship between mother tuber mass and tuber recovery mass per site in the highveld vegetation region. A= HTWI (n = 7), B= TSA (n = 4).Each data point represents a plant.

4.5.2.3. The effect of mother tuber size (biomass and diameter) on the number of stems per site

A large mother tuber has enough food reserves and surface area for successful resprouting. Therefore, the size of a mother tuber was expected to influence the number of stems produced. However, mother tuber size did not affect the number of stems produced following harvest. Thus there was no significant relationship between mother tuber mass, mother tuber diameter and the number of stems produced ($P > 0.05$) (Figure 4.16 A (i), (ii), B (i), (ii)). These kind of results may have been obtained as a result of less variability in times since last harvest.

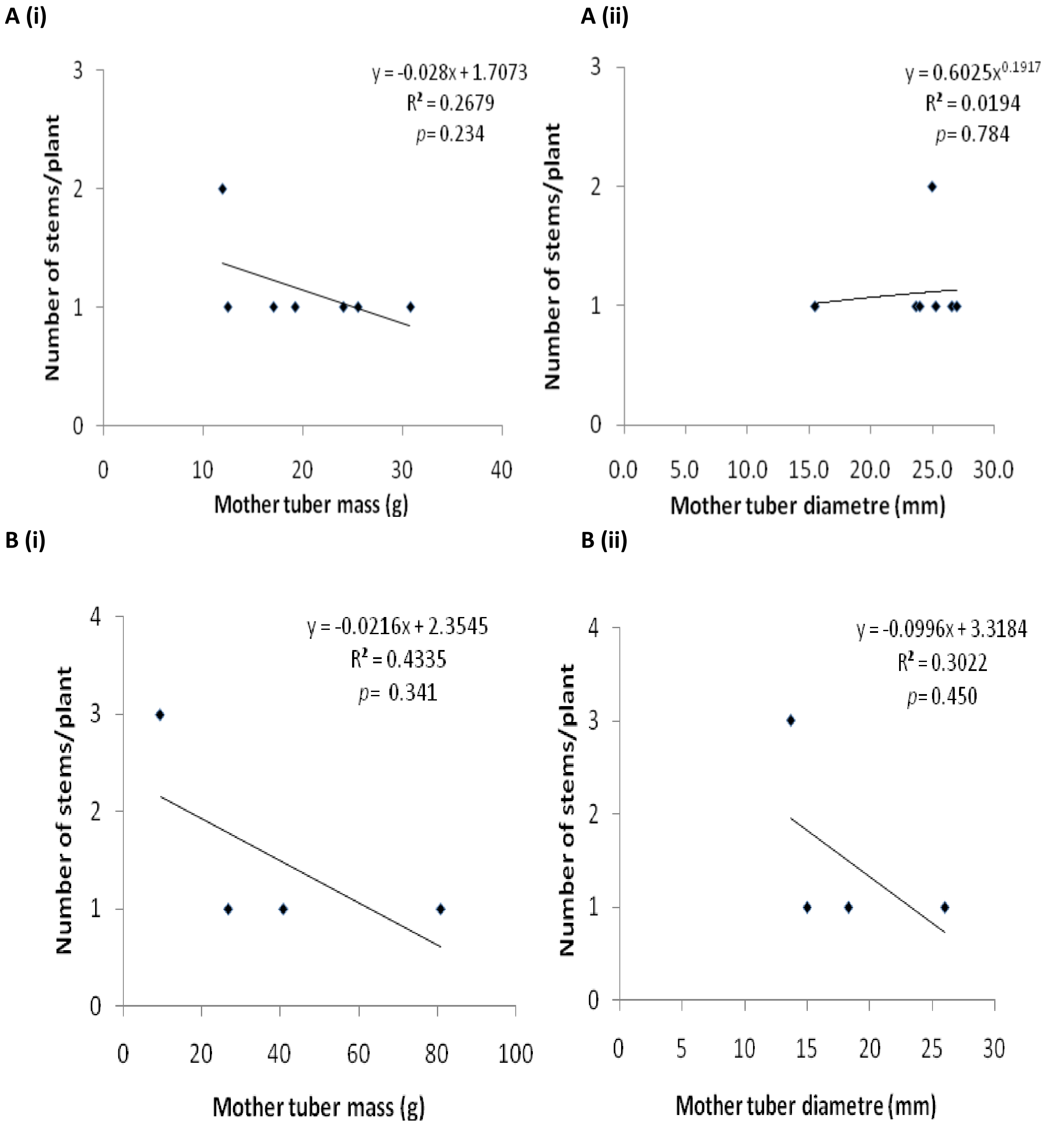


Figure 4.16. The relationship between mother tuber mass and total number of stems per site in the highveld vegetation region. A= HTWI (n = 7) B= TSA (n = 4). (i)= mass, (ii)= diameter. Each data point represents a plant.

4.5.2.4. The effect of canopy area on tuber recovery mass per site

Harvesing of *P.sidoides* usually entails removal of entire plant including leaves and this can affect photosynthesis. As such the effect of canopy area on tuber recovery mass was determined. However there was no significant relationship (P > 0.05) (Figure 4.17A, B) probably because there was little variability in terms of times since last harvest of the plants at site level.

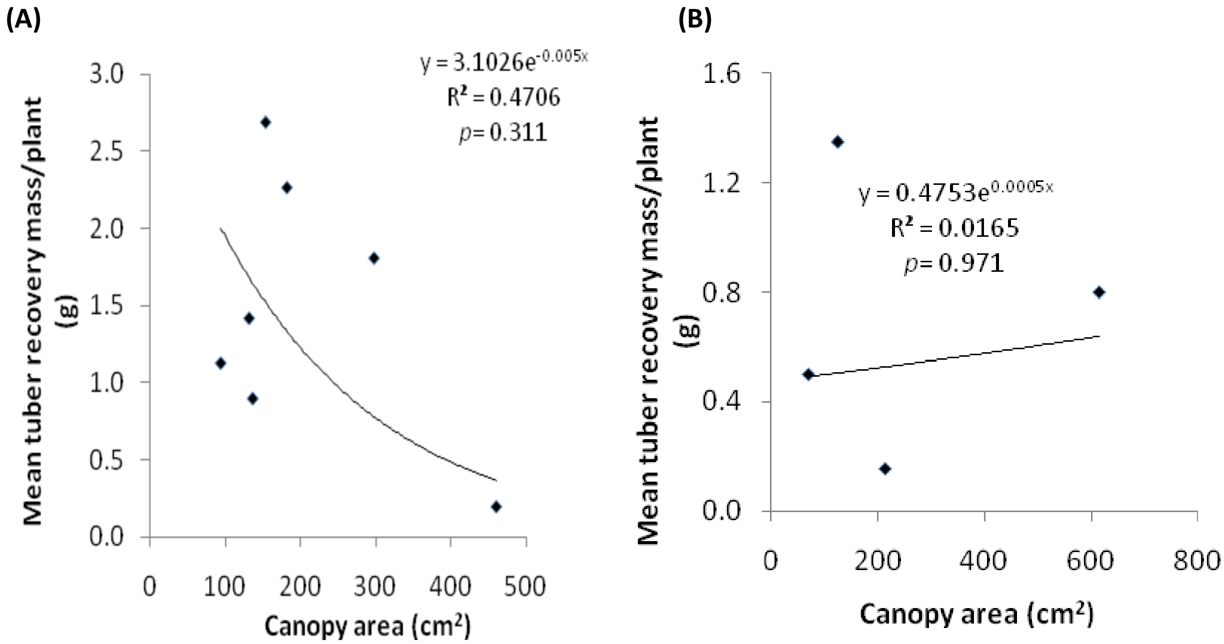


Figure 4.17. The relationship between canopy area and tuber recovery mass per site in the highveld vegetation region. A= HTW I (n = 7), B= TSA (n = 4). Each data point represents a plant.

4.5.2.5. The effect of tuber biomass on canopy area per site

Harvesters cannot tell how big the tubers are before uprooting the plant so in order to come up with a surrogate for tuber size, relationship between tuber mass and canopy area was investigated. No significant relationship between tuber mass and canopy area was found (P > 0.05) (Figure 4.18A, B). This may imply that tuber biomass does not affect canopy area and vice versa hence canopy area cannot be used as a marker for tuber size. However, at site level, there was less variability in time since last harvest of plants.

(A) **(B)**

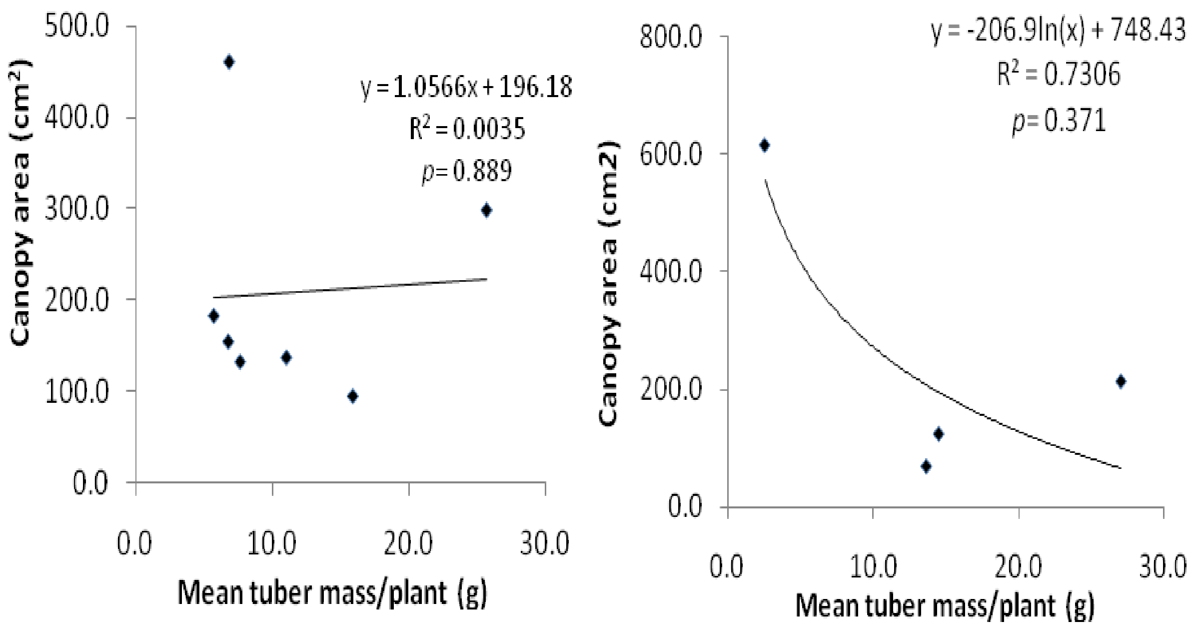


Figure 4.18. The relationship between tuber mass and canopy area per site in the "highveld" vegetation region. A= HTWI (n = 7), B= TSA (n = 4). Each data point represents a plant.

4.5.2.7. The effect of depth of soil covering mother tuber on tuber recovery biomass per region

The expectation was that covering the mother tuber with soil post harvest might influence tuber recovery. Therefore the effect of depth of soil above mother tuber on tuber recovery was examined. There was however no significant relationship between these variables when mean of mean tuber recovery mass values were used (*P* > 0.05) (Figure 4.19A). On the other hand, when mean of total tuber recovery mass values were used, the relationship was significant at 90% confidence interval with a high R^2 value (Figure 4.19B). Additionally, a positive exponential trend was observed.

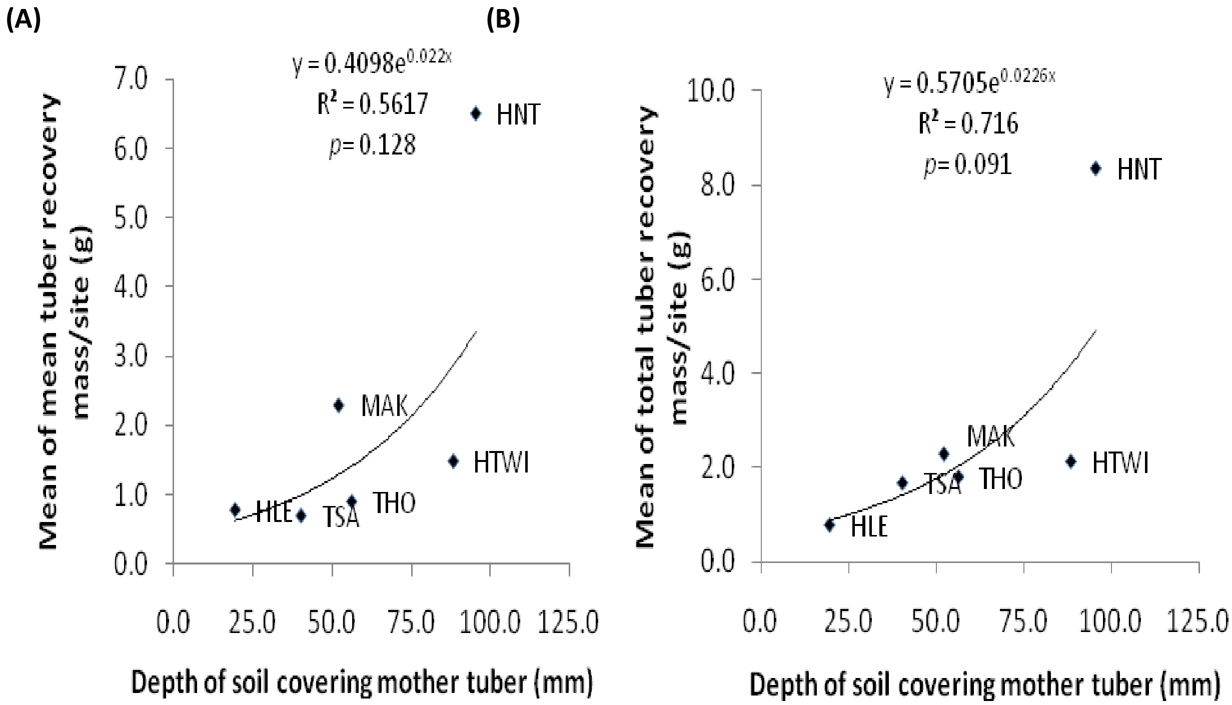


Figure 4.19. The relationship between depth of harvest of soil covering mother tuber and tuber recovery mass in the "highveld" vegetation region (n = 6). HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.2.8. The effect of mother tuber biomass on tuber recovery biomass per region

The mother tuber is expected to supply nutrients to the resprouts which will develop into tubers. Hence when recovery occurs, the mother tuber provides nutrients to the tuber recovery as well. Thus the relationship between mother tuber mass and tuber recovery mass was investigated. However, no significant relationship resulted ($P > 0.05$) (Figure 4.20A, B). This may imply that although the mother tuber supplies nutrients for resprouting, recovering tubers get independent at some stage.

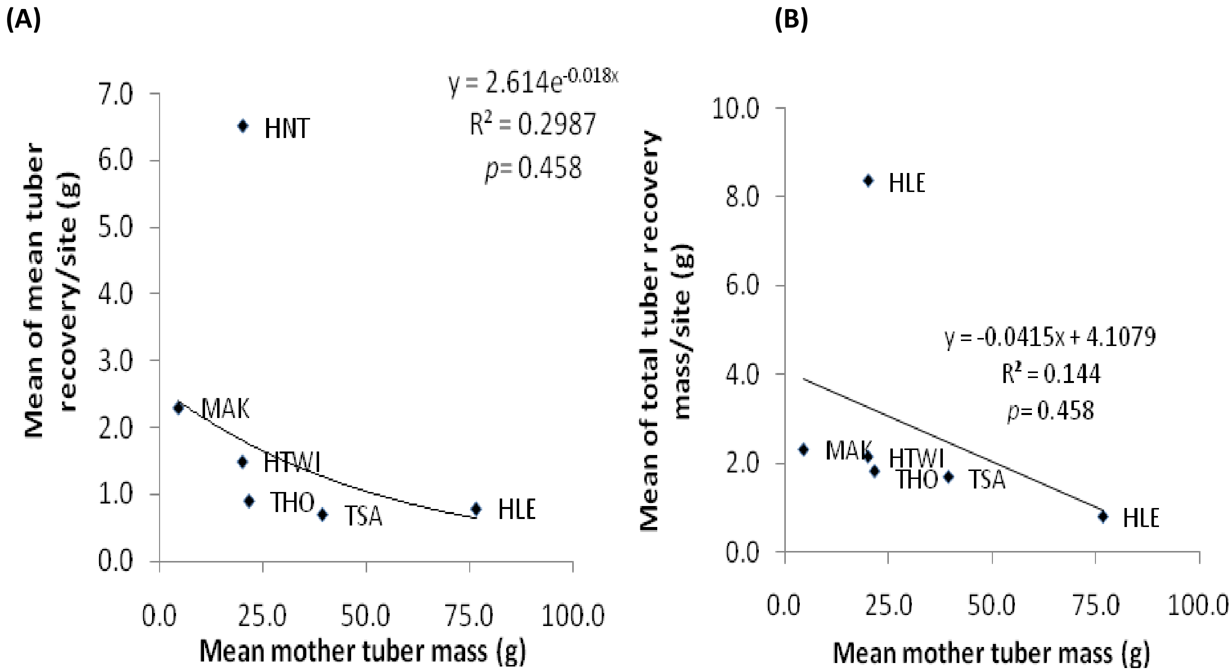


Figure 4.20. The relationship between mother tuber mass and tuber recovery mass in the "highveld" vegetation region (n = 6). HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.2.9. The effect of mother tuber mass on the number of stems per region

P. sidoides recovers by producing resprouts which later develop stems and as these stems grow, they swell up to eventually form the next generation of tubers (*pers. obs*.). In order to explore factors that may affect the number of stems after harvest, relationships between mother tuber mass and number of stems were examined. No significant relationship was found between mother tuber mass and tuber recovery mass ($P > 0.05$) (Figure 4.21 A, B). There results may suggest that the size of the mother tuber does not determine the number of stems that will develop when the mother tuber recovers post harvest.

(A) (B)

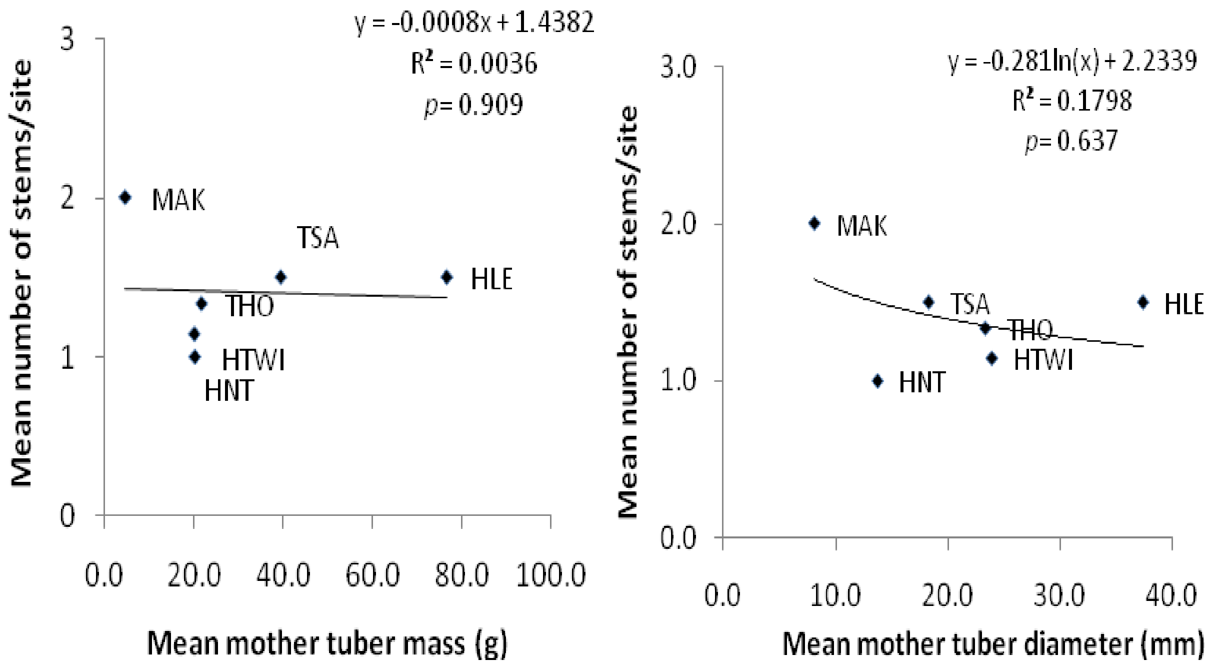


Figure 4.21. The relationship between mother tuber mass and number of stems in the "highveld" vegetation region (n= 6). HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.2.10. The effect of mother tuber biomass on tuber recovery colour per region

Tuber colour intensity is a requirement in the Pelargonium industry whereby dark-red coloured tubers are preferred to pale-coloured ones. This warrants investigations into factors that influence tuber colour intensification. So relationship between mother tuber mass and tuber recovery colour score was determined. However, no significant relationship was evident between the two variables (P > 0.05) (Figure 4.22) although a linear positive trend was observed.

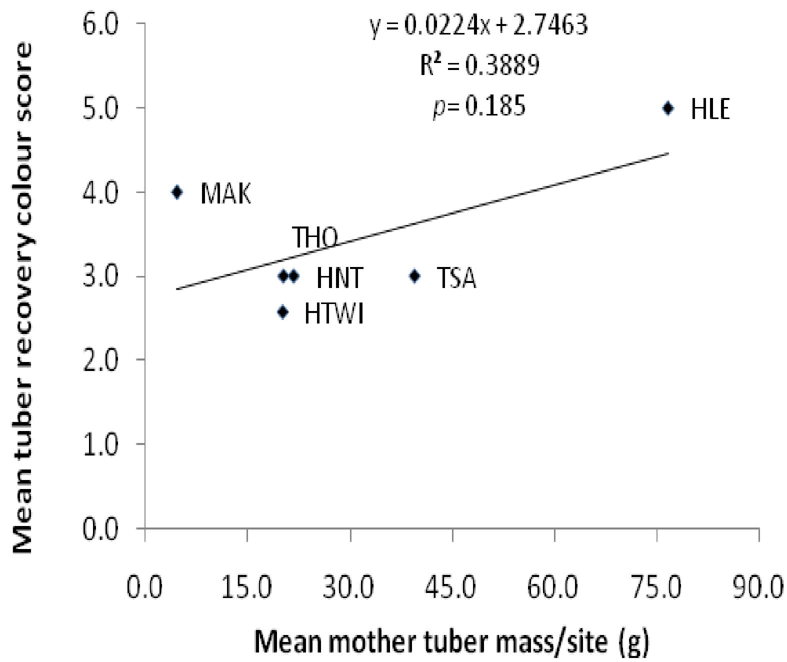
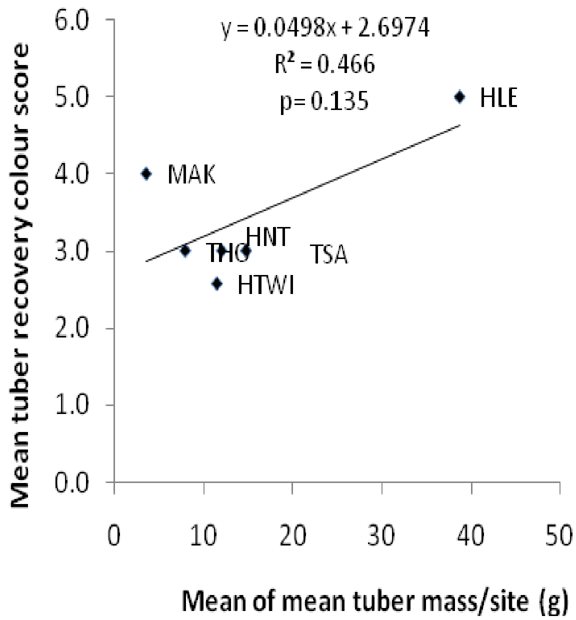


Figure 4.22. The relationship between mother tuber mass and tuber recovery colour score in the "highveld" vegetation region (n = 6). HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.2.11. The effect of tuber biomass size on tuber recovery colour per region

When relationship between tuber biomass and tuber recovery colour intensity were investigated no significant relationship resulted ($P > 0.05$) (Figure 4.23A, B). The results suggest that tuber colour is not dependent on the size of the mother tuber. However, when mean of mean tuber mass values were used, a positive linear trend was evident.

(**A**) (**B**)



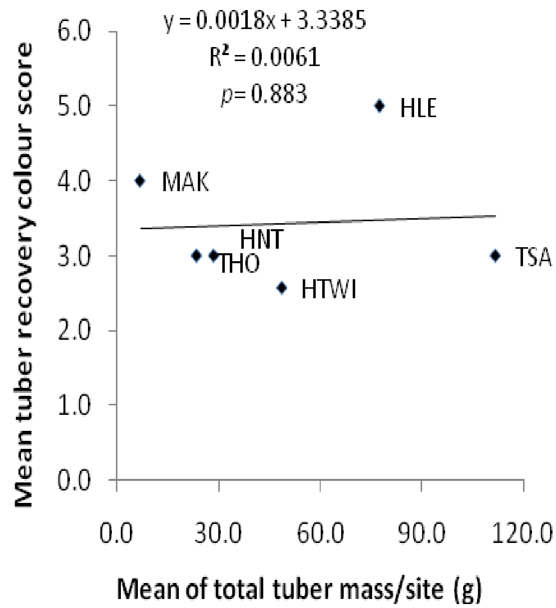


Figure 4.23. The relationship between tuber mass and tuber recovery colour score in the "highveld" vegetation region (n = 6). HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.2.12. The effect of altitude on tuber recovery per region

Altitude is one factor that influences plant growth. This means altitude can also determine tuber recovery in *P. sidoides* post harvest. In order to verify this, relationship between altitude and tuber recovery mass was explored. There was however no significant relationship between altitude and tuber recovery mass (P > 0.05) (Figure 4.24A, B). This implies that varying altitude does not result in an increase or decrease in tuber recovery biomass.

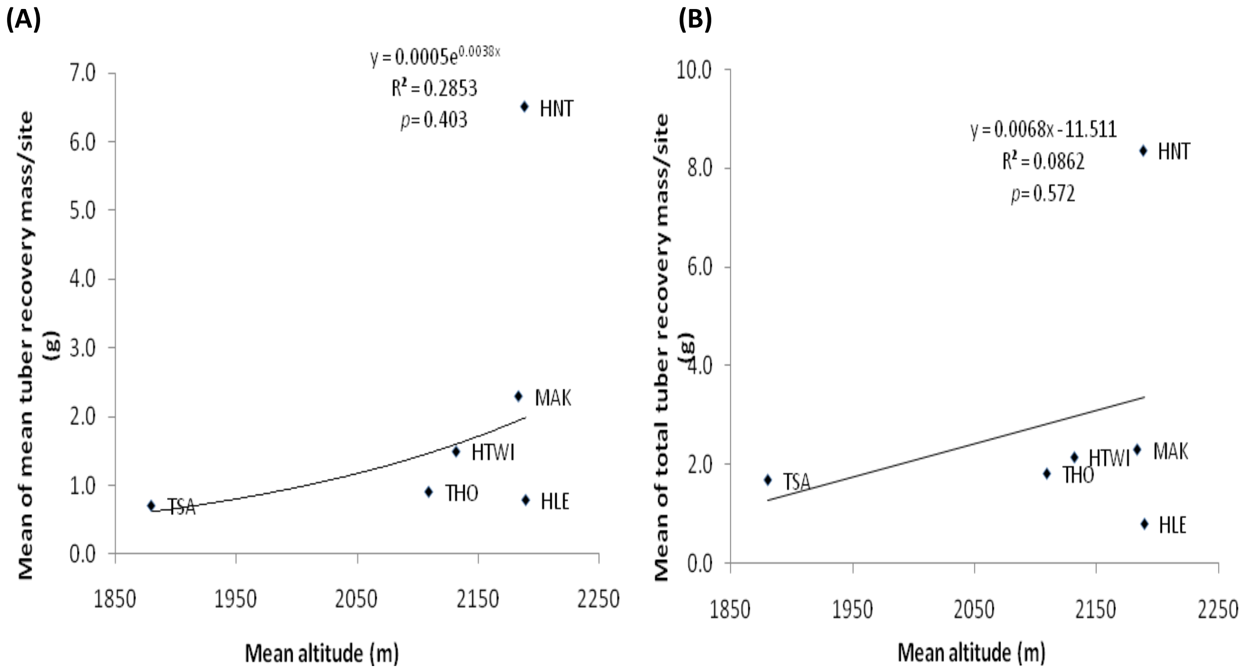


Figure 4.24. The relationship between altitude and tuber recovery mass in the "highveld' vegetation region (n = 6). HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3. "Lowveld" and "highveld" vegetation regions

4.5.3.2. The effect of depth of soil covering mother tuber on tuber recovery biomass

A mother tuber that is well covered with soil is protected from sun exposure and mechanical damage by livestock. Thus the chances of such a tuber resprouting successfully are enhanced. Therefore the effect of depth of soil covering the mother tuber on tuber recovery was investigated. No significant relationship was however found between these two variables ($P < 0.05$) (Figure 4.25A, B). However, a positive trend was observed.

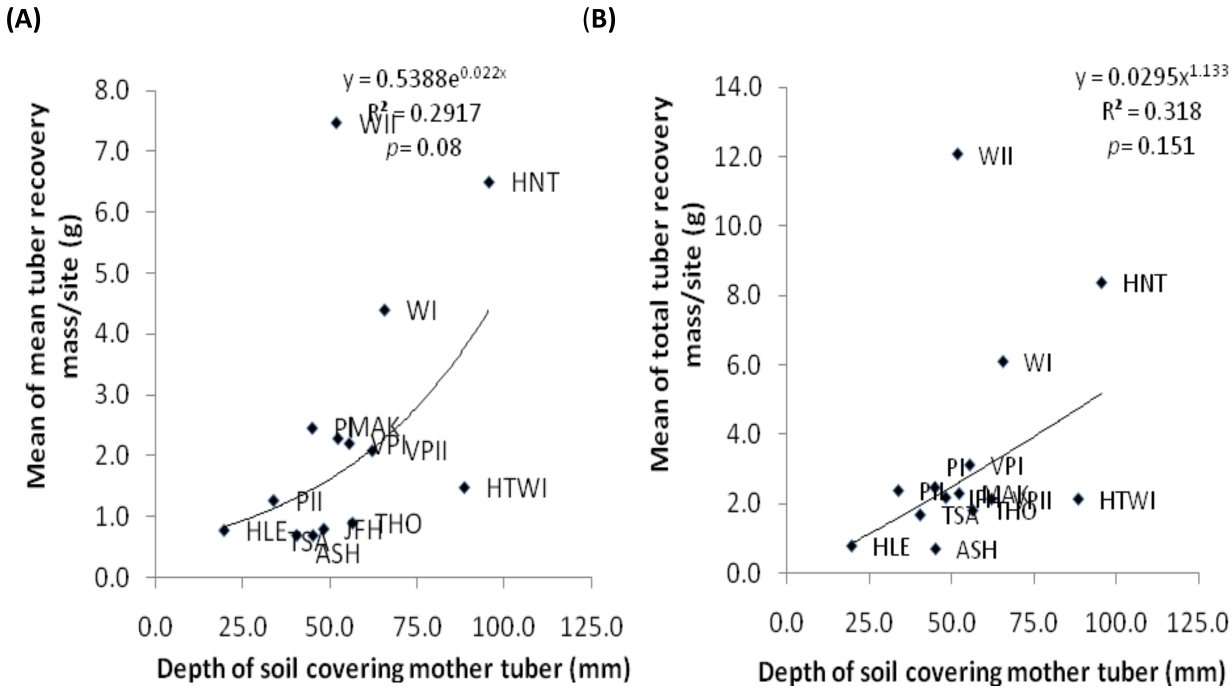


Figure 4.25. The relationship between depth of soil covering mother tuber and tuber recovery mass when two regions were combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.3. The effect of mother tuber biomass on tuber recovery biomass

A large mother tuber should have enough assimilates to support resprouting and consequently tuber recovery. Therefore the effect of mother tuber biomass on tuber recovery mass was explored. However, there was no significant relationship between the two variables ($P > 0.05$) (Figure 4.26A, B). On the other hand, a positive linear trend was detected.

(A) (B)

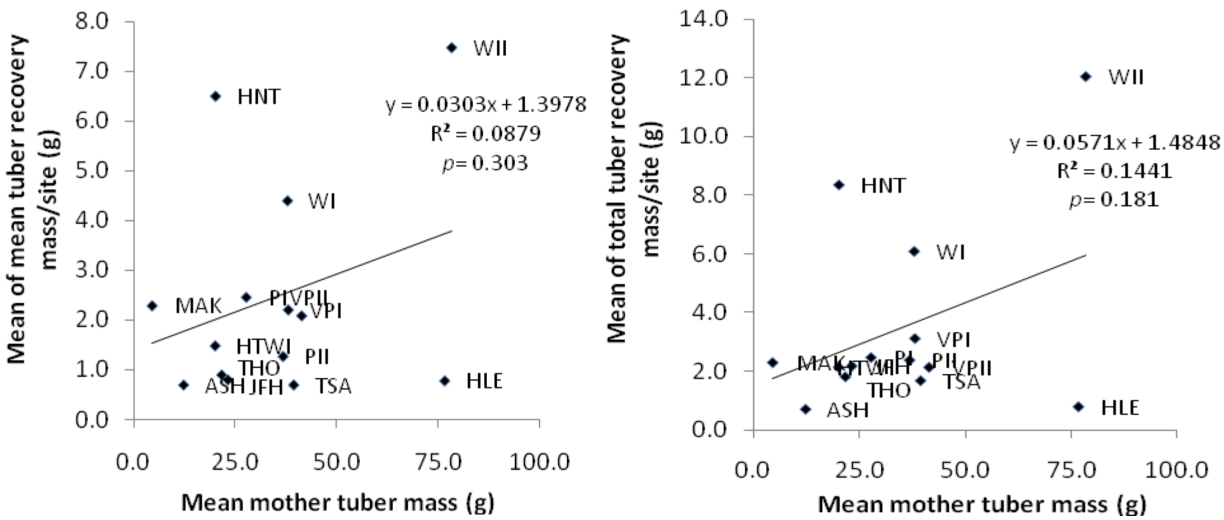


Figure 4.26. The relationship between mother tuber mass and tuber recovery mass when the two regions were combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.4. The effect of mother tuber size on the number of stems

Combining all the wild-harvested sites from the two regions did not produce a significant relationship between mother tuber size and the number of stems ($P > 0.05$) (Figure 4.27A, B). The results suggest that mother tuber size does not determine the number of stems a mother tuber can have post harvest. However, a linear positive trend was observed between mother tuber mass and mean number of stems.

(A) (B)

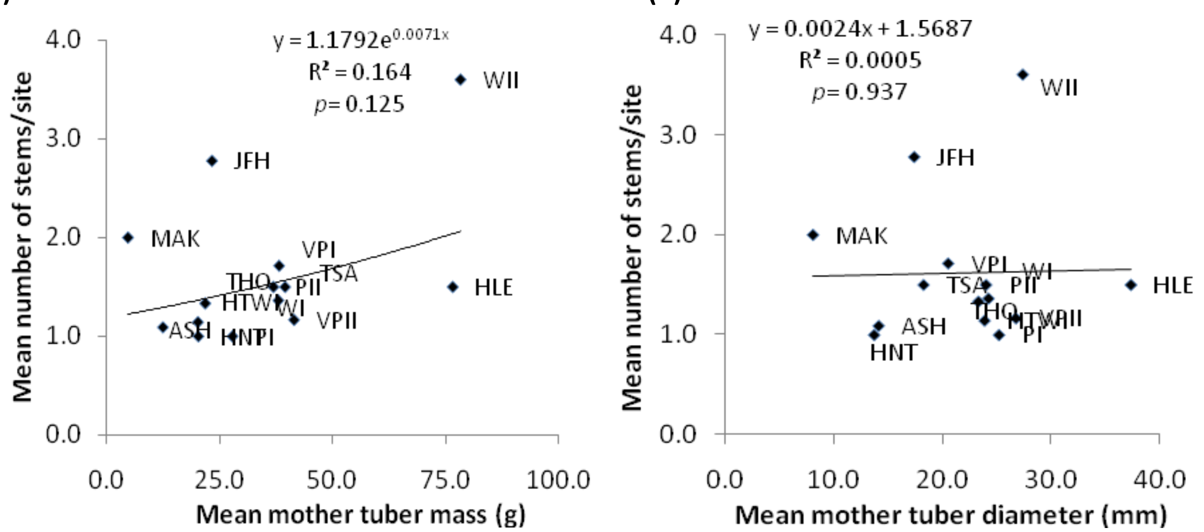


Figure 4.27. The relationship between mother tuber size and total number of stems for the two regions combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= Mother tuber mass, B= mother tuber diameter. A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.5. The effect of mother tuber biomass on tuber recovery colour

The Pelargonium industry seems to prefer dar-red coloured tubers hence factors that influence colour intensification in *P. sidoides* plants should be explored. Therefore the sites from the two regions were combined to investigate the effects of mother tuber biomass on tuber recovery colour development. A weak but significant relationship was found between the two variables ($P < 0.05$) (Figure 4.28). This means as mother tuber mass increases, tuber recovery colour intensifies.

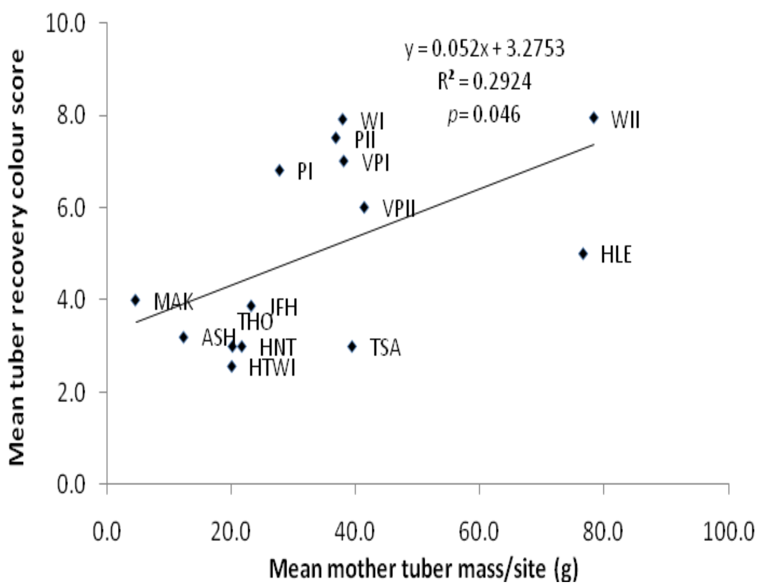


Figure 4.28. The relationship between mother tuber mass and tuber recovery colour score for the two regions combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.6. The effect of tuber biomass size on tuber recovery colour

There was no significant relationship between tuber mass and tuber recovery colour score when wild-harvested sites from the two regions were combined ($P > 0.05$) (Figure 4.29A, B). This implies that tuber mass in *P. sidoides* has no effect on tuber recovery colour intensification.

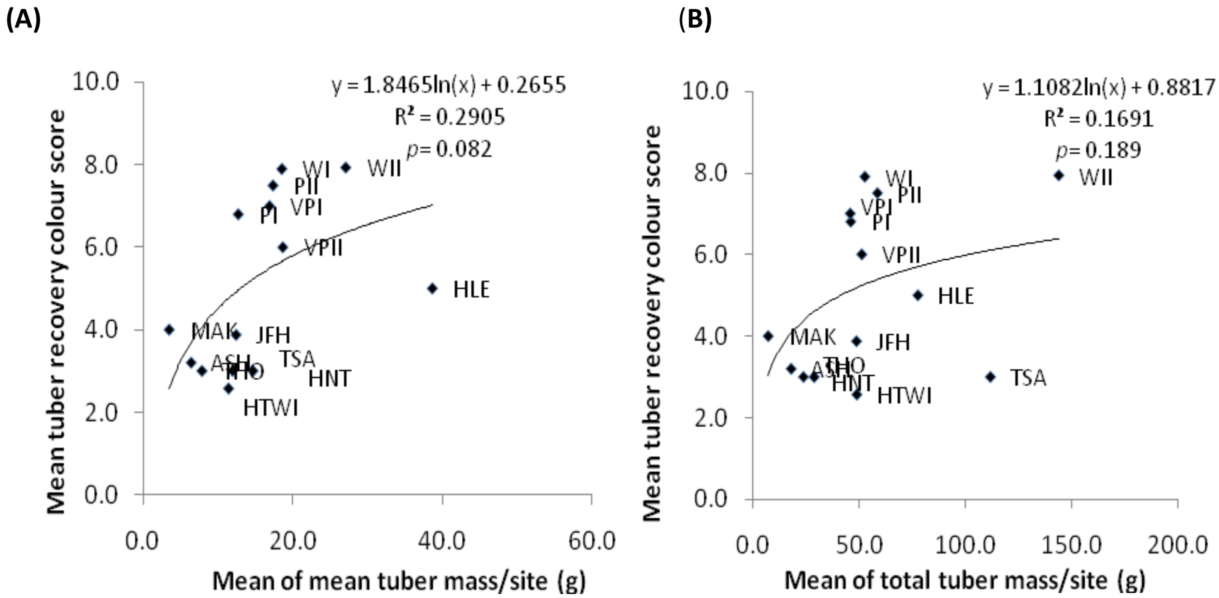


Figure 4.29. The relationship between tuber mass and tuber recovery colour for the two regions combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.7. The effect of canopy area on tuber recovery biomass

When sites from the two regions were combined, a positive significant relationship was found between canopy area and tuber recovery mass when mean of total tuber recovery mass values were used ($P < 0.05$) (Figure 4.30 B). However, when mean of mean tuber recovery mass values were used, there was no significant relationship. On the other hand, a positive linear trend was observed (Figure 4.30A).

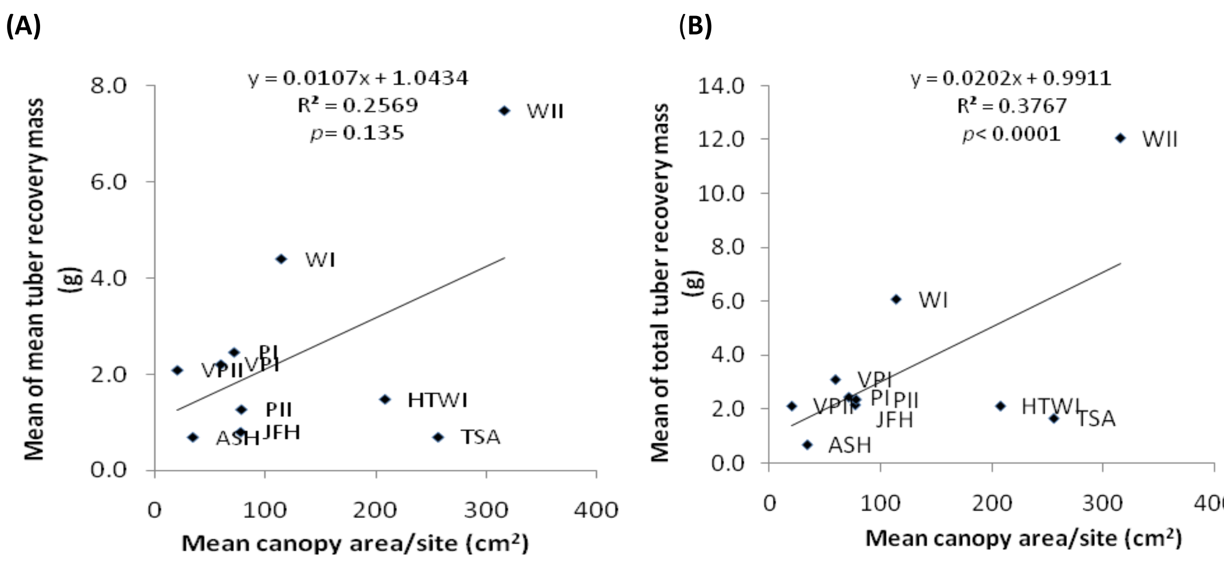


Figure 4.30. The relationship between canopy area and tuber recovery mass for the two regions combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.8. The effect of tuber biomass on canopy area

To determine whether canopy area can be used as a surrogate for tuber biomass, the relationship between tuber biomass and canopy area was investigated when data from the two regions was combined. However, there was no significant relationship found between the two variables when mean of mean tuber mass values were used ($P > 0.05$) (Figure 4.31A). On the other hand, when mean of total tuber mass values were used, a highly significant relationship resulted ($P < 0.01$) (Figure 4.31B).

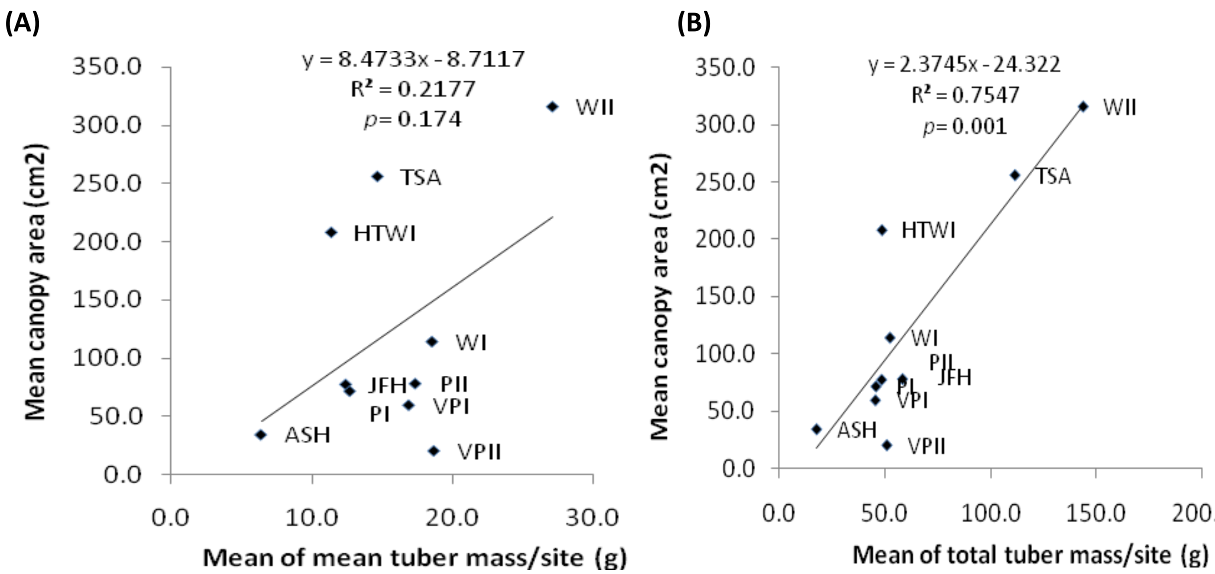


Figure 4.31. The relationship between tuber mass and canopy area for the two regions combined (n= 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). A= mean of mean tuber recovery mass, B= Mean of total tuber recovery mass. Each data point represents a site.

4.5.3.9. The effect of altitude on tuber recovery biomass

Altitude is known to affect plant growth so investigations were made on its effect on tuber recovery. No significant relationship was however found between altitude and tuber recovery ($P > 0.05$) (Figure 4.32A, B). This suggests that a change in altitude does not cause a change in tuber recovery biomass.

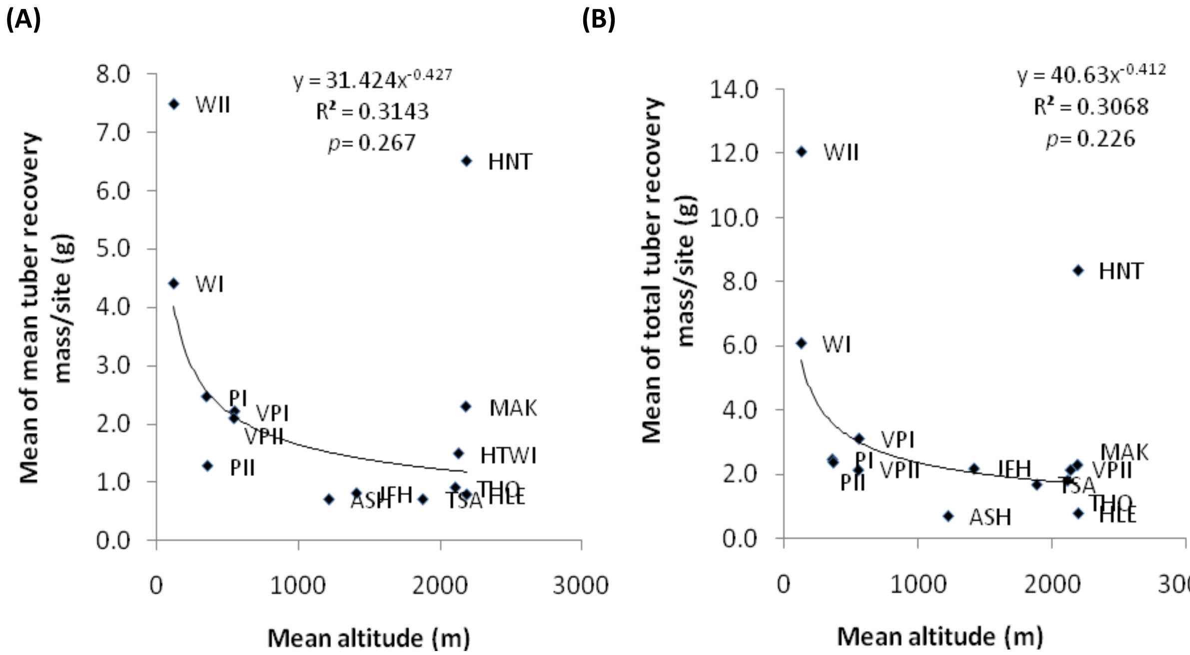


Figure 4.32. The relationship between altitude and tuber recovery mass for the two regions combined (n = 14). "Lowveld" vegetation region ((ASH= Airstrip, JFH= Janine Farm, PI= Peddie I, PII= Peddie II, VPI =Victoria Post I, VPII=Victoria Post II, WI= Wesley I, WII= Wesley II) and "highveld" vegetation region (HLE= Ha Lebelonyane, TSA= Tsatsane, THO= Thoteng, MAK= Makhoakhoeng, HTWI= Ha Tlhaku, HNT= Ha Ntho). Each data point represents a site.

4.6. DISCUSSION

The developmental stage of a plant is dependent on age, environmental factors and size (Schmid *et al*., 1995). Furthermore, plant response to environmental variation is not only dependent on the genetic potential of a species to express different traits, but can also be limited by above-ground longevity or presence of a storage organ (Werger and Huber, 2006). *P. sidoides* has storage organs in the form of tubers which allow the plant to buffer negative environmental flactuations and facilitate growth in periods of limited resources (Zimmerman and Whigham, 1992). *P. sidoides* tubers may buffer negative environmental flactuations but can they sustain wild populations of this plant as a result of harvest and current harvest methods?

Despite training given by the Pelargonium industry, tuber recovery is negatively affected by harvest and current harvesting methods (Chapters 2 and 3) neccesitating interventions on factors that enhance tuber recovery. This study investigated some of these factors across the species range, such as depth of soil covering the mother tuber, size of the mother tuber, total tuber biomass, canopy size and altitude.

4.6.1. The effect of depth of soil covering the mother tuber on tuber recovery biomass

Tuber recovery may be influenced by how deep the mother tuber was covered with soil post harvest. This is because there will be enough space for the emerging tubers to occupy and consequently expand into tubers. Additionally, the mother tuber will probably get enough soil nutrients and moisture for successful resprouting. Thus increased soil depth benefits the mother tuber through soil moisture, less surface exposure and larger tuber size (Kouwenhoven, 1970; Firman *et al*., 1992; Stalham *et al*., 2001).

The results obtained on the effects of soil depth covering the mother tuber on tuber recovery biomass were inconsistent. At site level in the "lowveld" vegetation region, there was a significant effect on tuber recovery biomass (Figure 4.2A, D, F, H) and tuber recovery biomass was found to increase the greater the depth of soil covering the mother tuber. At other sites there was no significant effect of tuber recovery biomass (Figure 4.1B, C, E, G). Furthermore, at regional level where each site represented a data point, no significant effect was detected. Similarly, in the "highveld" vegetation region, whether at site level or regional level, covering the mother tuber with soil after harvest was not found to significantly affect tuber recovery biomass. Combining data from both regions did not produce significant results. However, a positive exponential trend was detected at regional level implying that an increase in the number of sites might have caused a more significant relationship.

Several factors may have contributed to discrepancies in the results. Firstly, it was impossible to replicate plants and sites uniformly across the regions. For example, the intension was to obtain wild-harvested sites that were harvested 1 to 7 years ago from both regions and replicate these sites at least twice. However, this was not possible as this study was dependent on the available wild-harvested sites which varied in how long ago they were harvested. Additionally, it was not always possible to find 10 wild-harvested plants in a site and this reduced the number of replicates at site level.

Secondly, harvesting procedures differ across sites and regions. For example, some harvesters cover the harvest holes while others do not cover them. Thus harvesting procedures were not standard across the study areas and this could have varied the results. Increasing depth of soil covering mother tuber post harvest has been found to delay plant emergence and development as well as yield in other species (Bohl and Love, 2005).

Lastly, the terrain of a harvest site may determine the effectiveness of any harvesting procedures (such as covering harvest holes post harvest) employed. In Lesotho some harvest sites are situated in rocky areas which may affect how well the harvest holes are covered with soil and hence how well the mother tuber is covered as well post harvest. For instance, some plants occur on the side of a rock (*pers. obs.*) and as soon as they are uprooted, it is not possible to cover such holes unless harvesters lay some stone around the hole to prevent soil from retreating. The harvest holes that are not covered post harvest can pre-dispose the remaining tubers to stress such as desiccation and trampling by livestock. A similar finding was made on potato tubers that if they are not properly covered after planting, they experience sunburn and predation by insects such as tuber moth (Lorenz, 1945). These disturbances may disrupt tuber recovery and the state of the mother tuber in *P. sidoides*.

Although the effects of depth of soil covering mother tuber on tuber recovery biomass were inconsistent across the "lowveld" vegetation region and non-existent in the "highveld" vegetation region, there is scientific evidence that supports covering a mother tuber. Although the research was conducted on potatoes, Kouwenhoven (1970) established that planting a potato mother tuber at approximately 10 cm below the top of the ridge increased the size of tubers in potatoes and decreased their probability of turning green. Pavek and Thornton (2009) however recommended 15- 20 cm depth of soil covering a potato mother tuber although they warn that the depth depends on potato cultivar. The increase in potato tuber size as a mother tuber is deeply covered may be because distribution of secondary tubers is dependent on stolon length (Kouwenhoven, 1970). This may explain why *P. sidoides* tuber recovery may improve with covering the mother tuber post harvest because it was observed during field work for this study that *P. sidoides* tuber recovery may be dependent on stem length (*pers. obs*.). However, information is largely lacking if not non-existent on how much soil should cover the remaining tubers for medicinal plants following harvest. Shallow planting which can also refer to how much soil is covering a mother tuber, also reduced tuber yield in *Aconitum Carmichael* (Matsunyama *et al*., 2007).

4.6.2. The effect of mother tuber biomass on tuber recovery biomass

It was anticipated that *P. sidoides* mother tuber may supply nutrients to recovering tubers and contribute to increases in their biomass. This is because in plants such as potatoes, nutrients stored in a mother tuber are utilized by the sprouts growing out of the parent. The subsequent growth vigour of the sprout is related to the size of the mother tuber (Denny, 1929). However it seems that the developing tuber is only supplied with food reserves from the mother tuber for some time until it is left to be independent. But information on the exact stage at which the tubers get to be independent from the mother tuber is largely conflicting (Denny, 1929).

In the "lowveld" and "highveld" vegetation regions, mother tuber biomass did not significantly affect tuber recovery biomass at site level. This is probably because plants came from sites amongst which there was little variation in the time since last harvest which resulted in mother tubers with similar biomass. Other researchers confirm that for successful resprouting or rather emergence in the case of potatoes, a minimum mother tuber size is required. For example, Lommen (1994) found that attempts to grow potato crop from tubers with small biomass fail as food reserves from the mother tuber are limiting. However, *P. sidoides* mother tuber biomass significantly affected tuber recovery biomass in the "lowveld" vegetation region when each site represented a data point (at regional level). An increase in the biomass of the mother tuber resulted in increasing tuber recovery biomass. At regional level, each site represented a data point and these sites varied in tuber recovery age as they were last harvested 3 to 8 years ago which introduced age variability and produced significant results. Age was found to be important in *P. sidoides* tuber recovery (Chapter 2) with tuber recovery biomass increasing with age. In other studies, a potato mother tuber was found to furnish the resprouts with nutrients for some time after resprouting but thereafter nutrients were directed more to developing tubers (De Vries, 1878 and Ludwig, 1889 as cited by Denny, 1929). Milthorpe and Moorby (1967) (as cited by Denny, 1929) also found that an increase in weight of potato tubers is a linear function of time. In potatoes, physiological age of a mother tuber can determine initiation of tuberisation (van der Zaag and van Loon, 1987 as cited by Vilafranca *et al*., 1998; Vreugdenhil and Struik, 1989 as cited by Vilafranca *et al*., 1998; Vilafranca *et al*., 1998).

On the contrary, mother tuber biomass did not have any significant effect on tuber recovery biomass in the "highveld" vegetation region. One reason for this result may have been the limited number of experimental sites available. The study sites also did not vary much in tuber recovery age as they were last harvested only 1 to 3 years ago (Chapter 2).

When data from the two regions was combined, mother tuber biomass did not have an effect on tuber recovery biomass. This was unexpected as the number of sites had increased meaning more data points to run the analysis. On the other hand, Letsela (2004) also found no significant relationship between stump diameter and the growth rate of the resprouts in *Leucosidea sericea* and concluded that maybe once apical dominance is established; the growth rate of the resprouts becomes more independent of the stump.

4.6.3. The effect of mother tuber size (biomass and diameter) on number of stems

The size of a mother tuber can determine how well it resrouts following harvest. For example, Denny (1929) used a 28 g mother tuber for his experiment on the role of mother tubers in the growth of potatoes. This was done after establishing from literature that this is the smallest size that is needed to produce plants with full vigour. In another study on sustainable harvesting of Devil's claw, Strohbach and Cole (2007) observed that mother tubers with diameters of less than 2.3 cm were not able to produce minimum harvestable quantities of secondary storage tuber.

The size of a mother tuber in *P. sidoides* plants did not significantly increase the number of stems in the "lowveld" and "highveld" vegetation regions. This was despite the expectation that the bigger the mother tuber, the larger the surface area for more stems to develop. This is congruent to other authors' findings. For example, Letsela (2004) found a weak but significant relationship between stump diameter and number of shoots in *L. sericea* with the number of shoots increasing with stump diameter. A similar finding was made by Kalema (2010) of weak relationships between diameter and resprouts per stump in two woody species that are highly utilized for charcoal production in Nakasongola woodland, Uganda. On the other hand, it may not be very wise to compare recovery in woody species that are mostly harvested for their above-ground biomass to that of tubers that are harvested for their below-ground biomass as these plant parts may not be physiologically similar.

4.6.4. The effect of mother tuber biomass and tuber biomass on tuber recovery colour

Plants respond to physical injuries by varying the concentration of secondary metabolites (Pare and Tumlinson, 1999) and the concentration of these metabolites depends on genetic make-up of plants, environmental factors (e.g stress factors such as water and thermal stress) and their interactions (Fletcher *et al*., 2000; Kutchan, 2005). Thus production in plants is often restricted to species or genus and might be activated at a certain developmental stage or specific seasonal stress conditions (Veerporte *et al*., 2002). These metabolites can be in the form of flavonoids which are responsible for pigmentation in plant parts such as fruits and flowers (Schijlen, 2004) and tubers. The flavonoids also protect plants against thermal stress (Wollenweber, 1993). In *P. sidoides*, the plant may produce secondary metabolites in response to stress caused by harvesting. However, whether damage to the mother tuber can affect tuber recovery colour is unknown. Additionally, it is not clear which substances are passed from the mother tuber to the secondary tubers (Denny, 1929) or tuber recovery in the case of *P. sidoides*.

The biomass of the mother tuber was found to have a significant effect on tuber recovery colour in the "lowveld" vegetation region. As mother tuber biomass increases, tuber recovery colour also increased. However, in the "highveld" vegetation region, mother tuber biomass did not have an effect on tuber recovery colour. A reason for this could be there was little tuber variation in the age of sites ranging 1 to 3 years. Therefore the mother tuber and tuber recovery had not been exposed to abiotic stress factors for an adequate time. When data from the two regions were merged, increasing mother tuber biomass resulted in increased tuber recovery colour. Even when data from the two regions was combined, there was no effect. This suggests that maybe the tubers which are not directly connected to the tuber recovery do not contribute much to its physiological processes. Additionally, it may be the tubers that are not directly damaged by harvest do not directly influence physiological processes in the tuber recovery as a mother tuber does.

4.6.5. The effect of canopy area on tuber recovery biomass

Defoliation can affect plant production by reducing below-ground biomass (Moron Rios *et al*., 1997). For example, Esmaeili *et al*. (2009) noted that rhizome biomass was negatively affected by clipping treatments (used to mimic defoliation) for all five rhizomatous grassland species found in the French Atlantic Coast. Therefore removal of above-ground biomass during harvesting may have negative impacts on the tuber recovery of *P. sidoides* post harvest. However in plants such as *P. sidoides* that undergo asexual reproduction through its tubers, they may not be badly affected. This is because perennial plants accumulate carbohydrate reserves for regrowth when photosynthesis is not able to supply energy for plant functions (Richards and Caldwell, 1985). Therefore the effects of canopy area on tuber recovery biomass were investigated. In the "lowveld" vegetation region, the results obtained at site level were conflicting. For instance, in some sites, positive significant relationships were obtained whereas in other sites there were no relationships. This was unexpected because at site level, plants were assumed to have tuber recovery of the same age meaning there was not much age variation. On the other hand, at regional level where each site represented a data point, canopy area had an effect on tuber recovery biomass. This was expected as sites varied in age. Combining data from the "lowveld" and "highveld" vegetation region resulted in significant results only when mean of total tuber recovery mass values were used.

One of the reasons for the varying results at site level may have been due to repeat harvest (by harvesters) of some plants which caused plants to have different tuber recovery ages at a particular site. This would also affect canopy size of plants at one site and contribute to biased results hence why at site level significant effect of canopy area was observed at some sites. Secondly, *P. sidoides* plants occur in areas where there is livestock grazing therefore this disturbance might have affected canopy size of plants through trampling. Furthermore, the study sites were situated in different vegetation biomes. For instance, some sites such as WI (Wesley I) and WII (Wesley II) were situated near sea-level in the Albany Thicket biome whereas other sites were found in the grassland biome. Thus the type of vegetation may have influenced canopy size (area) as it was observed during this study that plants that occurred under shade had bigger canopies as opposed to those exposed to direct sun. Lastly, discrepancies in the effects of canopy area on tuber recovery can also be attributed to the different sampling seasons that were used which made the canopy size (area) from different sites to vary and hence different results.

4.6.6. The effect of altitude on tuber recovery size

Altitude is known to affect plant growth. This is because increase in altitude results in lower atmospheric temperature, stronger solar radiation (with higher gains in shortawave radiation) and reduced atmospheric pressure. A combination of these parameters contributes to more unfavourable conditions which negatively affect plant growth (Korner *et al*., 1989). However storage in a perennial plant such as *P. sidoides* is beneficial as it inhabits higher lying areas with cold winters in some parts of the “highveld” vegetation regions. Thus spring growth in such plants depends on accumulation of food reserves in its tubers and use of these for growth in the following season (Klimes *et al*., 1993, Klimes *et al*., 1999). In the “lowveld” vegetation region, tuber recovery biomass was found to increase significantly with decreasing altitude only when mean of mean tuber recovery values were used. This implies that tuber recovery biomass in *P. sidoides* is more pronounced at lower altitudes as conditions are less limiting compared to higher altitudes. However, areas that experience high temperatures such as those in the “lowveld” vegetation region (Mucina and Rutherford, 2006) pre-dispose plants to more respiratory loss of storage carbohydrates (Printz, 1933) especially in winter (Dahl, 1992, 1998). A result of this is a negative carbohydrate balance which will cause less available carbohydrate reserves in the next spring and reduced flowering. Such plants may produce less biomass at low compared to high altitudes in the long run (Scheidel, 2004). This suggests that there might be a reduced tuber recovery biomass in the “lowveld” vegetation region than the “highveld” vegetation region due to effect of intense harvest.

In the ‘highveld” vegetation region however, altitude did not have any effect on tuber recovery biomass. One reason for this could be the limited number of sites that were used (n = 6) which may have obscured significant patterns. Secondly, the time since last harvest for these sites varied little with values ranging from 1 to 3 years. This could have also concealed significant patterns as tuber recovery biomass did not differ much. Likewise, when data from the two regions was combined, altitude was found to have no significant effect on tuber recovery. On the contrary, research on other plants that reproduce clonally using either rhizomes or tubers shows different responses of plants to varying altitudes. For instance, *Achellia millefolium* was found to allocate more biomass to its rhizomes in relation to above-ground structures in high altitudes (Johnston and Pickering, 2004).

4.6.7. The effect of tuber biomass on canopy area

Harvesters of *P. sidoides* cannot currently tell the size of the below-ground biomass by looking at the above-ground biomass such as the size of the canopy. Therefore it was important to determine relationship between these two variables so that inferences could be made from above-ground biomass. In the “lowveld” vegetation region, tuber biomass significantly affected canopy area and results showed that plants with bigger canopies had larger tubers (more tuber biomass). Combining data from the “lowveld” and “highveld” vegetation region also produced significant results but only when mean of total tuber mass values were used. Other researchers (Gross *et al*., 1991) found relationships between below- and above-ground biomass in *Spartina alterniflora* in the American salt marshes. Whigham (1978) also detected significant relationships between below-ground and above-ground biomass of freshwater tidal macrophytes. On the contrary, White (2007) did not find any significant relationships between below and above-ground biomass for *P. sidoides* using non-linear regression models. White (2007) might have found no significant results probably because his samples varied little in age.

4.7 CONCLUSION

P. sidoides is widely distributed meaning it can withstand a wide range of environmental stress (van der Walt and Voster 1988) such as extreme temperatures and drought. Furthermore, because of developed underground system it is able to regenerate following disturbances such as fires and harvesting. Thus both environmental and human-induced factors determine how well it recovers post harvest. Therefore sustainable harvest methods and harvesting guidelines should incorporate these factors. This study has shown that other than time since last harvest (Chapter 2); there are other crucial factors that affect tuber recovery following harvest. Although results varied, covering the mother tuber post harvest has an effect on tuber recovery biomass. However more research is needed in terms of how deep or shallow the tubers should be buried. Tuber recovery biomass and colour also increased with an increase in mother tuber biomass suggesting that during harvest, only secondary tubers should be collected but not primary tubers. An increase in canopy area also resulted in increasing tuber recovery biomass meaning that plants with bigger canopies are able to supply more photosynthates to the developing tuber recovery. Lastly, canopy area can be used as a surrogate for tuber size since an increase in tuber biomass resulted in an increase in canopy area. Nevertheless the results were not conclusive hence further long-term monitoring that involves lots of replication and a larger sample size is required.

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Chapter 5

5.0. DISCUSSION AND RECOMMENDATIONS

5.1. General discussion

Many medicinal plants that used to be utilized for traditional use are now also used for commercial purposes. Wild harvesting of *P. sidoides* is occurring extensively in Lesotho and South Africa to supply local and international trade. Dried tubers of the plant are exported to Germany for production of respiratory infection medication under trade names such as Umckaloabo (van Wyk, *et al*., 1997). As a result of the popularity of *P. sidoides* in traditional and modern medicine, the number of plant collectors and rate of harvesting have increased over the years (Lewu *et al*., 2007). Increased demand for medicinal plants contributes to increased pressure on wild populations (Williams, *et al*., 2004) more so if unsustainable harvest methods are employed. Therefore increased harvesting of *P. sidoides* coupled with unsustainable harvest methods constitues a threat to the species especially if information on the impacts of wild harvesting is lacking. On the other hand, medicinal plants play a pivotal role in many people's livelihoods not only as traditional medicine but also as trade commodities (Schippmann, *et al*., 2002) and this is more the case in developing countries (Marshall, 1998). The World Health Organization (WHO) estimates that 80 % of the population in developing countries uses traditional medicine (Vines, 2004). The high number of people using medicinal plants is attributed to their low cost, cultural and religious preferences (Sheldon, *et al*., 1997; Shanley and Luz, 2003). For example, up to 100 million herbal remedy consumers have been reported in Southern Africa as well as 500 000 traditional healers (Mander and Le Breton, 2005). Furthermore, in South Africa, traditional medicine is regarded as complementary to western medicine (Cunningham, 1991). Therefore, striking a balance between sustainable use of medicinal plants and maintaining people's livelihood is essential (Letsela, 2004). To counteract the effects of increasing demand for medicinal plants and to ensure sustainability of wild harvest, the ecological resilience, physiological, economic, social and cultural values of these plants should be determined and appropriate management practices adopted (Shackleton, *et al*, 2000; Cavendish, 2002).

5.2. Conservation options

There are several conservation measures that can be applied to *P. sidoides* bearing in mind that the conservation approaches employed should be three dimensional. These dimensions should focus on the ecological, social and economic aspects. For example, such measures can include ethnobotanical and ecological studies, public participation, *in situ* conservation such as protected areas and other forms of legal control (e.g. permits and bans), *ex situ* conservation such as establishment of germplasm banks, management plans and cultivation (Shinwari and Gilani, 2003; Steward and Cole, 2005; Hamilton, 2008).

To date, there has been no ethnobotanical study carried out for *P. sidoides* (Brendler and van Wyk, 2008; van Niekerk, 2009) and lack of such information brings about problems in managing the resource sustainably [e.g. patent challenges by the African Centre for Biosafety (ACB) on behalf of the Alice community in the Eastern Cape]. Such a study should focus on gathering resource management information such as distribution, uses and harvesting techniques from local people such as traditional healers (Steward, 2003; Hamilton, 2005; Ticktin, 2006). More often than not, local people have information on the localities of the species in question, its uses, life history stages, harvesting intensities, harvesting response and harvesting frequencies (Cunningham, 2001). Although ethnobiological knowledge provides useful information, data collected through such methods has to be cross-checked for accuracy against data collected through scientific experimental trials (Cunningham, 2001). This is because although some plant uses such as harvesting of wood for fuel or building are more obvious, wild gathering of medicinal plants is often part of a "hidden economy" unnoticed by outsiders (Cunningham, 2001). As such careful field observation, sensitive consultation with local people and strategic planning are required (Cunningham, 2001). In the case of *P. sidoides*, it may be difficult to obtain information from target groups such as traditional healers as they consider some of the information as a gift from the ancestors.

The ecological requirements of harvested medicinal plants should also be known to make informed decisions concerning sustainable harvest (Steward, 2009). Such information can be obtained by carrying out ecological studies focusing on the effects of harvest on post harvest recovery of species, population dynamics and whole ecosystems (Struhsaker, 1998; Swartz *et al.,* 2002; Peres *et al.,* 2003; Rock *et al.,* 2004). This is especially useful if the study in question is intended to provide policy makers and conservationists with criteria for evaluating the above measures for maintaining a sustainable harvest (Ticktin, 2004; Egli *et al*., 2006). The field methodologies should contain suitable experimental designs, measures of vital rates, assessment of genetic structure and diversity, documentation of patterns of abundance, density and population structure, modeling of population dynamics and sustainable harvest

(Ticktin, 2006). This is especially the case because understanding vegetation response to disturbances such as harvesting is vital in understanding ecosystem structure and function (Lawrence and Ripple, 2000). Several ecological studies that have investigated the impacts of wild harvesting on *P. sidoides* populations have also considered some of the above-mentioned parameters (e.g. Vlok, 2003, 2005; Newton, 2004; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008; Newton *et al*., *in prep.*; de Castro *et al*., *in prep*.).

Medicinal plants can also be managed *in situ* through establishment of protected areas. But due to limited resources, the managers of many protected areas in most African countries tend to take little interest in medicinal plants conservation, especially in forest reserves whereby their main interest is mainly on timber products (Hamilton, 2008). Hence McNeely and Thorsell (1991) recommend several guidelines before medicinal plants are included in protected areas. These include a review of what is known about the distribution of original and existing vegetation in the given country and identification of medicinal uses of plants. This is because conservation issues do not only involve the complex biology of the population under scrutiny, but also include a multitude of other factors such as human impacts, as well as social, political and environmental systems (Lacey *et al*., 2003). Therefore increased coordination and cooperation between communities and traders on plant use is also important (Shinwari and Gilani, 2003; Stewart and Cole, 2005). In Lesotho and South Africa, *P. sidoides* is also found in protected areas such as Sehlabathebe National Park, Golden Gate Highland Nature Reserve and Double-Drift Nature Reserve (*pers. obs*.).

Besides protected areas, other forms of legal control measures such as the permitting system and total bans can be employed where a permit is required for collection, transport and export of medicinal plants (Hamilton, 2008). As with protected areas, these legal controls have proven difficult to enforce. A typical situation is with *P. sidoides* whereby a permitting system was used in the Eastern Cape for collection, transport and export. Due to confusion in managing wild harvest such as lack of information on annual harvest quotas, only three permits have been issued to date (N. Bam, DEDEA, *pers. comm*., 2009). Additionally, due to the non-compliance of the permit holders, such as collection of the species from privately owned land and over harvesting, the DEDEA had to announce a moratorium on the wild harvesting of the species. The Lesotho government also adopted the permitting system, but because Lesotho's environmental laws are fragmented and contradictory (*Anon*., 2010), the system is currently not working and there is no monitoring (Newton, *et al*., *in prep*.). This is why Witkowski *et al*. (1997) believe that legally protecting plant species which are used as medicine and hoping that they will recover naturally is not enough; therefore other options such as cultivation should be employed. Thus the development of appropriate harvesting techniques coupled with good cultivation may provide for sustainable utilization of *P. sidoides* in future (*Anon*., 1993; White, 2007).

Although adequate protection of some species can be achieved through increased regulation, and use of sustainable harvesting methods, a more long-term alternative is to increase cultivation of medicinal plants (Canter *et al*., 2005). Cultivation of medicinal plants threatened with over-exploitation such as *P. sidoides* can be carried out with the intention of reducing the collection pressure in the wild (White, 2007; White *et. al*., 2008; van Niekerk, 2009). Commercial propagation has been shown to be successful for this species (Lewu *et al*., 2006) and the plant also responds well to vegetative propagation using tuber cuttings in the presence of some moisture (White, 2007; U. Feiter, Parceval, *pers. comm.,* 2008; White *et. al*., 2008; *per. obs*.). Other than using tubers for propagation, leaf petioles which are usually not replanted post harvest, can be used (Lewu *et al.*, 2006). Furthermore, propagation using seeds has also been reported to be viable (Afolayan and Masika, 2004; *pers. obs*.). Once established, the Pelargonium industry insists that the tubers reach a harvestable size after about 4 years (U. Feiter, Parceval, *pers. comm.,* 2008). According to one trader who also cultivates the plant, the tubers are taking longer than the expected 4 year period to mature in relation to the required colour transition from pale to dark-red (J. Lentz, Glen Avon Farm, *pers. comm*., 2009). This study however found that cultivated plants require at leat 9 years to reach similar biomass to that of unharvested plants and at least 8 years to attain the preferred dark-red colouration (Chapter 2).

Even though cultivation is encouraged as a conservation measure for *P. sidoides* to provide alternative supplies for the markets, it becomes problematic in most African countries such as Lesotho and South Africa. These problems include small size of land holdings, limited supplies of good quality seeds, uncertainties about cultivation protocols, long gestation periods for many species, poor access to market and water problems in dry regions (Hamilton, 2008). Furthermore, it becomes difficult to predict which extracts will remain marketable and the likely market preference for what is seen as wild sourced extracts (Canter *et al*., 2005). These are probably some of the reasons why there is currently a minimal number of agriculturally grown *P. sidoides* plots in South Africa and Lesotho. The plots in South Africa are situated in the Western Cape, Free State (Newton *et al*., *in prep*.) and the Eastern Cape (M. Booi, Imingcangathelo Development Trust, *pers. comm*., 2009; *pers. obs*.). In Lesotho, the plots are situated in Mohale's Hoek (H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2007).

Another important strategy for conservation of *P. sidoides* can be in the form of a species management plan. This was why TRAFFIC East/Southern Africa (TESA) in conjunction with SANBI initiated the process of drawing up a *P. sidodies* management plan for Lesotho and South Africa according to South Africa's

National Environmental Management Biodiversity Act 2004 (NEMBA) and the International Standard for Sustainable Wild Collection of Medicinal and Aromatic Plants (ISSCMAP) guidelines (D. Newton, TESA, *pers. comm*., 2009). The final draft of the management plan has been submitted to Lesotho DoE and South African DEA for approval. In South Africa, following submission of the management plan, several meetings and workshops have been held by the Pelargonium Working Group to get stakeholder inputs in order to finalize the plan (D. Newton, TESA, *pers. comm*., 2010). Since receiving the BMP, the South African Government has also invited comments from the public as of 1st August 2011 as one of the steps required to finalize the gazettement of the plan (D. Newton, TESA, *pers. comm*.., 2011). Thus the BMP is expected to be adopted in South Africa during 2011.

5.3. Towards sustainability of harvesting *P. sidoides*

P. sidoides has been used locally to treat various stomach ailments in humans and livestock (Watt and Breyer-Brandwijk, 1962; Hutchings, 1996; Matsiliza and Barker 2001; Bladt and Wagner, 2007; Lewu *et al*., 2007; Brendler and van Wyk, 2008). Following the "miraculous" cure of an Englishman named Charles Stevens ascribed to the effects of *P. sidoides* and his attempts at advocating its efficacy (see Brendler and van Wyk, 2008), the plant entered the medicinal plant trade. Various people investigated *P. sidoides* efficacy (see White, 2007 and Brendler and van Wyk, 2008) until the plant became successfully commercialized.

This popularity that attracted local and international markets initiated extensive harvesting of the resource in the wild which became more pronounced from about 2001 onwards (Newton, 2004; Newton *et al*. *in prep*.). Demand for medicinal plants often increases with growth in human numbers, needs and trade (Schipmann *et al*., 2002). Moreover, species such as *P. sidoides* which are are slow growing (or have slow tuber recovery) are vulnerable to over-exploitation (Zschocke *et al*., 2000) hence interventions ensuring sustainable harvesting operations are needed. This is particularly the case for species such as *P. sidoides* that are destructively harvested for their underground parts such as tubers. Various studies have attempted in the past to provide such information on *P. sidoides* (Vlok, 2003, 2005; Newton, 2004; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008; Newton *et al*., *in prep*.). Although these studies have been helpful, none have conducted detailed research into the impacts of wild harvest on tuber recovery. Unavailability of such information has to this point constrained conservation efforts.

Therefore in this study, attempts were made to arscertain under which scenarios *P. sidoides* can be harvested sustainably in the wild and suggest alternatives to wild harvest. Hence the study investigated (i) rate of tuber recovery in *P. sidoides* plants, (ii) impacts of wild harvest on its tuber recovery and (iii) recommended sustainable harvest options for the species.

5.3.1. Rate of tuber recovery of *P. sidoides* plants

Medicinal plants that are harvested for their underground parts such as roots, rhizomes and tubers are susceptible to the effects of harvesting (Cunningham, 2001) particularly when there is limited information on the impacts of such harvest. Few studies have attempted to determine impacts of harvesting on such plants. These are studies such as those on *Allium triccoccum* (Nantel *et al*., 1996), *Panax quinquifolius* (Charron and Gagnon, 1991; Nantel *et al*., 1996) and *Hydrastis canadensis* (Sanders and Mcgraw, 2002). However, even with these studies, the effects of harvest investigated were on bulbs, rhizhome and roots but not on tubers.

P. sidoides tubers have been targeted by local and international markets in the production of respiratory infection medication however; no studies have determined fully how its tubers are affected by wild harvest. Furthermore, previous studies have not tackled how long it takes for previously harvested tubers to regenerate dark-red tubers that are also of a commercially valuable size. Linear and non linear regression models used in this study provided this information. The Pelargonium industry seems to prefer dark-red coloured tubers and for the purposes of this study, tuber colour was thought to be correlated with the concentration of medicinal compounds. This study revealed that previously wild harvested *P. sidoides* tubers require at least 8 years to develop the preferred dark-red colouration. Although the effect of time on the colour of cultivated tubers was not significant, positive trends were observed in the “lowveld” and “highveld” vegetation regions suggesting that if more cultivated sites were obtained, significant results would have been possible. Furthermore, when all types of sites were combined, the effect of time on tuber colour development was significant implying that whether in the wild or cultivated sites, tuber colour development increases with time.

Time also had a significant effect on tuber recovery biomass and previously wild-harvested *P. sidoides* tubers were found to require at least 10-15 years to attain pre-harvest biomass (Chapter 2, section 2.4.4). These long tuber recovery periods, especially for biomass mean that for a sustainable wild harvest, no repeat harvest should occur in previously wild-harvested sites before these periods have lapsed. Tuber regrowth biomass of cultivated plants was also found to increase with time when cultivated sites from the “lowveld” and “highveld” vegetation regions were combined. This study established that tuber regrowth biomass of cultivated plants needs at least 9 years to attain similar biomass to that of unharvested control plants. Thus should the Pelargonium industry find the 10-15 year return harvest interval for wild-harvested plants too long, cultivation can be an alternative to produce *P. sidoides* resource needed for local and international trade.

5.3. 2. Harvesting impacts on *P. sidoides* tuber recovery

A widespread disturbance to plant populations in Southern Africa is caused by harvesting of plants from the wild (Hoffman, 1997; Dzerefos and Witkowski, 2001). However, information on how such a disturbance affects harvested populations is largely lacking, more so for plants harvested for their medicinal tubers. This situation is also applicable to *P. sidoides*. The lack of such information coupled with commercialization of this plant increases difficulty in managing wild populations sustainably. Past research efforts into the impacts of wild harvest on *P. sidoides* wild populations have focused mainly on estimation of plant densities, number of leaves/per plant, resprouting and flowering ability (Vlok, 2003, 2005; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008) but how tubers are affected by harvest has been ignored. As such this study attempted to resolve this mystery.

Comparisons on above-ground and below-ground plant size using ANOVA showed significant differences in plant size across different types of sites. Worth noting were vast differences in tuber size (mass, diameter, length and volume) between previously wild-harvested sites and unharvested sites. Even after 8 years since last harvest (e.g. at Wesley II study site), wild-harvested plants had not reached pre-harvest tuber size. This shows that if previously wild harvested *P. sidoides* tubers are not given enough time to recover (i.e. 10-15 years, Chapter 2), wild populations can be negatively affected.

Similarly, cultivated sites (semi-wild and agricultural), were found to have plants with larger tubers than wild-harvested sites suggesting that cultivation of *P. sidoides* can be used as an alternative to supply the markets while reducing harvest pressure on wild populations. More importantly, cultivated plants were seen to attain similar tuber biomass to that of unharvested control plants after about 9 years. While tuber regrowth rate is shorter in cultivated plants compared to tuber recovery in wild-harvested plants, it seems tuber colour development into the commercially preferred dark-red colouration for cultivated plants takes longer.

Above-ground plant size was also significantly different across sites. Generally, plants from cultivated sites had larger canopies than plants from wild-harvested and unharvested control sites. In wild-harvested sites, plants that were last harvested 8 years ago also had larger canopies. A similar trend was observed in the number of stems/plant. The results indicate that plants in cultivation grow faster than those in wild populations probably due to regular management such plants receive (e.g. watering). Furthermore, in concurrence with findings of this study (chapter 2), tuber recovery colour of wild-harvested plants at 8 years since last harvest was not significantly different to tuber colour of unharvested control plants.

This study concludes that tuber recovery size of previously wild-harvested *P. sidoides* plants is smaller compared to tuber size of unharvested control plants even when these plants were last harvested 8 years ago. This shows that repeat harvest in one site can negatively affect how *P. sidoides* plants recover post harvest and this can ultimately lead to local population declines. This more so because tuber recovery was found to take longer to reach pre-harvest biomass (10-15 years, Chapter 2).

5.3.3. Sustainable harvesting options for *P. sidoides* plants

Several authors have reported unsustainable harvesting of *P. sidoides* plants from the wild which involve not filling up harvest holes post harvest and replanting unwanted plant parts (Vlok, 2003, 2005; Lewu *et al.,* 2006, 2007; White 2007; White *et al.,* 2008). This is despite training on sustainable harvesting procedures that the Pelargonium industry insist they offer their harvesters prior to a commercial harvest (K. Paulsen, BZH, *pers. comm*., 2008; H. Nieuwoudt, Bophelo Natural Products *pers. comm.,* 2008; R. Gowar, Gowar Enterprises, *in litt*., 2009). Sustainable harvest is thought to be an important conservation strategy for most wild harvested species and their habitats with the idea that non-destructive harvests will maintain population, species and ecosystem diversity (Schippmann *et al*., 2002). Sustainable harvesting of plants would be achieved if biomass harvested equaled annual growth (Letsela, 2004). This means harvest rates should not exceed the capacity of populations to replace individuals that were removed through harvest (Hall and Bawa, 1993; Luoga *et al*., 2002). For *P. sidoides*, sustainable harvest can be achieved if previously the tubers of wild harvested plants are given enough time to recover (i.e. 10-15 years) as this will ensure that there are enough assimilates to support successful resprouting.

Adhering to the 10-15 year return harvest interval alone is not enough to ensure sustainable harvest of *P. sidoides*. How the actual harvest of individual plants occurs in the field is also crucial. Therefore several other factors that were expected to affect tuber recovery in *P. sidoides* were explored. Of the factors tested, depth of soil covering the mother tuber post harvest seemed to be important when carrying out the actual harvest. A positive increase in tuber recovery mass was evident with an increase in depth of soil covering the mother tuber indicating the importance of filling up harvest holes post harvest. This pattern was not seen in the "highveld" vegetation region and this was attributed to limited sites that were obtained for this study hence more research is needed in future which involves several trials. A similar observation was made on potatoes that planting potatoes at various depths increased or decreased resprouting ability and probability of them turning green (Kouwenhoven, 1970; Pavek and Thornton, 2009). However, these authors warned that other factors such as potato cultivar may affect the planting depth or depth of soil covering a mother tuber in the case of *P. sidoides*.

An increase in the biomass of the mother tuber also resulted in increasing tuber recovery biomass at regional level in the "lowveld" where each site represented a data point. These sites varied in tuber recovery age as they were last harvested 3 to 8 years ago which introduced age variability and produced significant results. Time was found to be important in *P. sidoides* tuber recovery (chapter 2) with tuber recovery biomass increasing with time. The results suggest that as a mother tuber increases in size, it accumulates enough food reserves to support tuber recovery implying that only mature plants should be harvested and larger tubers should be left behind which will be able to support larger tuber recovery.

Furthermore, an increase in canopy area also resulted in increasing tuber recovery biomass meaning that plants with bigger canopies are able to supply more assimilates to the developing tuber recovery. Lastly, in the "lowveld" vegetation region, tuber biomass significantly affected canopy area and results showed that plants with bigger canopies had larger tubers (more tuber biomass). The results indicate that *P. sidoides* harvesters should target plants with large canopies as these plants seem to possess bigger tubers.

5.4. Conclusions and Recommendations

This study has demonstrated that tuber recovery measured using tuber colour development (8 years) and tuber recovery biomass (10-15 years) in previously wild harvested *P. sidoides* plants is slow for a sustainable Pelargonium industry. The long periods required for *P. sidoides* tubers to develop the dark-red colouration and to also recover to pre-harvest biomass thus questions the sustainability of wild harvest to supply local and international markets. This is despite despite training on harvest methods that the Pelargonium industry gives. On the other hand, although the results obtained varied, filling up harvest holes with soil post harvest seems to lead to more tuber recovery size suggesting that tuber recovery can be enhanced through this harvesting method.

Compared to tuber recovery rate in wild harvested plants, tuber regrowth biomass in cultivated sites can attain biomass similar to that of unharvested control plants after 9 years. Due to data limitations, the 9 years was estimated based on differences between tuber biomass of unharvested control plants and "remains" biomass of wild harvested plants. This implies that cultivated plants may actually reach a harvestable size sooner than 9 years hence cultivation of *P. sidoides* may be used to achieve its sustainable use. While cultivation may be an alternative to wild harvest, future research is required on tuber colour development in cultivated plants and what the Pelargonium industry considers as commercially harvestable. In addition, more research on pre and post harvest management is needed that involves several trials and longterm monitoring in previously harvested sites.

5.4.1. Harvesting recommendations

5.4.1.1 Specific harvest recommendations based on results of this study

The following harvest guidelines are made having been scientifically proven during this study:

Closure of harvest holes

- It is important that following wild harvest the holes are filled with soil. This ensures that the remaining tubers are not exposed to the sun and livestock. Furthermore, well covered tubers get enough moisture for succesful resprouting.
- The remaining tubers should be buried at a reasonable depth which will ensure that the resprouts develop long enough stems as they emerge. The long stems will create a larger surface area for swellings on the stems that appear after resprouting. Swellings on the stems eventually develop into tubers hence the larger the swelling, the larger the tuber recovery.
- However, the remaining tubers should not be buried too deep as they may not resprout hence more research on burying *P. sidoides* tubers at various depths is required to arcertain the optimal depth.

Plant size

- Above and below-ground plant size was seen to influence tuber recovery in *P. sidoides* plants post harvest.
- A larger mother tuber resulted in an increase in tuber recovery biomass suggesting that remaining tubers, especially the mother tuber should be large enough to support resprouting post harvest. This means that careful consideration should be made as to which tubers are collected, how much is collected and how much is left behind. It is recommended that only some of the secondary tubers should be collected during harvest. The remaining primary tuber should be injured to initiate resprouting.

- When repeat harvest occurs in previously wild-harvested sites, plants with bigger canopies should be targetted because an increase in canopy area resulted in increased tuber recovery biomass suggesting that bigger canopies are able to supply more assimilates to developing below-ground tubers.
- In unharvested areas (new harvest sites), plants with bigger canopies should be targetted because canopy area was found to increase with increasing tuber biomass. This will ensure that mature and large tubers are collected. However, it is not always that large tubers will have the preferred dark-red colouration. Smaller tubers can possess this quality as well.
- Further research is suggested involving a larger sample at different locations to determine relationships between tuber size and canopy area in *P. sidoides* plants.

Return harvest interval

- Previously wild-harvested sites should not be harvested before a 10- 15 year harvest interval has lapsed. Consequently there should be strict monitoring on previously wild-harvested sites so that there is no repeat harvest before this period has lapsed.

5.4.1.2. Specific harvest recommendations based on observations during this study and future research

These recommendations are made based on observations and experiences from this study. Although they are quite relavant, they are hypothesized and hence need further scientific proof. They could not be tested during this study due to limitations such as limited data, time and financial constraints.

Harvest tools

- Harvest tools that minimize tuber damage and soil disturbance should be used. Hence a portable and strong pointed metal object should be used to loosen they soil. The size and shape of a harvesting tool is very important as it can determine the extent to which soil disturbance occurs as well as plant damage. The smaller the harvesting tool, the smaller the soil disturbance and damage to the plant.
- On the other hand, the choice of a harvest tool depends on the terrain of a harvest site. For instance, using the above proposed tool will be more practical in some harvest sites in Lesotho where the sites are located in rocky areas thus rendering the use of a smaller pointed tool

possible. On the contrary, in the Eastern Cape where the soils are hard, it may not be feasible hence may be a pick-axe can be used. During field work for this study, it was easier to uproot the plants using a pick-axe than a spade or digging fork.

- Under no circumstances should a spade be used as it increases tuber damage and soil disturbance. Its use should only be restricted to filling the harvest holes with soil.

Tuber positioning

- It could not be tested during this study whether the positioning of the remaining tubers following harvest can affect resprouting. But observations on one pot plant suggested that if tubers are buried vertically, surface area for regenerating buds along the length of the tuber is increased as the tuber was resprouting from several nodes along the tuber.
- Additionally during fieldwork in the Eastern Cape, it was established that tubers at Stutterheim agricultural sites were planted vertically and this seemed to increase the number of tubers per plant.
- Scientific eveidence is needed for this recommendation hence future research on this aspect is necessary.

Mulching

- **B**esides covering the harvest hole, it may be important to use mulching to cover the harvested plants so that the resprouts are protected from the sun as soon as they emerge. Mulching will also ensure that moisture loss is decreased especially in hot areas such as the Eastern Cape.

Watering

- Watering was observed to increase tuber biomass in agriculturally grown plants. Therefore as soon as harvesting is completed and the holes are covered, the plants should be watered whenever possible.
- However, this may not be practical in some harvest sites that are far from water sources.

5.4.2. General recommendations

In light of the above discussed issues surrounding medicinal plant trade, with reference to *P. sidoides*, conservation options and findings of this study, the following recommendations are made:

- There should be strict monitoring in previously harvested sites so that there is no repeat harvest before a 10- 15 year harvest interval has lapsed. All relevant stakeholders such as government departments, municipalities, Pelargonium industry, harvesters, local councils and chiefs should take part in monitoring programmes. Local structures such as community councils and chiefs should have a monitoring plan in place that also includes boundaries of different villages to facilitate identification of new harvest areas and to avoid conflicts due to harvesters from one village harvesting in another village. The plan should also have detailed maps of *P. sidoides* distribution.
- The monitoring plans mentioned above should be developed as per the Biodiversity Management Plan that has been submitted to the Lesotho and South African Goverments. The Lesotho and South African Governments should also create enabling environment for the implementation of the species management plan for *P. sidoides*. This can be in the form of law amendments (e.g. in the case of Lesotho) to allow for the plan to be legally binding. Additionally, recommendations of studies such as that of the assessment of the environmental legislative review of Lesotho (*Anon*., 2010) should be implemented to mitigate the problems associated with fragmented laws governing *P. sidoides* harvest. In the case of Lesotho, the country should make a decision quickly on the mode of implementing the management plan. For example, a Pelargonium Working Group (PWG) has been formed in South Africa and Lesotho was given the option of joining this group. However, Lesotho opted to form its PWG which has to date not been formed.
- The Lesotho and South African governments should advocate for more cultivation projects in order to decrease pressure on wild populations. Harvesters should be encouraged to form associations so that cultivation schemes are done jointly. Because initiating cultivation projects can be expensive for rural people, as part of benefit sharing agreements, the Pelargonium industry should be encouraged to inject some capital into such initiatives. These can be in the form of provision of seeds, training on propagation methods and securing markets. However, more research is required on tuber regrowth colour development in cultivated plants.
- A fully functional benefit sharing system is needed in *P. sidoides* trade. The current prices paid to harvesters and consequently other benefits are not satisfactory (van Niekerk, 2009) thus other forms of benefits should be investigated. These could be in the form of skills transfer, for instance, in the production of medicinal products.

- Detailed studies are needed which will carry out different trials to determine sustainable harvest methods on *P. sidoides* plants such as the effect of closure of harvest holes on tuber recovery.
- It is essential that the Pelargonium industry shares crucial information such as trade volumes harvested and exported with the relevant government departments in Lesotho and South Africa. This kind of information is relevant for implementing the Biodiversity Management Plan.
- The judicial system in Lesotho and South Africa should be informed of the positive role of sustainable harvesting of *P. sidoides* and its impacts on wild populations and peoples livelihoods. Similarly, the judiciary should be encouraged to prosecute illegal harvesters because of the negative role they play in damaging the long term sustainability of the *P. sidoides* resource.
- A thorough ethnobotanical study covering the *P. sidoides* entire distribution range is required. This information will be crucial especially now that NGOs are challenging patents of different companies for using traditional knowledge on *P. sidoides*.

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