DEVELOPMENT OF FIELD MANAGEMENT PROTOCOLS FOR ATLANTIC ROSE HIP PRODUCTION

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ABSTRACT

Roses of the genus *Rosa* are found growing wild throughout the Atlantic Provinces in a multitude of different habitats. Rose hips, the marketable product from these roses, are a rich natural source of bioactive compounds useful in the pharmaceutical industry. In 2004, two wild rose field experiments were established in Prince Edward Island. Experiment #1 was established at the Agriculture and Agri-Food Canada Harrington Research Farm, while experiment #2 was created on private land in the Argyle Shore area. The sites chosen for the experiments differed in soil conditions, microclimate, and the number and isolates of the rose plants used. Planting stock for these experiments was propagated from numerous wild rose (*Rosa virginiana* x *carolina*) isolates collected from populations throughout Prince Edward Island.

The experimental design for experiment #1 was a 3 x 3 x 2 factorial with 800 plants in a randomized complete block design, and four replicates of each treatment. Treatments were applied at planting and included: in-row mulch (none, bark and straw), in-row fertility (none, compost and fertilizer), and inter-row management (tilled and sod). The experimental design for experiment #2 in 2004 was a 3 x 2 factorial with 560 plants in a randomized split-block design, and eight replicates of each treatment. In-row fertility treatments (no fertilizer and fertilizer) were not included in the initial design for experiment #2, and were added in 2005. In-row mulch and fertility treatments were reapplied to both experiments in 2005. The objective of this study was to investigate the effects of several field management practices (in-row mulching, in-row fertility, and inter-row sod) in the establishment of a commercial rose hip plantation in Atlantic Canada. Data collected from both experiments included: mean shoot length, shoot

diameter, number of branches per shoot, number of shoots per plant, plant spread, yield of rose hips per plant, and percentage of rotten and failed rose hips.

Mulching had a positive impact on several aspects of rose plant growth, resulting in larger shoots (length, diameter, and number of branches) and greater plant spreads for rose plants than no mulch. Mulching did not increase the number of shoots per plant, and in some instances had the opposite effect. Straw and bark mulches also improved plant nutrient uptake of P and N, but had no effect on rose hip yields in either experiment. Straw mulch was the most effective in-row mulch treatment for promoting plant vegetative growth in experiment #1, while bark mulch was the most effective in experiment #2.

Fertilized plants in experiment #1 had greater vegetative growth (significantly higher values for shoot length, branches per shoot, and plant spread) than plants with no fertilizer or compost treatments. The compost used in experiment #1 had clearly positive effects on soil fertility, but not on plant growth or productivity. Fertilized plants in experiment #2 had more shoots and greater plant spreads than did plants with no fertilizer. Use of fertilizer increased plant growth in both experiments, and rose hip yields in experiment #1.

Tilled inter-row areas led to a larger mean increase (from May to September, 2005) in shoot lengths, diameters, and plant spreads than for the inter-row sod treatments. Biological yield of rose hips was also significantly lower in inter-row sod treatments when compared to tilled treatments in experiment #2. Inter-row sod increased plant uptake of P in both experiments, but was not as effective at promoting plant growth and rose hip yields as the tilled inter-row treatment used in this study.

In general, the results from this study showed that wild roses responded very well to agricultural management. There was excellent survival of wild plants after transplanting, with only 2 deaths from the more than 1300 rose plants grown in these experiments. Regardless of the original collection source of wild plants, the plants displayed a similar growth pattern with few phenotypic differences under Prince Edward Island growing conditions. When these wild plants were removed from their natural habitat and grown in an agricultural setting, they established well and most began rose hip production in their second season, earlier than in published reports from other countries. The creation of a rose hip plantation is a long-term venture, and the rose plants used in this study are expected to reach full yielding potential only after four or more years of non-irrigated growth. The knowledge gained from this research will be a part of a long term project for establishing wild roses as an alternative agricultural crop for Atlantic Canada.

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"I was just guessing

at numbers and figures,

pulling the puzzles apart.

Questions of science,

science and progress,

do not speak as loud as my heart."

- The Scientist, by Coldplay

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Introduction, Literature Review, and Statement of Study Objective and Hypotheses

1.0 INTRODUCTION

Roses are perhaps the most readily recognizable flowering plants in the world. Although most people are familiar with domesticated varieties of rose, their more humble origins may still be seen in the wild species found in nature. A rose hip is the berry-like structure formed after a rose flower is pollinated. Research into several species of the genus *Rosa* was carried out as part of a collaborative research project in Atlantic Canada to establish rose hips as an alternative field crop for the region. The goal of this research effort is to devlop a local source of high quality rose hip powder for incorporation into existing and new products for the human and animal nutrition markets. The vigorous growth and wide Atlantic Canadian distribution of numerous *Rosa* species, the rich profile of phytochemical antioxidants of rose hips, along with significant regional and international activity in the health market for rose hips, was the impetus for this project.

The objectives of this study were to investigate the effects of several management techniques on rose plant growth and rose hip production, and to establish baseline information on physical qualities of rose hips. This study focused primarily on investigating the growth and development of rose plants prior to rose hip production and, to a lesser extent, began to look at rose hips and factors affecting their production. A combination of field experiments, morphological measurements, and qualitative assessments was used to complete study objectives. Results from this study will be used as the foundation for future research into rose hip production for Atlantic Canada.

1.1 LITERATURE REVIEW

1.1.1 *Rosa* Distribution in Atlantic Canada

Wild roses (genus *Rosa* L.) are a semi-woody perennial belonging to the family Rosaceae (Figure 1.1). According to the taxonomic system of Rehder (1940), the genus is divided into four subgenera: *Hulthemia*, *Platyrhodon*, *Hesperhodos* and *Rosa* (Wissemann 2003). The subgenus *Rosa* comprises 10 sections. Section *Carolinae* includes species that are native to the eastern and central portions of the United States and eastern Canada. The five native species of wild rose (subgenus *Rosa*) in Atlantic Canada include *R. blanda* Ait., *R. carolina* L., *R. nitida* Willd., *R. palustris* L. and *R. virginiana* Mill. .

While some native rose species may be found in hedgerows between cultivated fields, others are found growing wild in wet pastures, thickets, swamps, and along the heads of salt marshes. A number of species may also be found bordering spruce thickets, dry pastures, roadsides, and uplands in dry sandy soil. *R. virginiana* Mill. and *R. carolina* L. are the most common species in Prince Edward Island, and are found growing in roadside ditches, hedgerows, and many disturbed habitats (Erksine et al. 1985). What is remarkable about these plants is that several species may be found in most, if not all of these very different habitats. The abundance and diversity of growing regions, and the long term growth patterns of these two species makes them suitable candidates for development as a sustainable commercial crop in Atlantic Canada.

(a) Rose plant in bloom

(b) Rose plant with ripening hips

Figure 1.1 Photographs of a rose plant with: **(a)** flowers and **(b)** ripening rose hips.

1.1.1.1 Distinguishing between *Rosa carolina* and *R. virginiana*

Morphological characters on which early rose researchers based their observations are still used to identify the species we have today. These characters are usually scored through manual inspection of live or pressed material (Nilsson 1967; Malmgren 1986). The taxonomic keys currently available for identifying native species of *Rosa* in Atlantic Canada were primarily derived from experimental studies carried out by Eileen Erlanson during the early part of the 20th century (Erlanson 1929, 1934). These studies looked at known species of the genus *Rosa* in North America and recommended that more accurate keys be developed for local populations by rhodologists (rose experts) familiar with the plants and the methods used in her study. According to Erlanson (1934), the most important identifying characteristics include the habitat, time of flowering, hardiness and climatic tolerance. Important morphological characters include the habit, foliage, length of flowering laterals, inflorescence, length of the pedicel, sepals, petals, stamens, achenes, disc and urceole, and the chromosome number.

While a quick investigation of most rose plants in the wild will result in a rather accurate taxonomic identification, there are several species that are very similar morphologically, making a proper identification challenging. Some species of *Rosa* are identified without difficulty, breeding true and showing only minor variability. Others (e.g. *R. carolina*) display an enormous degree of variation (Roland 1998; Hinds 2000). Distinguishing between *R. virginiana* and *R. carolina* is a difficult task because they are very similar morphologically, and where their ranges overlap they often hybridize (Erlanson 1929; Lewis 1959; Erksine et al. 1985; Roland 1998; Hinds 2000). According

to the floral keys developed for Atlantic Canada (Erksine et al. 1985; Roland 1998; Hinds 2000), the two species can be distinguished using several characteristics. In general, *R. carolina* is smaller in size than *R. virginiana*, growing to approximately 1 m, whereas *R. virginiana* is said to grow up to 2 m in height. *R. carolina* has thorns that are slender, straight, and terete (cylindrical and elongate), while *R. virginiana* is a coarser plant throughout, with stout and broad-based, recurved thorns. *R. carolina* tends to grow in lighter soils from diffusely-spreading rootstocks and shoots from the ground will often bear flowers on the first year's growth. *R. virginiana* tends to grow more in clumps and the flowers are almost always borne on branches from the old wood. *R. carolina* flowers earlier, beginning in late June, whereas *R. virginiana* flowers in July. *R. carolina* has 3, 5, or 7 leaflets per leaf, each 1.0-1.5 cm wide. *R. virginiana* has 7-9 leaflets per leaf, each 1-3 cm wide (Erksine et al. 1985; Roland 1998; Hinds 2000).

1.1.2 Rosa Genetics

The vast majority of research into rose genetics has been conducted on species of dog roses (section *Caninae*), due to their peculiar meiosis. This "*canina* meiosis" was first described by Täckholm (1920) and is a situation in which more genetic material is inherited from the maternal plant than the paternal plant (matroclinial inheritance). Many species of rose are said to hybridize in the wild, yet only a small number of these hybrids have been verified experimentally (Jičínská 1976). Much of the available literature and corresponding experiments were conducted in the first half of the twentieth century, and before many of the genetic testing methods now available were developed. Literature

searches have revealed little or no recently published research focusing on Atlantic Canada's native species of *Rosa*.

Wild species of the genus *Rosa* consist of a typical polyploidy complex with a basic chromosome number of seven (n = 7). The genus has long been of interest to taxonomists and cytogeneticists because of the large amount of variability encountered in nature, and the ensuing difficulties of classification. Many of the species have been examined cytologically by various researchers and their chromosome numbers are well established (e.g. Jičínská 1976).

In general, a higher ploidy is said to result in a higher fertility in roses (Cole and Melton 1986). A self-incompatibility system is said to exist widely within the genus, particularly in the diploid species and in a minority of the polyploid species (Cole and Melton 1986). In tetraploid and hexaploid species the breakdown of self-incompatibility is found and species can readily form hybrids across the genus (Ueda and Akimoto 2001). The question of natural hybridization between species in the subgenus *Rosa* is highly speculative (Darlington 1928; Ratsek et al. 1939; Nybom et al. 2001). Intermediate types have usually been judged as hybrids, and the supposed identity of the two parents guessed at (Nybom et al. 2001).

Erlanson (1934) suggests that within the genus *Rosa* there may be a markedly high degree of variation found within a species (e.g. *R.. carolina*), and even within a population (several rose bushes of the same species occupying the same area). Recent studies in Sweden have investigated such claims using molecular techniques (e.g. Amplified Fragment Length Polymorphisms, Random Amplified Polymorphic DNA, and

isozyme assays) and have found that this is true for some species and not for others (Olsson et al. 2000; Nybom and Werlemark 2005). Studies on the morphological variation among and within Nordic dog rose species have shown that although very closely related, these species are still morphologically distinguishable (Nybom et al. 1996, 1997).

1.1.3 Rosa Morphology

The morphological characters of leaves are used as a taxonomic identifier for a large proportion of plants, including for the genus *Rosa* (Erlanson 1929; Lewis 1959; Erksine et al. 1985; Roland 1998; Hinds 2000). The leaves of a rose can show great structural diversity depending on the cultivar, and their locations on the shoot. Roses have pinnately compound leaves which, in all but one case (*Rosa persica*), are always oddly-pinnate (Torre 2003). Leaflets generally number from 7-9 in most species, but across the genus vary from as little as 3 to as many as 19 per leaf (Erlanson 1929; Lewis 1959; Erksine et al. 1985; Roland 1998; Hinds 2000; Torre 2003). There is a pair of rudimentary green growths known as stipules where the leaf stalk meets the stem. Some species also have bracts, which are modified and reduced leaves. Bracts can occur on the inflorescence, the pedicle, or the peduncle (Torre 2003). They are simple and never pinnate (Torre 2003). The leaflets are more or less ovate or elliptical in shape, with a rounded, wedgeform or slightly heart-shaped base.

Axillary buds are important in various aspects of the development of the rose plant. When propagated vegetatively, an axillary bud gives rise to the above-ground part

of a new rose plant (Chimonidou 2003). They are assumed to give rise to new basal shoots, which determine the potential flower production (Bredmose et al. 1999). The degree of branching of shoots depends on the growth of axillary buds, and is an important determinant of potential flower production. Axillary buds give rise to the flowering shoots which determine the actual flower production and, consequently, the potential rose hip production (Chimonidou 2003). The upper nodes of a growing rose shoot are formed after release from apical dominance (neoformed), and their number varies with the age of the plants (Marcelis-van Acker 1994). The presence and abundance of thorns on the shoots are generally considered to be varietal characters. Their density generally decreases from the proximal to the distal ends of the stem (Roland 1998; Hinds 2000).

As with other plants, the roots of roses provide uptake surfaces for water and nutrients, and keep the plant steady in the ground. They also provide sites for synthesis and storage of various substances of importance for the growth and function of the whole plant. The morphology and, to some extent, the anatomy of the root system depends on several biotic and abiotic factors. Biotic factors such as the species or selection (cultivar) of the plant can be important in this regard. Abiotic factors such as the soil in which the roots grow, the climatic conditions to which the above ground parts are subjected to and the treatments to which the plants are submitted (e.g. pruning), play a role as well (Andersen and Fuchs 2003). The root morphology of rose plants changes considerably with root temperature. In a greenhouse experiment by Dieleman et al. (1998) it was found that roots of rose plants kept at 11°C were white, succulent, short and sparsely branched, whereas those kept at 26°C were long, brown, thin and branched. However, root dry

weight was not affected by root temperature. Axillary bud break was earlier at higher root temperatures, resulting in a higher shoot dry weight. These results suggest that management practices that regulate root temperature could be used to promote vegetative growth in rose plants.

The genus *Rosa* is not dependent upon seed production for survival because the species can increase vegetatively through numerous underground runners. "Root suckering" is the ability of the plant to produce new shoots from the stem base or from the roots (Little and Jones 1980). The strength of root suckering in a species could be an important factor in its suitability as a crop species. There have been reports in the literature of individual rose plants suspected of being extremely long-lived (Cole and Melton 1986). Due to the colonizing capabilities of rose plants, the age of a genotype could far exceed that of individuals within a clone (Cole and Melton 1986).

1.1.3.1 Flowers And Hips

Most wild roses are described as seasonal-flowering because they produce flowers only during a short flowering season. Flowering time is a characteristic feature of a species (Kovacs et al. 2005). The full flowering period of a wild rose species lasts for 14 days on average, but may continue for a month or more (Kovacs et al. 2005). The flowering period may last for only one week in hot weather (Kovacs et al. 2005). A flowering plant is usually described as juvenile until it is competent to produce flowers and described as mature thereafter. In their first growing season, seedlings of seasonal-flowering roses produce no flowers and can be regarded as juvenile. In their second or,

sometimes, third growing season they produce flowers and can be regarded as mature (Roberts and Blake 2003). The transition between the juvenile and mature phases is often accompanied by changes in the vegetative characters. In many woody plants, changes occur in growth rates, the shape of leaves and the ability of cuttings to form roots.

In temperate climates, wild roses shed their leaves in late autumn and enter a dormant period. In most seasonal-flowering roses, the secondary shoots form leaves continuously throughout the remainder of the growing season, and rarely form flowers (Roberts and Blake 2003). In this way, resources are not wasted on production of new flowers that would be unlikely to form fertile seeds in the same growing season (Roberts and Blake 2003).

1.1.4 Rose-derived Products

Rose hips are the hypanthiums of the rose flowers which, once pollinated, swell to produce a berry-like structure. The fleshy walls of the hypanthium enclose hard, seed-containing achenes. Rose hip products can be consumed in the form of jams, jellies, marmalades, teas, powders, and as an ingredient in baked goods, ice cream, yogurt, candies, pulps, nectars, juices, wines, and liquors (Cutler 2003a; Uggla et al. 2003; Çinar and Çolakoğlu 2005). Rose hip achenes can be cold pressed for the oil they contain. This oil is also a high quality product in the cosmetic industry, used for fighting contact dermatitis (Valladares et al. 1985; Szentmihalyi et al. 2002; Çinar and Çolakoğlu 2005). The petals of the rose flowers are also edible and can be added to salads and baked goods, candied, or used as garnishes (Cutler 2003a).

1.1.4.1 Potential Health Benefits of Rose-derived Products

Historically, roses have been used as laxatives, eyewashes, and treatment for sore throats, stomach problems, and irregular menstrual cycles (Halloran 2000). The biological and nutritional values of rose hips received renewed attention during the second World War, when rose hips were used as a domestic source of vitamin C for England (Crockett 1973; Cutler 2003b). The role of dietary antioxidants, including vitamin C, vitamin E, carotenoids and polyphenols, in disease prevention has received increased attention in recent years. Antioxidants are protective agents that inactivate reactive oxygen species and therefore significantly delay or prevent oxidative damage (Halliwell 1997). Evidence suggests that dietary antioxidants have a wide range of anticancer properties. Block et al. (1992) established this in an epidemiologic review of 156 studies that examined the relationship between fruit and vegetable intake and cancers of the lung, colon, breast, cervix, esophagus, oral cavity, stomach, bladder, pancreas, and ovary. In the majority of the dietary studies reviewed, the consumption of fruit and vegetables was found to have a significant protective effect (Block et al. 1992). Another study involving approximately 10,000 people in Finland showed an inverse association between the intake of flavonoids (phenolic antioxidants) and the incidence of all sites of cancer combined (Knekt et al. 1997). Clinical studies have shown that dried rose hips induced a reduction in pain and inflammation in patients previously diagnosed with osteoarthritis (Winther et al. 1999; Larsen et al. 2003; Warholm et al. 2003; Rein et al. 2004). Rose hips had an anti-ulcerogenic activity in a study by Gürbüz et al. (2003), in

which rats that had ethanol induced ulcers received 100% protection from ingestion of rose hips.

In a recent survey, rose hips exhibited the highest total antioxidant properties among a variety of plants including various fruits, berries, vegetables, cereals, nuts and pulses (Halvorsen et al. 2002). The levels of vitamin C in rose hips can be up to 15 times those found in citrus fruits (Honero-Mendez and Minguez-Mosquera 2000). Vitamin C content is highest when hips first ripen (pale red), and lowest when hips become over-ripe and darker in colour (Bakos et al. 1981; Spiro and Chen 1993). In addition to vitamin C, rose hips contain B1, B2, E and K vitamins as well as various minerals (Şakiroğlu et al. 1996). They contain high levels of carotenoids and phenolics, the majority of which are proanthocyanidines, and a minority of flavonols (Razungles et al. 1989; Mikangi et al. 1995; Hashidoko 1996; Hodison et al. 1997; Daels-Rakotoarison et al. 2002). The antioxidant capacity of rose hips is not due solely to their high vitamin C content, but is determined more by their phenolics content (Daels-Rakotoarison et al. 2002). In fact, Gao et al. (2000) found that the phenolics in rose hips were responsible for 76-91% of total antioxidant activity compared with only 9-17% from vitamin C.

Lycopene is a carotenoid which acts as a natural pigment. It is synthesized by plants and microorganisms, but not animals. It is one of the most potent antioxidants among dietary carotenoids (Agarwal and Rao 2000; Sanjiv and Rao 2000). It is the high levels of lycopene in tomatoes that gives them their bright red colour and makes them an important dietary source of carotenoids (Clinton 1998). Rose hips are known to contain relatively large amounts of lycopene, concentrations of which may be higher than those

found in tomatoes (Böhm et al. 2003). Rose hips are also a rich source of folate, especially when fresh (Strålsjö et al. 2003). Adequate folate intake is associated with a reduced risk for chronic conditions that may particularly affect the elderly, including vascular disease, cancer and cognitive dysfunction (Rampersaud et al. 2003). The chemical profile of rose hips may vary depending upon many different factors such as the species, ripeness, cultivation, climate, and losses from harvest or storage (Vuorinen et al. 2000; Strålsiö et al. 2003). A study by Spiro and Chen (1993) suggests there might be a latitudinal effect on the chemical content of rose hips, as those grown in the north of Europe contain more vitamin C than those of the same species found growing in the south.

1.1.5 Potential Environmental and Economic Benefits of Wild Roses

Improper agricultural production practices (e.g. excessive tillage, continued cultivation of marginal land) can result in soil degradation through wind and water erosion, salinization, declining soil organic matter levels, soil acidification, degradation of soil structure, and decreased soil fertility (Morgan 2005). Many areas in Atlantic Canada have soil degradation issues associated with agriculture, with soil erosion and organic matter loss the most common.

There are more than 170,000 hectares of land in agricultural production in Prince Edward Island, and the most prominent crop is potatoes (Statistics Canada 2001). More than 600 farms in Prince Edward Island produce potatoes, with an average size of 215 hectares (Statistics Canada 2001). Unfortunately, the potato lands of New Brunswick and

Prince Edward Island have had some of the worst water erosion problems in Canada (Dumanski et al. 1986). Soil losses of up to 4000 t/ km^2/ year have been recorded in New Brunswick, while losses as high as 10,000 t/ km^2/ year have been reported for other areas in Canada (Standing Senate Committee on Agriculture, Fisheries and Forestry 1984; Dumanski et al. 1986). Irrigation is a common activity in some regions of the country, and may also lead to water quality problems. Improper irrigation practices may degrade soil structure and compound many of the water quality issues associated with agriculture. Wild roses have been shown to grow well with no irrigation (Uggla et al. 2003).

Recent legislation was implemented in Prince Edward Island to address environmental concerns associated with agriculture, such as soil loss and water quality. Amendments to the Agricultural Crop Rotation Act (Government of PEI 2002) have made it difficult to farm potatoes and other regulated crops for more than one year in succession, or on land with a slope greater than 9%. Additional legislation requires farmers to have a minimum 10-meter buffer zone between agricultural fields and watercourses. This was done in an effort to decrease the levels of sediment, nutrients, and pesticides flowing off fields and into waterways across Prince Edward Island.

Wild roses have been described as a potentially profitable agricultural crop because they require relatively low levels of maintenance and grow well in marginal lands (Çinar and Çolakoğlu 2005). *Rosa* sp. could be well-suited to grow in zones where environmental quality is a concern, such as low-lying areas (including runoff and riparian zones) and other lands unsuitable for row crops. Roses could potentially be farmed on these lands every year with minimum tillage and soil loss, and could supplement grower

income. Roses could benefit the environment indirectly as well. It has been found that *Rosa rugosa* growing in areas with high levels of air pollution accumulates heavy metals in the leaves. Because these metals can be attributed by air pollutants, it has been suggested that this plant could be used as an indicator of air and soil pollution (Bagatto et al. 1991; Hashidoko 1996).

There are several potential advantages to introducing wild roses into Atlantic Canadian agriculture. It may increase crop diversity and sustainability of farming in the region, and may alleviate major environmental problems such as soil erosion, and surface and ground water contamination associated with more erosive crops (e.g. potatoes and vegetables). The development of roses in marginal areas and areas unsuitable for other forms of agriculture could have a beneficial impact on environmental quality and agricultural productivity in Atlantic Canada. Another complementary aspect of regional rose production is related to the beekeeping industry. Maximum production of rose hips requires efficient pollination. Use of honeybees for rose pollination would contribute to hive strength and colony populations, and beekeepers may find this to be an attractive use of their hives.

1.1.6 Rose Hips as a Crop

While roses have been grown for commercial hip production in Europe for decades, scientific reports describing field management practices have only recently been made public. Commercial production of rose hips has been investigated in various countries on different continents, including Azerbaijan (Shamsizade and Novruzov

2005), Bulgaria (Popova and Kozhuharova, 1983), Chile (Joublan and Rios 2005), Czechoslovakia (Simanek 1982), Germany (Strizke 1962, pp 22-23), Hungary (Kovacs et al. 2005), India (Tejaswini and Prakash 2005), Russia (Friedrich and Schuricht 1985, 163), Sweden (Uggla and Martinsson 2005), Tadjikistan (Mamadrizohonv et al. 1994), and Turkey (Ercişli and Güleryüz 2004). Although there is no published data on the longevity of rose hip plantation, there are individual rose plants in British gardens that are more than 50 years old (Crockett 1971). The productivity of rose pants may be maintained through selective pruning when yield of flowers and rose hips decline over time (Allen 1948; Crockett 1971; Uggla and Martinsson 2005)

The principle use for rose hips in Sweden is for rose hip soup, a staple dessert in Norwegian culture. The hips used for this soup are from roses of the section *Caninae*, which have a characteristic flavour limited to the section (Uggla and Nybom 1999). The primary source of rose hips for Sweden has traditionally been from Chile and Argentina, which together export approximately 4500 tonnes of dried hips to Europe each year (Joublan et al. 1996; Uggla and Martinsson 2005). Domestication of wild roses in Sweden began in the 1980s as a way of providing the local food manufacturing industry with domestically grown rose hips. Wild rose selections (i.e. varieties, cultivars) that could be grown on a commercial scale and that were suitable for mechanical harvesting were developed through a government-funded breeding program. The Swedish project was largely successful until prices changed in 2000, and it became more economical to import hips once again (Uggla and Martinsson 2005).

When domesticating a wild plant for commercial crop production, desirable characteristics include suitability for mechanical harvesting, a short and concentrated fruit ripening period, high levels of bioactive compounds, satisfactory fruit quality, high productivity, and disease resistance. The method of harvesting may help to determine the importance of certain plant characteristics such as bush shape (Kovacs et al. 2005). Modified black currant harvesters had been used to harvest rose plants in Sweden, and it was found that selections with long branches could not be harvested properly (Uggla and Martinsson 2005). Varieties that produce fewer shoots may be preferred as they are reported to mature earlier (Kovacs et al. 2005) and may be easier to cultivate than more unwieldy bushes. It has been reported that pruning 5-10 cm above the ground can help to rejuvenate rose plants that become too large, too vigorous, or too old to yield to their full potential (Uggla and Martinsson 2005). Pruning roses in early springtime could also help to ensure a suitable plant shape and enhance the longevity of a rose plantation (Nitransky 1972). If plants are being grown on a small scale, harvesting of rose hips may be performed by hand and plants with large hips might be desirable. The abundance or density of thorns on the plants must also be taken into consideration for manual harvesting, as species vary widely in this regard. A modified raking tool (rasqueta) is used by peasants in Chile for manual harvesting of wild rose hips (Joublan and Rios 2005).

Rose plants usually start producing hips in their second year of growth. Reports from Sweden indicate that the first harvestable yield from a rose plantation can be obtained 3 to 4 years after planting (Uggla and Martinsson 2005). The highest yields may

be obtained when the plants are 4 to 6 years old and fully mature (Uggla and Martinsson 2005). This development may be delayed by one or two years if irrigation is not used (Joublan and Rios 2005). The yield of rose hips per bush varies with climate and species. In Sweden, more than 2 kg of hips per bush was seen under optimum growing conditions, while in Chile the average was 3 kg (Uggla and Nybom 1999; Joublan and Rios 2005). Harvesting time varies with environmental conditions and is generally determined by the colour of the hips. Optimal bioactive levels coincide with ripe fruit which is firm and bright red in colour (Bakos et al. 1981; Spiro and Chen 1993). Over-ripe fruit are dark red to crimson in colour, while under-ripe fruit are green to light orange (Bakos et al. 1981; Spiro and Chen 1993).

Physical rose hip characteristics that should be considered for selection improvement include the size and mass of hips, dry weight of hips, and the ratio of flesh-to-achenes. Cultivated varieties of rose have been reported to have large heavy hips (3-7 g), high flesh ratio (70-80%), and low numbers of achenes (Ercisli and Esitken 2004). An ideal rose selection would be one which produces large hips with a high flesh-to-achene ratio as well as a high bioactive (carotenoid) content.

1.1.6.1 Management Practices

Roses are grown commercially in many places in the world, from northern regions to the tropical highlands, suggesting a high capacity to adapt to a broad range of growing conditions. Roses appear to be resistant or tolerant to salinity stress, drought, low relative humidity of the air and high temperature and irradiance (Erlanson 1934;

Demir and Özcan 2001). Many outdoor cultivars thrive in polluted environments, suggesting that roses are also resistant to oxidative stress (Hashidoko 1996). But the highest crop performance can be achieved only if roses are provided with optimal growing conditions. As there are few published studies on cultivation practices for roses as a field crop for rose hip production, it is necessary to look at other similarly grown horticultural crops. Establishment of perennial plants takes time, and often factors affecting fruit or harvest yields are set in motion the previous year. Raspberry (genus *Rubus*) is a high-value perennial crop with considerable establishment costs. Significant investments of time and money can be lost if raspberries are not provided with adequate care during their early years. For raspberries, minimal disturbance of the root system, adequate soil moisture, and warm soil temperatures will allow plants to establish well, and result in a dense stand of canes the following year (Darrow and Magness 1938; Clark 1940; Childs 1941). Unlike raspberries which require a raised bed for adequate drainage, rose plants are often found growing quite well in wet pastures and roadside ditches where drainage is very poor.

In a study of arctic bramble in Sweden, it was found that good plant establishment with rapid vegetative development during the first growth season was reflected in higher yields in both the first and second harvest years (Hellqvist 2000). Yields were often highest in the third and fourth year after planting, when the spreading crop had just filled up the cultivation area (Hellqvist 2000). Yields for roses are also reported to be higher after establishment, with maximum yields obtained 4 to 6 years after planting (Joublan and Rios 2005). Several important fruit properties including acids, sugars, colour,

maturity, and yield are influenced by the levels of minerals in the fruit (Ferguson and Boyd 2002). Some pre-harvest factors that affect fruit mineral content include pollination, soil nutrient levels, soil pH, water economy, fruiting position on the plant, and crop load.

1.1.6.1.1 Mulching

Mulches can be made from a wide variety of materials including straws, barks, plastic films, grass clippings, and even seaweeds. Mulches are commonly used to hold moisture close to the plant and insulate plants from extremes in temperature. If roses are to be grown organically, then pesticides will not be available to use for weed suppression, and mechanical weeding will soon become difficult as field sizes increase. Covering or mulching the soil surface can prevent weed seed germination or physically suppress seedling emergence (Bond and Grundy 2001). Mulching may therefore be the most feasible method of weed suppression for organically grown roses. In general, the cost of mulching makes it economical only for high-value crops (Runham and Town 1995), or perennial crops in which it will remain effective for several years (Wofford and Orzolek 1993). The benefits of mulching on different crop species are well documented. Mulching has resulted in greater plant growth and yields for many agricultural crops such as raspberry (Darrow and Magness 1938; Clark 1940; Childs 1941; Trinka and Pritts 1992), tomato (Abdul-baki et al. 1992, 1996; Agele et al. 2000), strawberry (Laugale et al., 2000; Kimak et al., 2001), corn (Jones et al. 1969; Chaudhary and Prihar 1974; Lal 1974) and potato (Ruiz et al. 1999).

Mulching raspberry plants with straw has been shown to double shoot growth comparative to cultivation during the first year of growth, and be as much as 4 times greater after 2 and 3 seasons of growth (Clark 1938; Childs 1941). Straw mulch can also increase the number of shoots produced and can greatly increase wood production (Clark 1938; Childs 1941). Wood production in raspberry has been shown to be highly correlated to fruit yield in most instances (Childs 1941). Another explanation for the increased levels of vegetative growth and fruit yield in mulched crops is a possible leaching of micronutrients from mulch into the soil. On the other hand, when organic mulches decompose they may cause a decrease in soil mineral nitrogen, effectively limiting potential plant growth and development (Bond and Grundy 2001; Strik et al. 2006).

Mulching during the initial planting period can significantly promote establishment of crop species and affect growth positively in following seasons. In field management experiments conducted by Trent Webster (1995), it was found that raspberry plants mulched with straw during the first ten weeks after planting produced twice as many shoots in the second and third years as did plants where herbicides were used for weed control. Straw mulched plantings also produced an earlier crop in the second year than did raspberry plants with no mulch (Nova Scotia Dept. Agriculture and Fisheries 1995). Mulches are also associated with higher fruit yields for raspberry than simple cultivation (Darrow and Magness 1938; Clark 1940; Childs 1941; Trinka 1992). Mulches keep soil temperature around the plants much more uniform than simple cultivation (Darrow and Magness 1938). Studies have indicated that a surface residue of straw can

increase the amount of stored precipitation in a field by two-fold, which can have a positive impact on fruit yield and size (Clark 1940; Childs 1941).

Like roses, arctic bramble (*Rubus arcticus*) spreads vegetatively by its root system. Mulching with a dark plastic film improved plant development in a study on the establishment of hybrid arctic bramble (nothosubsp. *stellarcticus*) under field conditions in Sweden (Hellqvist 2000). Black plastic mulch increases soil temperature (Hill et al. 1984; Hellqvist 2000), and an increased soil temperature may help rose plants to grow longer roots (Dieleman et al. 1998). This could be beneficial for establishment of wild roses in Atlantic Canada during the spring growing season.

1.1.6.1.2 Fertilizers and Composts

Chemical fertilizers applied to the soil generally contain salts of the macronutrients, especially those of nitrogen, phosphorous, and potassium. Fertilizers that contain two or more of these key mineral nutrients are called "compound" or "mixed" fertilizers. Nutrient availability and, in particular, a lack of certain major nutrients such as nitrogen (N) and phosphorous (P) may restrict the root size of plants. Low P supply has been used successfully in pot rose production as a means of restricting top growth (Weinard and Lehenbauer 1927). Plants with minimal P available have a much higher root to top ratio than plants with an adequate or abundant P supply (Weinard and Lehenbauer 1927). They also keep their flowers considerably longer (Weinard and Lehenbauer 1927).

The amount of biologically available nitrogen is often the key determinant of the productivity of agricultural ecosystems (Stanford and Legg 1984). Since nitrogen is a constituent of amino acids, amides, proteins, nucleic acids, nucleotides and coenzymes, hexosamines, etc., it is essential for maintaining the growth of a developing plant (Schrader 1984). Nitrogen is the fourth most abundant element in plants. There is typically between 1% and 4% nitrogen in plant dry matter content (Hill 1984). Nitrogen increases plant cation exchange capacity, water uptake and nutrient absorption. Because nitrogen is required in such a large quantity, it is often a factor that limits yield in commercial fruit production (Rempel et al. 2004). As a result, the addition of nitrogen fertilizers is one of the most common cultural practices used to achieve high yields and meet the nitrogen requirement of commercially grown fruit crops.

Some of the common forms of nitrogen fertilizer include nitrate, urea, ammonium, and manure (Schrader 1984). However, only nitrogen present in the soil solution as nitrate (NO_3^-) and ammonium (NH_4^+) are usable by most crop plants (Barber 1984). Nitrogen derived from manure or urea fertilizers must be transformed into either nitrate or ammonium prior to being assimilated by the crop. A study comparing effects of nitrate and ammonium nutrition (the latter at two different pH regimes) on growth, CO_2 gas exchange, and on the activity of key enzymes of the nitrogen metabolism of raspberry, blueberry and strawberry was completed by Claussen and Lenz (1999) in the United States. Strawberries fed ammonium nitrogen had a decrease in net photosynthesis and dry matter production while blueberries fed with ammonium nitrogen saw an increase in both parameters. Dry matter production of raspberries was not affected by the

nitrogen form supplied. This may reflect the different crops adaptability to soil pH and N form, and is probably due to the conditions of their natural environment (Claussen and Lenz 1999).

Soil analysis involves chemical determination of the content of a nutrient in a soil sample. This technique depends on careful soil sampling methods and interpretations of soil parameters. A major limitation of soil analysis is that it reflects the levels of nutrients potentially available to the plant roots but fails to evaluate uptake conditions and the amounts of nutrients actually taken up by plants. To obtain this information, plant tissue analysis must be done. Adequate use of plant tissue analysis requires an understanding of the relationship between plant growth (or yield) and the mineral content of plant tissue samples (Bouma 1983). Although plant tissue analysis has been applied to many different plant organs and tissues, it has generally been observed that changes in nutrient content brought about by changes in the nutrient supply are closely correlated with the nutrient content of the leaves (Bouma 1983). For example, concentrations of relatively immobile cations such as calcium and magnesium typically have fruit to leaf ratios of less than 0.2, whereas more mobile nutrients such as potassium may reach close to 1.0 (e.g. in tomatoes, Anderson et al. 1999).

1.1.6.1.3 Inter-row Areas

Inter-row areas (alleyways) provide space for agricultural equipment such as tractors or harvesters to be moved through a field. They should not be continuously cultivated for weed control because the soil structure will eventually break down,

allowing muddy alleyways to occur after rains. If wild roses are to be planted in areas with slopes too great for row crops, a permanent groundcover in inter-row areas might be necessary. Grasses that can be mowed and managed could be planted in these areas to help prevent erosion and soil deterioration. One disadvantage to grasses planted in inter-row areas is that they compete with the crop plants for water and nutrients, and may have a negative impact on crop growth and yield (Bond 2001). However, research with raspberries has shown that shoot production and yield of fruit do not necessarily decrease with a reduction in soil cultivation (Clay and Ivens 1966; Robinson 1967). In fact, yields may actually increase when soil cultivation is discontinued as reported by Robinson (1967) for several small fruit crops.

1.2 Statement of Study Objective and Hypotheses:

The establishment of a rose hip plantation is a long term venture. There is currently no literature available on field management practices for rose hip production in Atlantic Canada. The objective of this study was to investigate the effects of several field management practices (in-row mulching, in-row fertility, and inter-row sod) in the establishment of a commercial rose hip plantation. In order to achieve this objective, the following hypotheses were proposed:

1. In-row mulching of rose plants will result in increased rose plant growth (shoot production, shoot size, and plant size). With this increased plant growth there will be an associated increase in yield of rose hips in the first production year.

2. In-row compost and in-row fertilizer will result in increased rose plant growth and yield of rose hips in the first production year.
3. Inter-row tillage will result in increased rose plant growth and yield of rose hips in the first production year.

CHAPTER 2:

Materials and Methods

2.0 MATERIALS AND METHODS

2.1 Plant Material

Two wild rose field management experiments were established in Prince Edward Island (46°20′N, 62°59′W) in 2004 using selections from wild *Rosa* populations indigenous to Prince Edward Island. Collection sites were large ($\geq$ 5 m^2) populations of *Rosa virginiana* or *R. carolina,* that appeared to be free of pests and disease, and with easy road access. Many different collection sites were used in an attempt to secure enough plants for planting several sites. Selections were taken as stem cuttings and propagated to plants at the J. Frank Gaudet Forestry Nursery (Department of Agriculture and Forestry) in Charlottetown, Prince Edward Island. Unequal numbers of many different selections were used to plant the experiments because of the low rate of success when propagating the rose cuttings.

The plants used for both experiments were originally taken as stem cuttings from plants identified as *Rosa virginiana* or *R. carolina* using standard floral keys, primarily Hinds (2000) and Roland (1998). It must be noted that differentiating between the two species is extremely difficult as they are very similar in appearance, and are known to have a high degree of variation within the species (Erlanson 1934; Lewis 1959). *R. virginiana* and *R. carolina* are also known to hybridize quite readily where their distributions overlap (Lewis 1959). All stem cutting collection sites were revisited in 2005 and a second attempt was made at identifying the species at each site. It was decided that traditional morphological characteristics were insufficient for an accurate

species designation, and all sites were classified as potential *Rosa virginiana x carolina* hybrids for the purposes of this study.

All of the plants used for planting the experiments appeared to be free of pests and disease, and were relatively homogenous in height and appearance, with only one shoot and few branches. All plants were given an identification number (ID) that was imprinted on a metal tag and tied around the base of each plant. Each ID included: the site the cutting was collected from, the year it was collected, and an individual plant number. This tag provided plant reference information for the duration of the experiment.

2.2 Experiment #1

2.2.1 Location of Experiment

This experiment was established at the Agriculture and Agri-Food Canada (AAFC) Crops and Livestock Research Centre in Harrington (46°22'N, 63°14'W), PEI. The site selected was Field 350, which is a long, narrow field (east-west) with substantial hedge row protection bordering on the north and south (Figure 2.1). The experiment was established along the south side of the field and extended ≈ 100 m along the hedge and ≈ 60 m across the field. Plots were located ≈ 20 m from the south hedge to remove any shading effect. Soil at this site is classified as a Charlottetown Soil, Orthic Humo-Ferric Podzol (Orthic Podzol in F.A.O. system) with sandy loam to loamy sand textures (MacDougall et al. 1988). The previous crop grown in this field was potatoes in 2003.

2.2.2 Experimental Design

The experimental design was a 3 x 3 x 2 factorial in randomized complete block design (Gomez and Gomez 1984) with 4 replicates of each treatment (Figure 2.2). There were 18 different treatments per block. A "guard row" was established on each side of the entire trial to eliminate potential edge effects on measured plants. The plants used for the guard rows were propagated from *R. virginiana* rootstock at the provincial tree nursery (nursery stock). No data were collected from these guard rows. There was ≈ 5 m between replicates and at each headland. Each plot consisted of a single row of 10 plants, with 0.9 m between each plant and 4 m between plots. A total of 8 different selections were used to plant experiment #1; all selections were from sites in Prince Edward Island (Table 2.1).

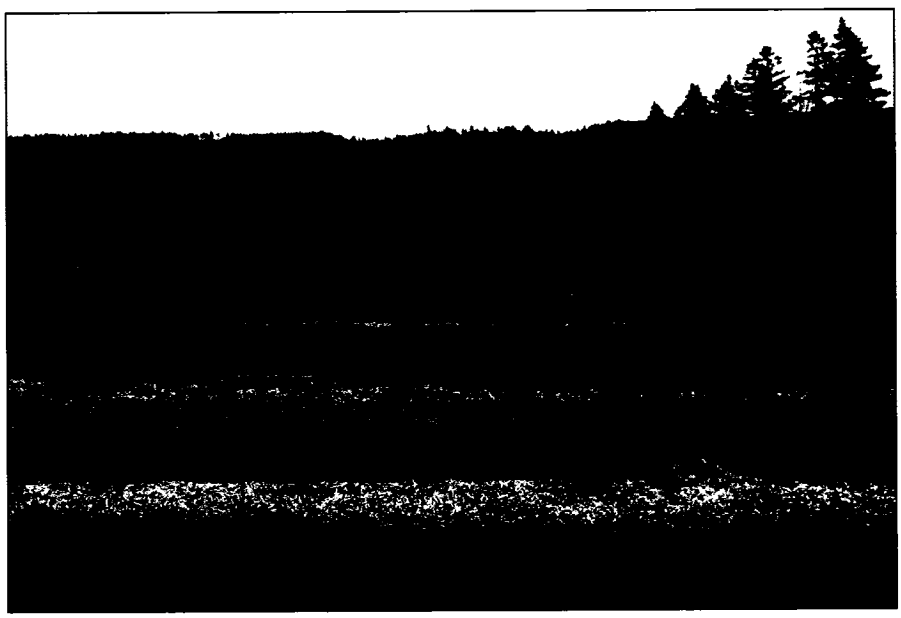

Figure 2.1 A photograph of experiment #1, located in Harrington, PEI, 2004.

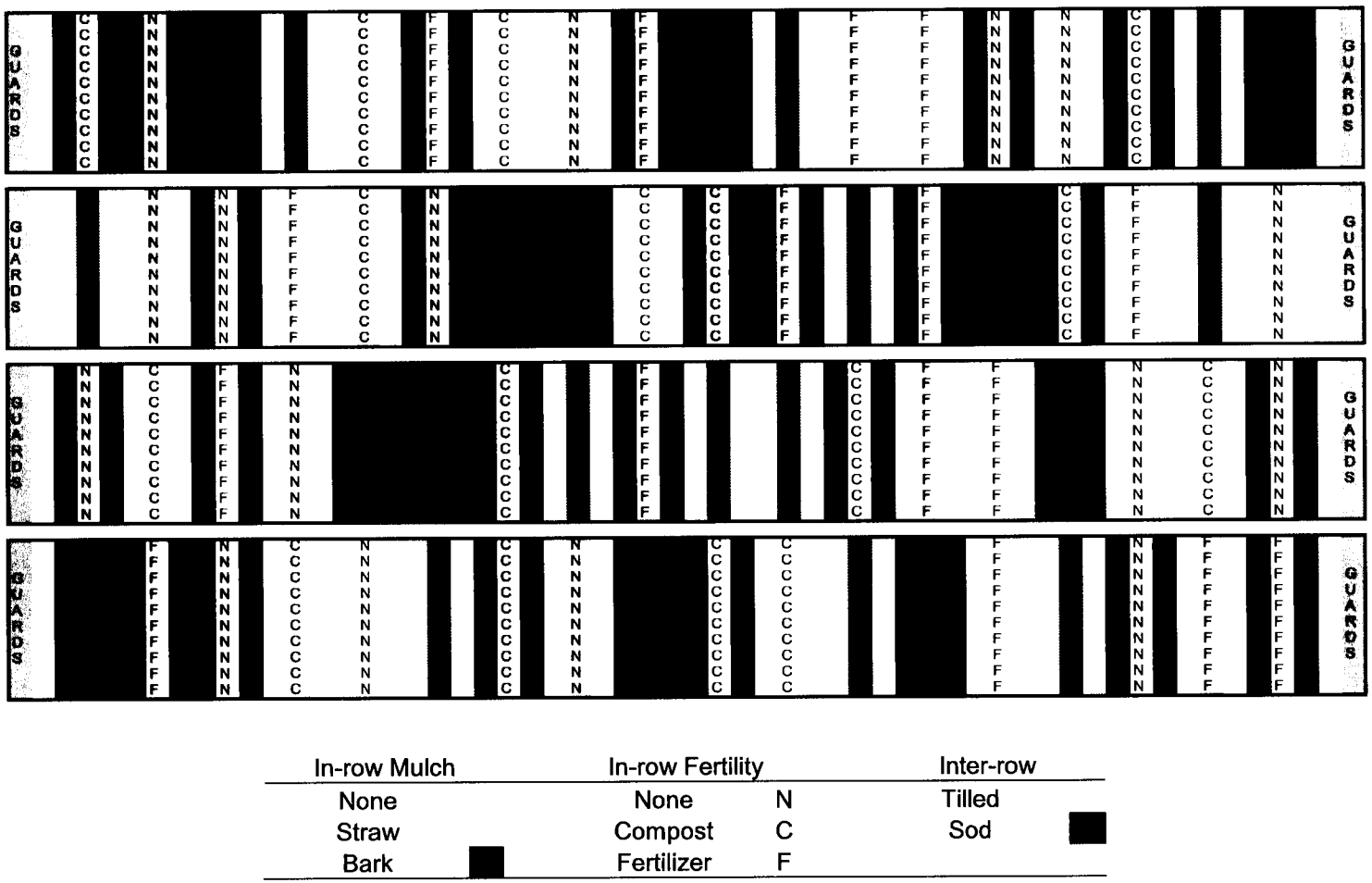

Figure 2.2 Field plan for experiment #1 showing applied treatments for each plot of 10 plants. Each treatment was a combination of three test factors: in-row mulch (none, straw, bark), in-row fertility (none, compost, fertilizer), and inter-row (tilled, sod). A randomized complete block design was used with four replicates of each of the 18 treatments.

Table 2.1 Original collection site numbers, locations (including longitude and latitude in decimal degrees) and number of plants used to plant experiment #1.

Site Number	Site Location	Longitude	Latitude	Plants Used
12	Naufrage	62.43353	46.46371	296
25	St. Peter's	62.62265	46.46553	97
27	Old Cardigan Rd.	62.85138	46.36366	68
36	Meadowbank Rd.	63.24777	46.20844	38
38	Egmont Bay	64.09052	46.40260	108
39	Greenwich	62.62156	46.46121	52
58	Greenwich	62.62133	46.46561	37
60	New Glasgow	63.34677	46.43278	4

The factors used in this experiment included in-row mulch (none, bark and straw), in-row fertility (none, compost and fertilizer), and inter-row management (tilled and sod) (Table 2.2). The site was cultivated prior to planting with 2 passes of a Restill™ conservation tiller. Plots were marked and fertility treatments applied and incorporated on June 21st, 2004. Experiment #1 was hand planted on June 22nd, 2004. Mulches were applied on June 28th, 2004. Inter-row sod treatment was seeded on June 29th, 2004.

2.2.3 Treatment Descriptions

The straw mulch was a barley straw applied post plant at ≈ 7.5 cm depth (13.5 t ha^{-1}). The bark mulch was commercial landscape bark mulch (Georgetown Lumber, Georgetown, PEI) applied post plant at ≈ 5 cm depth (1.6 t ha^{-1}). The bark mulch was a mixture of spruce and fir bark which was ground and composted for 6-8 months (Table 2.3). Mulch application rates were calculated by determining the amount necessary to adequately cover the ground while allowing for some compaction due to wind and rain. Both straw and bark mulches were applied by hand (with no injury to the plants), in a 1 m band over the row. Some settling of the mulches occurred, so additional mulches were added in mid-summer to maintain the appropriate mulch thickness. Mulch treatments were reapplied in May 2005.

The compost was prepared by Roger Henry, Compost Technician, AAFC. The compost was created in the autumn of 2002 and consisted of an initial mix of softwood sawdust, lobster waste and old hay (Table 2.4). The pile was allowed to decompose and additional lobster waste was added several times in the 2003 composting season (May to

Table 2.2 Management treatments used in experiment #1. Each treatment was a combination of three test factors: in-row mulch, in-row fertility, and inter-row.

Treatment Number	Mulch	Fertility	Inter-row
1	None	None	Tilled
2	None	None	Sod
3	None	Compost	Tilled
4	None	Compost	Sod
5	None	Fertilizer	Tilled
6	None	Fertilizer	Sod
7	Straw	None	Tilled
8	Straw	None	Sod
9	Straw	Compost	Tilled
10	Straw	Compost	Sod
11	Straw	Fertilizer	Tilled
12	Straw	Fertilizer	Sod
13	Bark	None	Tilled
14	Bark	None	Sod
15	Bark	Compost	Tilled
16	Bark	Compost	Sod
17	Bark	Fertilizer	Tilled
18	Bark	Fertilizer	Sod

Table 2.3 Nutrient analysis of bark mulch used in experiments #1 and #2 in 2004 and 2005.

Factor	Symbol	Amount in Mulch
pH	-	5.40
Dry Matter	-	35%
Carbon	C	16%
Nitrogen	N	0.14%
C:N Ratio	-	110
Boron	B	2.8 ppm
Calcium	Ca	0.26%
Copper	Cu	1.5 ppm
Iron	Fe	752 ppm
Potassium	K	0.04%
Phosphorus	P	0.01%
Magnesium	Mg	0.03%
Manganese	Mn	286 ppm
Zinc	Zn	29 ppm

Table 2.4 Nutrient analysis of compost used in experiment #1 in 2004 and 2005.

Factor	Symbol	Amount in Compost
pH	-	7.9
Dry Matter	-	72%
Carbon	C	9.2%
Nitrogen	N	0.67%
C:N Ratio	-	14
Boron	B	5.8 ppm
Calcium	Ca	8.4%
Copper	Cu	10 ppm
Iron	Fe	n/a
Potassium	K	0.09%
Phosphorus	P	0.59%
Magnesium	Mg	0.40%
Manganese	Mn	177 ppm
Zinc	Zn	29 ppm

October). The material was stockpiled for use in 2004. Compost was applied at 60 t ha^{-1} (54 kg $plot^{-1}$) on a 1 m band over the row and incorporated by hand raking, with no injury to the rose plants. Compost was reapplied as top-dress (spread around plants with no additional incorporation into soil) on June 22nd, 2005.

The fertilizer used was a commercial grade 5-20-20 (N-P-K). It was applied on June 21st, 2004 and incorporated by hand raking, with no injury to rose plants. This fertilizer formulation was chosen for use during the first year to promote root development and plant establishment. During the second year (2005), the fertilizer used was a commercial grade 10-10-10 (N-P-K), applied as top-dress on May 25th. A fertilizer with higher nitrogen content was chosen with the aim of improving overall plant health and yield during the second growing season. Fertilizer was applied at a rate of 800 kg ha^{-1} (648 g $plot^{-1}$) in a 1 m band over the planting row.

The inter-row sod was established using Canada No. 1 lawn seed mix (McCardle Seeds Inc., Kinkora, PEI), which was a mixture of 40 % Kentucky Blue Grass, 40 % Creeping Red Fescue and 20 % Perennial Ryegrass. Inter-row sod treatments were seeded at ≈ 5 kg ha^{-1} in strips 1.5 m wide on either side of the plots. Headlands were also seeded to allow for movement of plot equipment and maintenance. The grass was seeded with a Brillion™ seeder. Weeds were controlled in-row by hand weeding weekly. Inter-row areas with tilled treatment were cultivated to a depth of ≈ 7 cm as required to control weeds throughout the entire growing season each year. The inter-row sod treatments were routinely mowed to ≈ 5 cm throughout the entire growing season each year (Sanderson

and Cutcliffe 1988). Any plant material that grew up outside of the 1 m wide plots were tilled or mown and disregarded. The plots were not irrigated.

2.2.4 Data Collection

Out of the 10 plants located in each plot, 4 were randomly selected for data collection. The first and last plants of each plot were never selected for data collection to reduce potential edge effects. A total of 288 rose plants were used for data collection from experiment #1. Data were collected from the same plants each time. From both experiments, the number of shoots, and the length and stem diameter of the longest shoot were recorded for each of the selected plants twice in 2004 (late July and late September). Data collection for both experiments was expanded in 2005. Data were collected in mid-May and early September. Shoots ($\geq$ 10 cm in length) on plants used for data collection were affixed with individual identification tags in May, 2005. This was necessary to ensure an accurate comparison of shoot measurements for the duration of the study.

From each plant the following information was collected: the total number of shoots, length and diameter of each tagged shoot, the number of branches on each tagged shoot, and the overall plant spread (Figure 2.3). Plant spread was defined as the greatest lateral distance between any two points on a single plant, measured with a standard measuring tape. It was necessary to limit the number of shoots measured because of time constraints. Therefore, during the data collection in September 2005, those shoots without a tag (newly produced shoots) were not measured, but were recorded in the total number of shoots per plant.

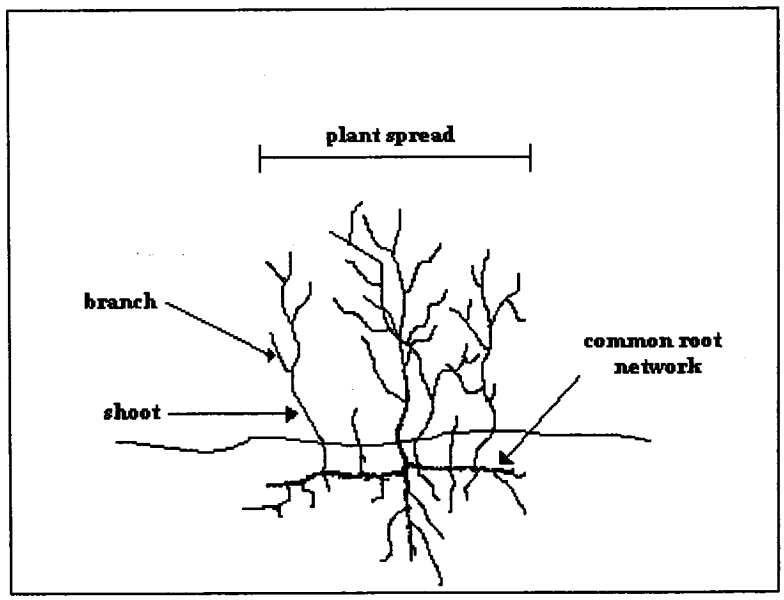

Figure 2.3 Drawing of a rose plant showing shoots with branches, and a common root network. Plant spread is the greatest lateral distance between any 2 points on a single plant.

Soil and leaf samples were collected from experiment #1 on August 3rd, 2005. Six to eight soil samples were taken with a standard soil probe to a depth of 15 cm from all plots in both experiments. In plots with either straw or bark mulch, the mulch was cleared away to expose the soil before the soil sample was taken. Soil samples were then sent to the provincial Soil and Feed Testing Laboratory (PEI Department of Agriculture and Forestry, Charlottetown) for macro and micronutrient testing. Samples were air dried and passed through a 2 mm sieve prior to analysis. The pH of soil samples was determined with a 1:1 soil-to-water ratio. Soil nutrient concentrations of P, K, Ca, Mg, Cu, Zn, B, Fe, Mn, and S were extracted with Mehlich III, and the supernatant analyzed using inductively coupled argon plasma spectrometry (ICAP 1100; Therms Jarell Ash Corp., Waltham, MA) (Tran and Simard 1993).

Plant leaf tissue was randomly collected from all plots and obtained following a procedure for sampling rose leaf tissue described by Mills and Jones (1991). The upper 3 leaflets from mature leaves were collected until a total of 35 leaflets had been collected from each plot. Leaf tissue samples were then sent to the provincial Soil and Feed Testing Laboratory (PEI Department of Agriculture and Forestry, Charlottetown) for macro and micronutrient testing. Samples were dried at 80°C, ground to 1 mm, ashed at 500°C, and extracted in 2 M HCl. The extract was centrifuged and concentrations of P, K, Ca, Mg, Cu, Zn, Mn, Fe, B, and S were determined in the supernatant using ICAP 1100. The N content of plant tissue was determined by gas analysis of the combustion stream using a Leco 200 CNS analyzer (Leco Corp., St. Joseph, MI) (Kowalenko 2001).

In late October 2005, rose hips were harvested from all previously measured plants in the experiment. All hips produced by each plant were collected regardless of condition. All of the rose hips from each of the plants were placed into labelled Ziploc® bags and stored in a freezer in the UPEI Biology department for further analysis. In December 2005, the rose hips from each plant were graded as marketable or unmarketable (failed to set, or rotten), counted and then weighed to determine biological yields. The cause of rose hips that failed to set properly or that appeared rotten was not investigated in this study.

A second analysis was conducted in June 2006 using the stored rose hips. The top yielding plant (total number of hips) from each plot was used to assess treatment effects on physical rose hip properties. Effects of storage on hip mass were first assessed by weighing each bag of hips after 9 months of storage in a Woods Custom® chest freezer at -18 °C and then comparing to the mass before storage. Ten rose hips from each plant were randomly selected and had mass, equatorial length and polar length recorded. Hips were then placed in a Stabil-Therm® constant temperature cabinet at 80 °C for 24 hours to allow for desiccation (Blue M Electric Co., Blue Island, IL). Dry weights for each sample of 10 hips were later determined.

2.2.5 Statistical Analysis

Testing for statistical significance of treatments used in experiments # 1 and #2, and significance of interactions between treatments was achieved using a General Linear Model (GLM). The key element of this approach is to describe any given model in terms

of its link function and variance functions. The variance function describes the relationship between the mean and the variance of the dependent variable. This allows the proper calculation of the variance (and everything that depends on it) under non-normal conditions (Nelder and WedderBurn 1972). The link function describes the (usually) non-linear relationship between the mean of the dependent variable and the linear right hand side (Nelder and WedderBurn 1972). The GLM may have nonconstant variances for the response variables, making tests for normality unnecessary. (Neter et al. 1996). Values for all response variables in each experiment were averaged by plot to minimize extreme values caused by individual plant differences, thereby reducing artificial treatment effects. Measurements recorded for shoot lengths, shoot diameters, and number of branches per shoot were averaged first for each plant, and then by plot. Tukey's method of multiple comparisons was used to compare all possible pairs of level means for the specified factors. All statistical analyses were conducted using Minitab (version 14) statistical software.

2.3 Experiment #2

2.3.1 Location of Experiment

The second experiment was established at MacPhail Farms, in Argyle Shore (46°10'N, 63°20'W), Prince Edward Island. Experiment #2 was a commercial grower experiment, created in consultation with the site owner (regarding experiment location, size limitations, etc.). This site was created to fufill intial project funding agreements that stipulated the creation of commercial grower trials in Atlantic Canada. The site used was

south of the main road (Rt.19) in a large, level field with little wind protection offered, situated close to the shore of the Northumberland Strait (Figure 2.4). Experiment #2 was established at the northern end of the field and extended ≈ 50 m along the western border and ≈ 60 m across the field. This site had been in year 3 of a three year rotation for potato production (year 1 grain, year 2 underseed to clover, year 3 potato) the previous year.

2.3.2 Experimental Design

The experimental design for this experiment was a 3 x 2 factorial in a randomized split-block design (Gomez and Gomez 1984) with eight replicates in 2004 (Figure 2.5). There were six different treatments in each block in 2004. A "guard row" was established on each side of the entire trial to eliminate potential edge effects on measured plants. The plants used for the guard rows were propagated from *R. virginiana* rootstock at the provincial tree nursery (nursery stock). No data were collected from these guard rows. There was ≈ 5 m between blocks and at each headland which was seeded, allowing for movement of plot equipment and maintenance. Each plot consisted of a single row of 10 plants, with 0.9 m between each plant. A total of 31 different selections were used to plant experiment #2; all selections were from sites in Prince Edward Island (Table 2.5).

In 2004, experiment #2 consisted of 2 factors: in-row mulch (none, straw, bark) and inter-row (tilled, sod) (Table 2.6). The experimental design was altered in 2005 to include in-row fertility (none, fertilizer). In 2004, all plants were established without fertilizer; by adding the fertilizer treatment in 2005 it became possible to assess the

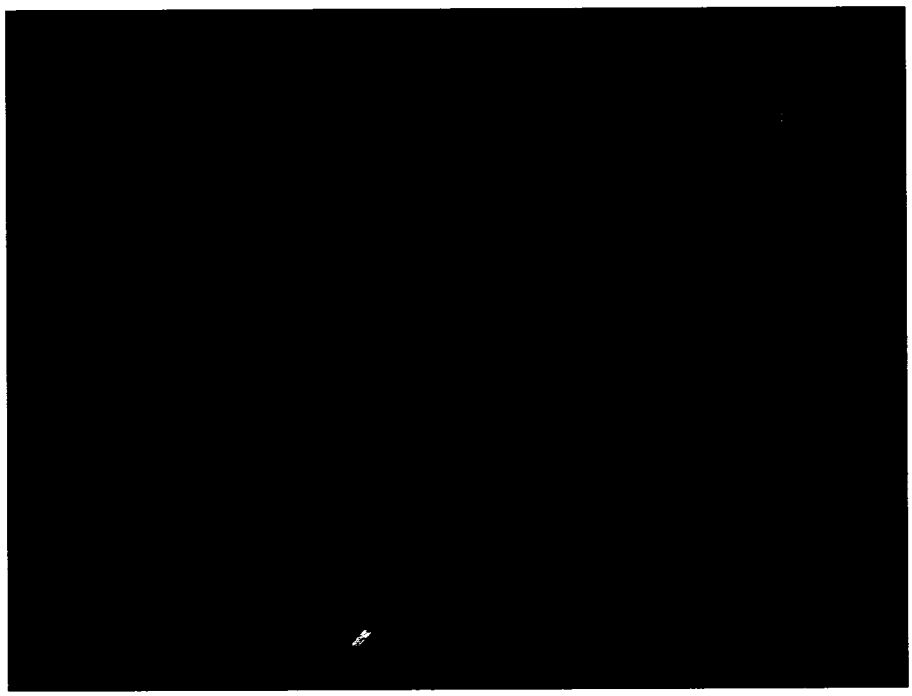

Figure 2.4 A photograph of experiment #2, located in Argyle Shore, PEI, 2005.

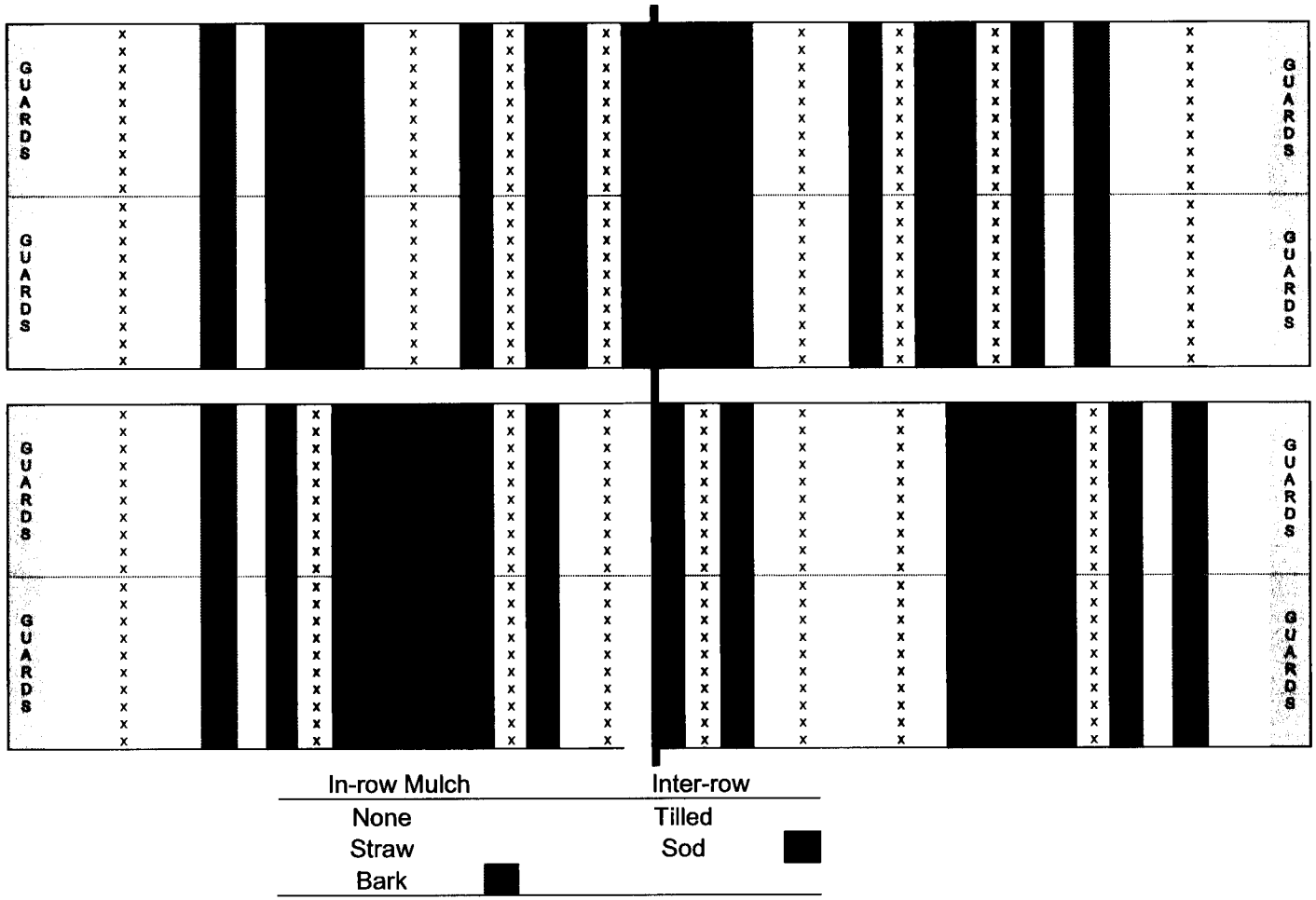

Figure 2.5 Field plan for experiment #2 in 2004, showing applied treatments for each plot of 10 plants. Each treatment was a combination of two test factors: in-row mulch (none, straw, bark), and inter-row (tilled, sod). A randomized split-block design was used with eight replicates of each of the 6 treatments.

Table 2.5 Original collection site numbers, locations (including longitude and latitude in decimal degrees), and number of plants used to plant experiment #2.

Site Number	Site Location	Longitude	Latitude	Plants Used
2	Blooming Point	62.94709	46.42038	5
4	Blooming Point	62.94918	46.41901	18
8	Greenwich	62.64578	46.44972	6
9	Greenwich	62.64586	46.44980	4
10	Tea Hill	63.06324	46.20640	4
11	Tarantum	62.94110	46.29269	19
13	Tarantum	62.94332	46.30037	72
17	York	63.10257	46.31761	34
18	York	63.10233	46.31754	24
19	York	63.09248	46.31484	44
22	Five Houses	62.53109	46.40897	34
23	St. Peter's	62.53846	46.40991	15
24	St. Peter's	62.53331	46.40873	8
26	Brackley Beach	63.20035	46.42286	14
28	St. Peter's Harbour	62.73174	46.41746	7
29	St. Peter's Harbour	62.73122	46.42177	8
30	Douglas Rd.	62.82985	46.38226	16
31	Tea Hill	63.06603	46.20179	12
32	Pisquid River	62.85810	46.33812	9
33	Mt. Herbert	63.04497	46.23622	17
34	Mt. Herbert	63.04511	46.22987	6
35	Meadowbank Rd.	63.24641	46.19845	5
37	Clyde River Rd.	63.26220	46.21817	8
43	McAllar Rd.	64.18148	46.65036	3
47	Cardigan	62.59545	46.27129	40
49	West Cape	64.40840	46.65837	12
50	Hampton	63.46317	46.21162	21
51	Murray River	62.61666	46.01105	3
52	Murray River	62.62189	46.00642	5
53	Monaghan Rd.	62.87426	46.21541	2
55	Greenwich	62.64389	46.49900	5

Table 2.6 Management treatments for experiment #2, 2004. Each treatment was a combination of two test factors: in-row mulch (none, straw or bark) and inter-row (tilled or sod).

Treatment Number	Mulch	Inter-row
1	None	Tilled
2	None	Sod
3	Straw	Tilled
4	Straw	Sod
5	Bark	Tilled
6	Bark	Sod

impact of fertilizer applications applied later in commercial site establishment. Consequently, the experimental design became a 3 x 2 x 2 factorial in a randomized split-block design (Gomez and Gomez 1984) with four replicates in 2005, resulting in 12 different treatments in each block (Table 2.7; Figure 2.6).

Experiment #2 was cultivated and planted on June 29th, 2004. Mulch treatments were applied on July 5th, 2004 and inter-row sod treatments were seeded on August 4th, 2004. Both mulches and inter-row treatments were applied and maintained using the protocol described for experiment #1. The fertilizer used in experiment #2 was the same used for experiment #1 in 2005 (10-10-10), and was applied using the same protocol on May 25th, 2005. The plots were not irrigated.

2.3.3 Data Collection and Statistical Analysis

All data were collected and analyzed following the procedures outlined for experiment #1. A total of 192 rose plants were used for data collection from experiment #2. Soil and leaf samples were collected on August 3rd, 2005. In late October 2005, rose hips were harvested from all previously measured plants in this experiment.

Table 2.7 Management treatments for experiment #2, 2005. Each treatment was a combination of three test factors: in-row mulch (none, straw or bark), in-row fertility (none or fertilizer), and inter-row (tilled or sod).

Treatment Number	Mulch	Fertility	Inter-row
1	None	None	Tilled
2	None	None	Sod
3	None	Fertilizer	Tilled
4	None	Fertilizer	Sod
5	Straw	None	Tilled
6	Straw	None	Sod
7	Straw	Fertilizer	Tilled
8	Straw	Fertilizer	Sod
9	Bark	None	Tilled
10	Bark	None	Sod
11	Bark	Fertilizer	Tilled
12	Bark	Fertilizer	Sod

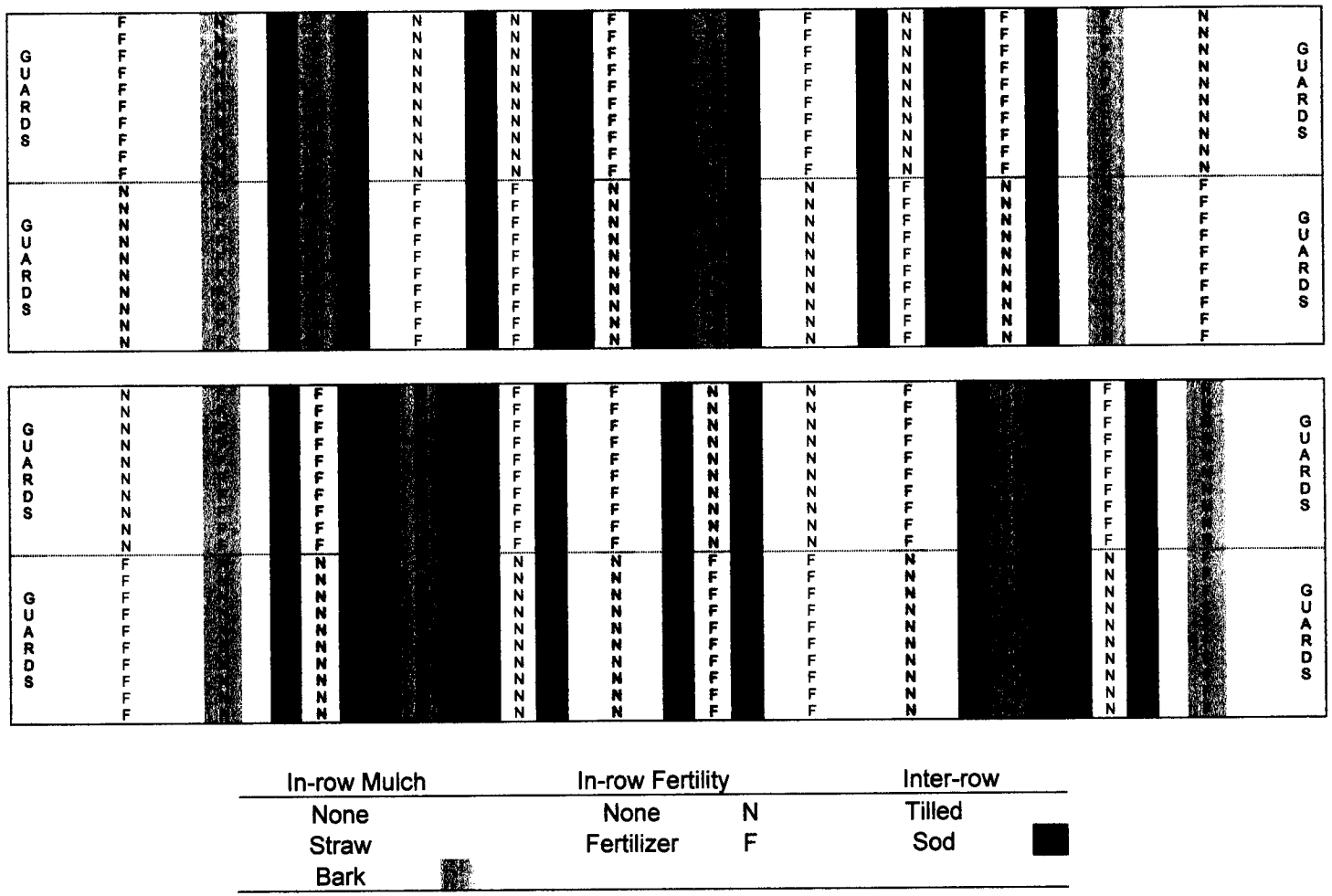

Figure 2.6 Field plan for experiment #2 in 2005, showing applied treatments for each plot of 10 plants. Each treatment was a combination of three test factors: in-row mulch (none, straw, bark), in-row fertility (none, fertilizer), and inter-row (tilled, sod). A randomized split-block design was used with four replicates of each of the 12 treatments.

CHAPTER 3:

Results

3.0 RESULTS

3.1 Experiment #1

3.1.1 Plant Growth and Development in 2004

In 2004, the shoot length (length of the longest shoot) averaged 18 ± 0.4 cm and 27 ± 0.8 cm for July and September, respectively and was not affected by treatments (Tables 3.1, 3.2). Shoot diameter (diameter of the longest shoot) averaged 3.3 ± 0.06 mm and 5.0 ± 0.11 mm for July and September, respectively (Table 3.1). Mulching significantly affected the mean diameter of the longest shoot recorded in September only (Table 3.2). Shoot diameter was significantly greater in plots with no mulch compared to plots with the straw or bark mulches. Straw and bark mulched plots did not differ significantly. Total number of shoots per plant was 1.8 ± 0.05 and 2.6 ± 0.09 in July and September, respectively (Table 3.1). Mulching also significantly affected the number of shoots per plant in July and September. The bark mulch decreased the total number of shoots compared to no mulch in July and September; however, straw mulch was intermediate and not different from no mulch and bark mulch. Fertility and inter-row treatments did not affect response variables (Table 3.2).

3.1.2 Plant Growth and Development in 2005

In 2005, shoot length averaged 24 ± 0.5 cm and 40 ± 1.0 cm for May and September, respectively (Table 3.3). Shoot lengths increased more in plots with the straw mulch than in the plots with no mulch or bark mulch (Table 3.3). A greater increase in shoot length was also seen in plots with fertilizer compared to plots with compost or no

Table 3.1 Mean values for plant growth variables for experiment #1 (July and September, 2004; n = 72) separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Shoot Length (cm)		Shoot Diameter (mm)		Shoots per Plant		
Treatment	July	Sept	July	Sept	July	Sept	Change
Mulch							
None	17	29	3.4	5.7 **a**[1]	2.0 **a**	2.7 **a**	0.7
Straw	19	27	3.2	4.7 **b**	1.7 **ab**	2.3 **ab**	0.6
Bark	18	26	3.2	4.7 **b**	1.6 **b**	2.1 **b**	0.5
SEM[2]	0.6	1.4	0.09	0.16	0.08	0.15	.08
Fertility							
None	19	27	3.4	5.1	1.7	2.5	0.8
Compost	18	27	3.3	4.9	1.8	2.7	0.9
Fertilizer	17	28	3.2	5.1	1.8	2.7	0.8
SEM	0.6	1.4	0.09	0.16	0.09	0.15	.09
Inter-row							
Tilled	17	26	3.2	5.0	1.8	2.7	0.9
Sod	19	28	3.4	5.1	1.8	2.5	0.7
SEM	0.5	1.1	0.08	0.13	0.07	0.12	.07
Grand Mean	18	27	3.3	5	1.8	2.6	0.8
SEM	0.4	0.8	0.06	0.11	0.05	0.09	0.06

[1] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.
[2] Standard error of the mean

Table 3.2 Significance of test factors and their interactions on plant growth variables for experiment #1 (July and September, 2004; n = 72), using a General Linear Model analysis of variance

Test Factor	Degrees of Freedom	Shoot Length (cm), July	Shoot Length (cm), Sept	Shoot Diameter (mm), July	Shoot Diameter (mm), Sept	Shoots per Plant, July	Shoots per Plant, Sept	Change in Shoots per Plant, July-Sept
Block	3	-	-	-	-	-	-	-
Mulch	2	-	-	-	***	*	*	-
Fertility	2	-	-	-	-	-	-	-
Inter-row	1	-	-	-	-	-	-	-
Mulch x Fertility	4	-	-	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-	-	-
Fertility x Inter-row	2	-	-	-	-	-	-	-
Mulch x Fertility x Inter-row	4	*	-	*	-	-	-	-
Error	51	-	-	-	-	-	-	-
Total	71	-	-	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

Table 3.3 Mean values for plant growth variables for experiment #1 (May and September, 2005; n = 72) separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Shoot Length (cm)			Shoot Diameter (mm)			Branches per Shoot		
Treatment	May	Sept	Change	May	Sept	Change	May	Sept	Change
Mulch									
None	24	37 **a**[1]	14 **a**	5.1	8.7	3.6 **a**	0.4	6.5	6.1
Straw	24	43 **b**	19 **b**	4.8	10.9	6.1 **b**	0.5	7.0	6.5
Bark	24	39 **ab**	15 **a**	4.7	10.8	6.0 **b**	0.5	7.2	6.6
SEM[2]	1.0	1.5	1.1	0.15	0.75	0.69	0.06	0.44	0.43
Fertility									
None	24	37 **a**	13 **a**	5.1	10.2	5.1	0.5 **a**	6.1 **a**	5.5 **a**
Compost	24	38 **a**	14 **a**	4.8	9.2	4.3	0.5 **a**	6.5 **a**	5.9 **a**
Fertilizer	24	43 **b**	20 **b**	4.7	11.0	6.2	0.3 **b**	8.1 **b**	7.8 **b**
SEM	1.0	1.5	1.1	0.15	0.75	0.69	0.06	0.44	0.43
Inter-row									
Tilled	23	42 **a**	19 **a**	4.8	11.2 **a**	6.4 **a**	0.4	7.5	7.1 **a**
Sod	25	37 **b**	13 **b**	4.9	9.0 **b**	4.0 **b**	0.5	6.3	5.8 **b**
SEM	0.8	1.2	0.9	0.1	0.61	0.56	0.05	0.40	0.35
Grand Mean	24	40	16	4.9	10.1	5.2	0.5	6.9	6.4
SEM	0.5	1.0	1.0	0.09	0.45	0.43	0.04	0.28	0.28

[1] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.
[2] Standard error of the mean

fertilizer treatment (Table 3.3). Plots with the tilled inter-row treatment had a greater increase in shoot lengths than those with the sod inter-row treatment (Table 3.3). The increase in shoot length from May to September was significantly affected by in-row mulch, in-row fertility and inter-row treatments (Table 3.4).

Shoot diameter averaged 4.9 ± .09 mm and 10.1 ± 0.45 mm in May and September, respectively (Table 3.3). The increase in shoot diameters was greater in plots with bark or straw mulch compared to plots with no mulch treatment (Table 3.3). Plants growing in plots with the tilled treatment saw a greater increase in shoot diameters than plants growing with the sod inter-row treatment (Table 3.3). In-row mulch and inter-row treatments significantly affected the increase in shoot diameters from May to September (Table 3.4).

The number of branches per shoot was 0.5 ± 0.04 and 6.9 ± 0.28 in May and September, respectively (Table 3.3). The increase in the number of branches per shoot was greater for the plots with fertilizer than for plots with compost or no fertilizer treatment (Table 3.3). Plants growing in plots with the tilled treatment saw an increase of 7.1 branches per shoot compared to 5.8 for plants with the sod inter-row treatment (Table 3.3). In-row fertility and inter-row treatments significantly affected the increase in the number of branches per shoot from May to September (Table 3.4). In-row mulch treatments had no effect on the increase in the number of branches per shoot (Table 3.4).

The average number of shoots per plant was 2.5 ± 0.09 in May and 3.8 ± 0.18 in September of 2005 (Table 3.5). None of the treatments in this experiment had a significant effect on the increase in number of shoots per plant from May to September (Table 3.6).

Table 3.4 Significance of test factors and their interactions on plant growth variables for experiment #1(May and September, 2005; n = 72), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	Shoot Length (cm), May	Shoot Length (cm), Sept	Change Shoot Length (cm)	Shoot Diameter (mm), May	Shoot Diameter (mm), Sept	Change Shoot Diameter (mm), May-Sept	Branches per Shoot, May	Branches per Shoot, Sept	Change in Branches per Shoot, May-Sept
Block	3	-	-	-	-	-	-	-	-	-
Mulch	2	-	*	**	-	-	**	-	-	-
Fertility	2	-	**	***	-	-	-	*	**	**
Inter-row	1	-	**	***	-	*	**	-	*	*
Mulch x Fertility	4	-	*	**	-	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-	-	-	-	-
Fertility x Inter-row	2	-	-	*	-	-	-	**	-	-
Mulch x Fertility x Inter-row	4	-	-	-	-	-	-	-	-	-
Error	51	-	-	-	-	-	-	-	-	-
Total	71	-	-	-	-	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

Table 3.5 Mean values for shoots per plant and plant spread, for experiment #1 (May and September, 2005; n = 72) separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Shoots Per Plant			Plant Spread (cm)		
Treatment	May	Sept	Change	May	Sept	Change
Mulch						
None	2.9 **a**[1]	4.1	1.2	29	75	46 **a**
Straw	2.5 **ab**	4.1	1.6	28	84	57 **b**
Bark	2.1 **b**	3.3	1.9	26	79	52 **ab**
SEM[2]	0.14	0.29	0.19	1.5	2.8	2.2
Fertility						
None	2.5	3.8	1.3	28	73 **a**	45 **a**
Compost	2.5	3.7	1.3	27	80 **ab**	53 **ab**
Fertilizer	2.6	4.0	1.5	29	85 **b**	56 **b**
SEM	0.14	0.29	0.19	1.5	2.8	2.2
Inter-row						
Tilled	2.6	4.0	1.4	28	86 **a**	58 **a**
Sod	2.4	3.7	1.3	27	73 **b**	45 **b**
SEM	0.11	0.24	0.16	1.3	2.3	1.8
Grand Mean	2.5	3.8	1.3	28	79	52
SEM	0.09	0.18	0.12	0.9	2.1	1.9

[1] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.
[2] Standard error of the mean

Table 3.6 Significance of test factors and their interactions on shoots per plant and plant spread for experiment #1(May and September, 2005; n = 72), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	Shoots per Plant, May	Shoots per Plant, Sept	Change in Shoots per Plant, May-Sept	Plant Spread (cm), May	Plant Spread (cm), Sept	Change Plant Spread (cm), May-Sept
Block	3	-	-	-	-	-	-
Mulch	2	**	-	-	-	-	**
Fertility	2	-	-	-	-	*	**
Inter-row	1	-	-	-	-	***	***
Mulch x Fertility	4	-	-	-	-	*	**
Mulch x Inter-row	2	-	-	-	-	*	**
Fertility x Inter-row	2	-	-	-	-	-	-
Mulch x Fertility x Inter-row	4	-	-	-	-	-	*
Error	51	-	-	-	-	-	-
Total	71	-	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

Plant spread averaged 28 ± 0.9 cm and 79 ± 2.1 cm in May and September, respectively (Table 3.5). Plant spreads increased more with straw mulch than no mulch; however, bark mulch was intermediate and not significantly different from no mulch or straw mulch (Table 3.5). Plant spreads were greater for plants with fertilizer than with no fertilizer treatment; however, compost was intermediate and not significantly different from the fertilizer or no fertilizer treatments (Table 3.5). Plant spreads also increased more in plots with the tilled treatment than with the sod inter-row treatment (Table 3.5). The increase in plant spread from May to September was significantly affected by in-row mulch, in-row fertility, and inter-row treatments (Table 3.6).

3.1.3 Rose Hip Yields

In 2005, approximately 85% of rose plants in experiment #1 produced flowers and consequently, rose hips. The flowering period (when a minimum of 5% of rose plants in both experiments had open flowers) began in the second week of July and lasted until mid-August. Total biological yield of rose hips per plant averaged 41 ± 3.0 g in experiment #1, of which 94% was deemed marketable (Table 3.7). Plants grown in plots with the fertilizer treatments produced almost twice the mass of hips per plant (61 g) as those with the compost (32 g), or no fertilizer (32 g) treatments (Figure 3.1). Yields of rose hips in experiment #1 were significantly affected by the in-row fertility treatments, but not by the in-row mulch or inter-row treatments (Table 3.8).

Table 3.7 Mean values for rose hip yield variables for experiment #1 (October, 2005; n = 72), separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Biological Yield (g)	Marketable Yield (g)	Total Hips	Percentage Rotten	Percentage Failed
Mulch					
None	43	41	41	2.9	6.4
Straw	43	40	39	5.0	3.5
Bark	38	36	34	5.6	4.0
SEM[1]	6.3	5.9	5.5	0.79	1.34
Fertility					
None	32 **a**[2]	30 **a**	30 **a**	5.1	5.4
Compost	32 **a**	30 **a**	31 **a**	3.9	4.1
Fertilizer	61 **b**	57 **b**	54 **b**	4.5	4.4
SEM	6.3	5.9	5.5	0.79	1.34
Inter-row					
Tilled	46	43	44	5.2	5.3
Sod	36	35	32	3.8	4.0
SEM	5.1	4.8	4.5	0.64	1.09
Grand Mean	41	39	44	5.3	5.7
SEM	3.0	2.8	3.4	0.57	0.97

[1] Standard error of the mean

[2] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.

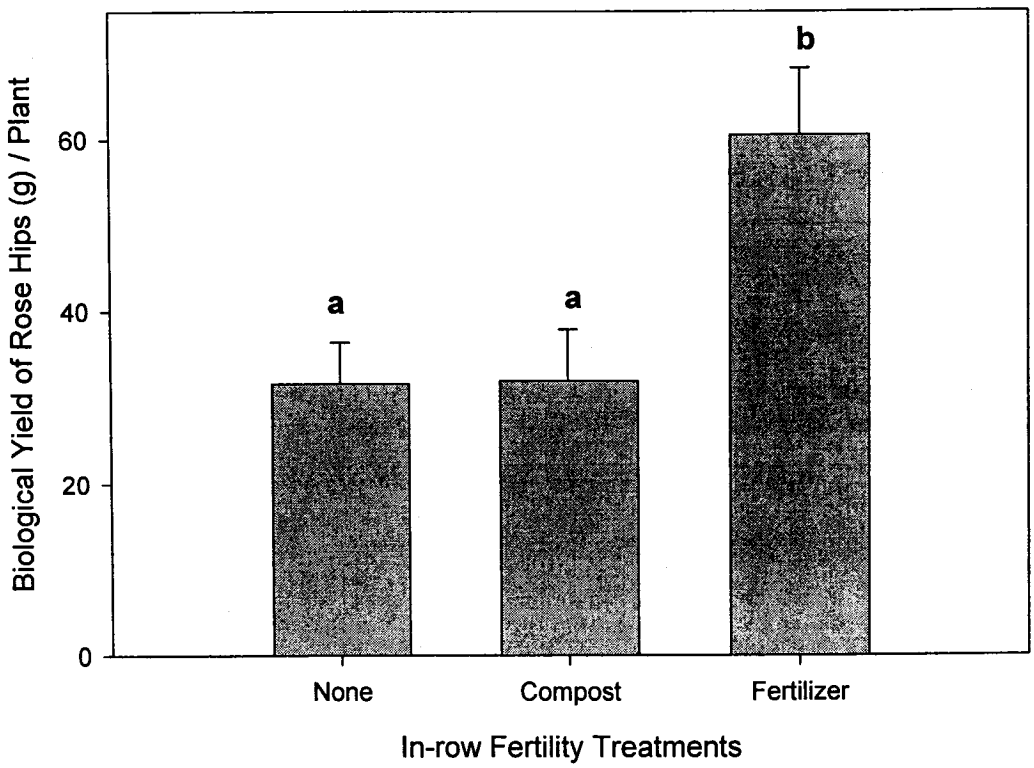

Figure 3.1 Total biological yield of rose hips for experiment #1 (October, 2005; n = 72), separated by fertility treatments using Tukey's method of multiple comparisons. Symbols *a* and *b* denote values of statistical significance between treatments, where *a* is significantly different from *b* at $p < 0.05$.

Table 3.8 Significance of test factors and their interactions on rose hip yield variables for experiment #1 (October, 2005; n = 72), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	Biological Yield (g) of Hips per Plant	Marketable Yield (g) of Hips per Plant	Total Number of Hips per Plant	Percentage Rotten	Percentage Failed
Block	3	-	-	-	-	-
Mulch	2	-	-	-	-	-
Fertility	2	**	**	**	-	-
Inter-row	1	-	-	-	-	-
Mulch x Fertility	4	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-
Fertility x Inter-row	2	-	-	-	-	-
Mulch x Fertility x Inter-row	4	-	-	-	-	-
Error	51	-	-	-	-	-
Total	71	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

3.1.4 Soil Analysis, Experiment #1

Soil pH, and concentrations of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in the soil were significantly affected by in-row fertility treatments in experiment #1 (2005; Table 3.9). Values for pH were higher for the compost than for the no fertilizer and fertilizer treatments (Figure 3.2). Soil concentrations of Mg were also higher for the compost than for the no fertilizer and fertilizer treatments (Figure 3.2). Compost treatments raised soil Ca concentrations to ≈1200 ppm, nearly twice the concentrations found in fertilizer (765 ppm) or no fertilizer (770 ppm) treatments. Values for P were significantly higher for the compost than for no fertilizer treatments; fertilizer treatments were intermediate (Figure 3.2). Inter-row treatments also significantly affected soil concentrations of P; levels of P were higher for tilled (159 ppm) than for sod treatments (150 ppm). Concentrations of K were significantly higher for the fertilizer than for the compost or no fertilizer treatments (Figure 3.3).

3.1.5 Tissue Analysis, Experiment #1

Both nitrogen (N) and phosphorus (P) content in rose leaf tissue were significantly affected by the applied treatments in experiment #1 (Table 3.10). N content was higher in plots with the straw mulch (2.5%) than in plots with no mulch (2.2%) or bark mulch (2.3%). N content was significantly lower in the fertilizer treatments (2.2%) than in the no fertilizer (2.4%) and compost (2.4%) treatments. P content was significantly higher for plants with sod inter-row (0.26%) than for those with the tilled (0.21%) treatments. Levels of K, Ca, and Mg in rose leaf tissue were not significantly affected by the applied treatments in this experiment (Table 3.10).

Table 3.9 Significance of test factors and their interactions on soil macronutrients for experiment #1 (2005; n = 72), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	pH	Potassium (K)	Phosphorus (P)	Calcium (Ca)	Magnesium (Mg)
Block	3	-	-	-	-	-
Mulch	2	-	-	-	-	-
Fertility	2	***	***	***	***	***
Inter-row	1	-	-	*	-	-
Mulch x Fertility	4	**	**	*	-	-
Mulch x Inter-row	2	-	-	-	*	*
Fertility x Inter-row	2	-	-	-	-	-
Mulch x Fertility x Inter-row	4	*	-	-	*	**
Error	51	-	-	-	-	-
Total	71	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

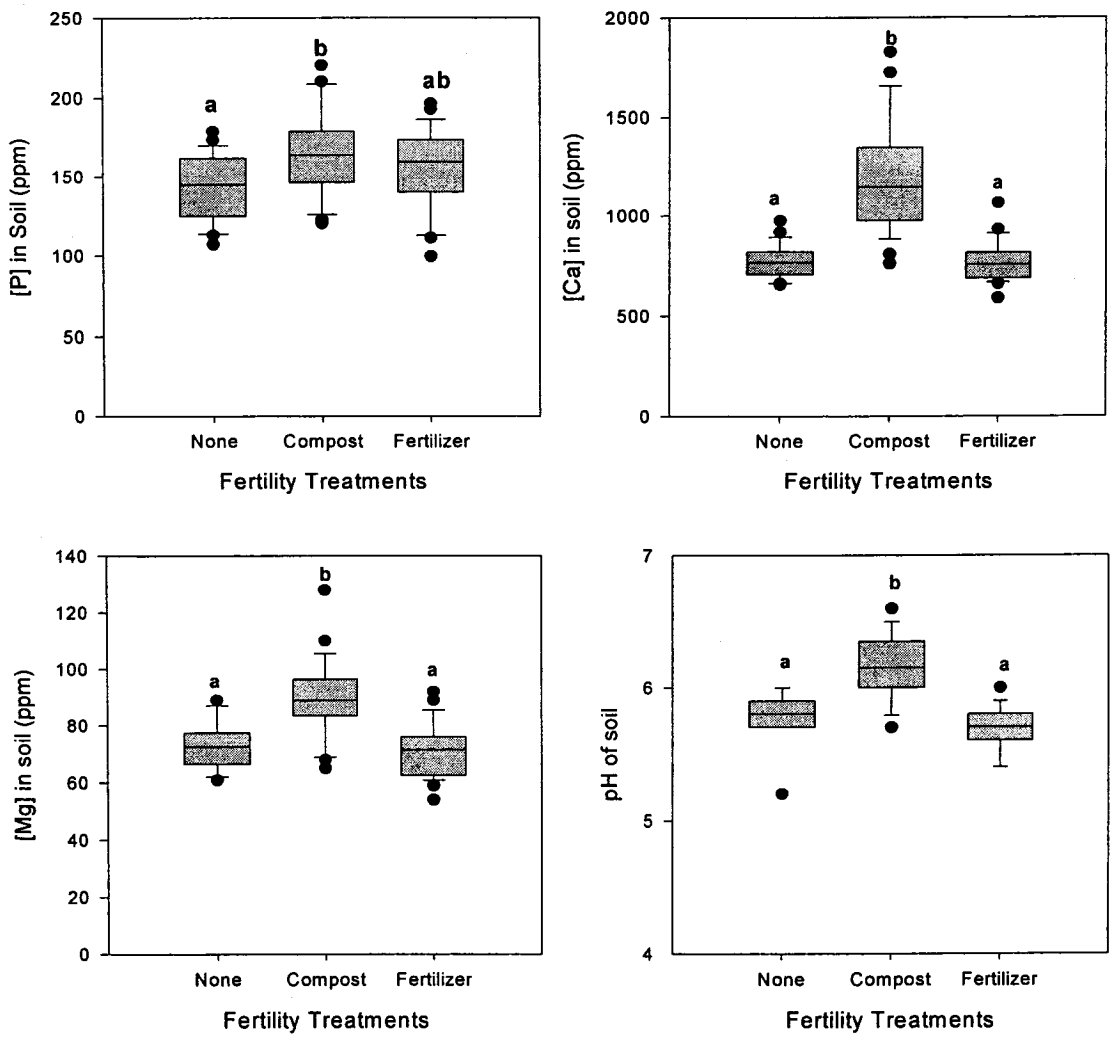

Figure 3.2 Soil pH, and concentrations of Phosphorus (P), Calcium (Ca), and Magnesium (Mg) in soil (ppm) for experiment #1 (2005; n = 72), separated by fertility treatments using Tukey's method of multiple comparisons. Symbols *a* and *b* denote values of statistical significance between treatments where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.

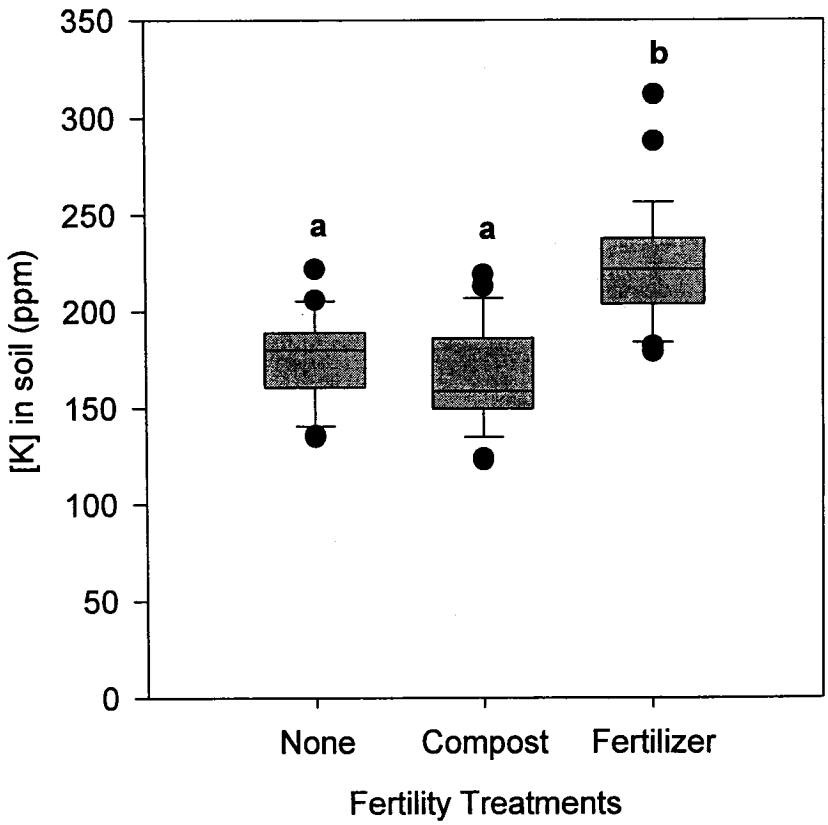

Figure 3.3 Concentration of potassium (K) in soil (ppm) for experiment #1 (2005; n = 72), separated by fertility treatments using Tukey's method of multiple comparisons. Symbols *a* and *b* denote values of statistical significance between treatments where *a* is significantly different from *b* at $p < 0.05$.

Table 3.10 Significance of test factors and their interactions on content (%) of macronutrients in rose leaf tissue for experiment #1 (2005; n = 72), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
Block	3	-	-	-	-	-
Mulch	2	***	-	-	-	-
Fertility	2	***	-	-	-	-
Inter-row	1	-	**	-	-	-
Mulch x Fertility	4	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-
Fertility x Inter-row	2	-	-	-	-	-
Mulch x Fertility x Inter-row	4	-	-	-	-	-
Error	51	-	-	-	-	-
Total	71	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

3.2 Experiment #2

3.2.1 Plant Growth and Development in 2004

In 2004, the shoot length averaged 18 ± 0.5 cm and 29 ± 1.1 cm for July and September, respectively and was not affected by treatment (Table 3.11). Shoot diameter (diameter of longest shoot) averaged 3.1 ± 0.07 mm and 4.8 ± 0.13 mm for July and September, respectively (Table 3.11). Total number of shoots per plant was 2.2 ± 0.08 and 2.7 ± 0.11 for July and September, respectively (Table 3.12). The total number of shoots per plant increased by 0.5 ± 0.06 from July to September, 2004 (Table 3.11). There were no significant treatment effects to report for experiment #2 in 2004.

3.2.2 Plant Growth and Development in 2005

In 2005, total shoot lengths were 24 ± 0.7 cm and 36 ± 1.2 cm for May and September, respectively (Table 3.12). Shoots were longer in plots with the tilled inter-row treatments than with the sod treatments (Table 3.12). The increase in shoot lengths from May to September was significantly affected by inter-row treatments only (Table 3.13). In-row mulch and fertility treatments had no significant effect on shoot lengths in experiment #2 (Table 3.13).

Shoot diameters were 4.3 ± 0.08 mm and 7.2 ± 0.22 mm in May and September, respectively (Table 3.12). Shoot diameters saw a greater increase in plots with bark mulch than in plots with straw mulch or no mulch treatments (Table 3.12). Shoot diameters increased more from May to September with the tilled treatments than with the sod inter-row treatments (Table 3.12). The increase in shoot diameters during this period

Table 3.11 Mean values for plant growth variables for experiment #2 (July and September, 2004; n = 48) separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Shoot Length (cm)		Shoot Diameter (mm)		Shoots per Plant		
Treatment	July	Sept	July	Sept	July	Sept	Change
Mulch							
None	17	28	3.1	4.9	2.3	2.8	0.5
Straw	18	33	3.0	4.7	2.1	2.4	0.3
Bark	19	27	3.0	4.8	2.1	2.8	0.7
SEM[1]	0.8	1.9	0.24	0.24	0.15	0.19	.10
Inter-row							
Tilled	18	29	3.1	4.9	2.1	2.6	0.5
Sod	18	29	3.0	4.7	2.2	2.7	0.5
SEM	0.6	1.5	0.19	0.20	0.12	0.16	.08
Grand Mean	18	29	3.0	4.8	2.2	2.7	0.5
SEM	0.5	1.1	0.07	0.13	0.08	0.11	0.06

[1] Standard error of the mean

Table 3.12 Mean values for plant growth variables for experiment #2 (May and September, 2005; n = 48) separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Shoot Length (cm)			Shoot Diameter (mm)			Branches per Shoot		
Treatment	May	Sept	Change	May	Sept	Change	May	Sept	Change
Mulch									
None	22 **a**[1]	35	12	4.4	6.8 **a**	2.4 **a**	0.5	7.2 **a**	6.7 **a**
Straw	27 **b**	37	10	4.1	6.8 **a**	2.6 **a**	0.5	7.3 **a**	6.8 **a**
Bark	24 **ab**	37	13	4.4	8.0 **b**	3.6 **b**	0.7	9.5 **b**	8.7 **b**
SEM[2]	1.2	1.4	1.2	0.14	0.28	0.25	0.12	0.47	0.49
Fertility									
None	24	36	11	4.3	7.4	3.1	0.5	7.7	7.2
Fertilizer	24	37	13	4.3	7.0	2.6	0.6	8.2	7.6
SEM	1.0	1.2	1.0	0.12	0.23	0.20	0.10	0.38	0.40
Inter-row									
Tilled	24	39 **a**	15 **a**	4.3	7.8	3.5 **a**	0.5	8.1	7.5
Sod	25	33 **b**	9 **b**	4.3	6.6	2.3 **b**	0.6	7.9	7.3
SEM	1.0	1.2	1.0	0.12	0.23	0.20	0.10	0.38	0.40
Grand Mean	24	36	12	4.3	7.2	2.9	0.6	8.0	7.4
SEM	0.7	1.2	1.1	0.08	0.22	0.20	0.07	0.30	0.30

[1] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.

[2] Standard error of the mean

Table 3.13 Significance of test factors and their interactions on plant growth variables for experiment #2 (May and September, 2005; n = 48), using a General Linear Model analysis of variance.

Test Factors	Degrees of Freedom	Shoot Length (cm), May	Shoot Length (cm), Sept	Change Shoot Length (cm), May-Sept	Shoot Diameter (mm), May	Shoot Diameter (mm), Sept	Change Shoot Diameter (mm), May-Sept	Branches per Shoot, May	Branches per Shoot, Sept	Change in Branches per Shoot, May-Sept
Block	3	-	-	-	-	-	-	-	-	-
Mulch	2	*	-	-	-	**	**	-	**	**
Fertility	1	-	-	-	-	-	-	-	-	-
Inter-row	1	-	**	***	-	**	***	-	-	-
Mulch x Fertility	2	-	-	-	-	-	-	-	-	-
Mulch x Inter-row	2	-	**	**	-	-	-	-	-	-
Fertility x Inter-row	1	-	-	-	-	-	-	-	-	-
Mulch x Fertility x Inter-row	2	-	-	-	-	-	-	-	-	-
Error	33	-	-	-	-	-	-	-	-	-
Total	47	-	-	-	-	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

was significantly affected by in-row mulch and inter-row treatments (Table 3.13). In-row fertility treatments did not significantly affect the increase in shoot diameters for experiment #2 (Table 3.13).

The total number of branches per shoot was 0.6 ± 0.07 and 8.0 ± 0.30 in May and September, respectively (Table 3.12). The increase in branches per shoot was greater in the bark mulch treatments than in the straw or no mulch treatments (Table 3.12). Treatments with straw mulch and no mulch were not significantly different (Table 3.12). In-row mulch treatments significantly affected the increase in total number of branches per shoot from May to September (Table 3.13). In-row fertility and inter-row treatments did not affect the increase in the number of branches per shoot (Table 3.13).

The number of shoots per plant was 2.8 ± 0.12 and 6.0 ± 0.45 in May and September, respectively (Table 3.14). The plots with fertilizer had an increase of 4.2 shoots per plant which was considerably higher than the increase of 2.1 shoots per plant in the plots with no fertilizer. Plants in the tilled inter-row treatments saw a greater increase (3.7) in shoots per plant than the plants in the seeded inter-row treatments (2.7). Both in-row fertility and inter-row treatments significantly affected the change in the number of shoots per plant from May to September; in-row mulch had no effect on the number of shoots per plant (Table 3.15).

Plant spread was 32 ± 1.5 cm and 93 ± 3.4 cm in May and September, respectively (Table 3.14). The increase in plant spread was higher with the straw and bark mulches than with no mulch (Table 3.14). The increase in plant spread for plots with fertilizer was greater than that found in plots with no fertilizer (Table 3.14). Plants with tilled inter-row treatments had larger increases in plant spread from May to September

Table 3.14 Mean values for shoots per plant and plant spread for experiment #2 (May and September, 2005; n = 48) separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Shoots Per Plant			Plant Spread (cm)		
Treatment	May	Sept	Change	May	Sept	Change
Mulch						
None	3.0	6.2	3.3	34	83	49 **a**[1]
Straw	2.7	6.0	3.1	30	99	66 **b**
Bark	2.9	5.9	3.0	34	98	65 **b**
SEM[2]	0.23	0.65	0.57	2.7	4.7	3.3
Fertility						
None	2.8	5.0 **a**	2.1 **a**	30	87 **a**	54 **a**
Fertilizer	2.9	7.1 **b**	4.2 **b**	35	100 **b**	66 **b**
SEM	0.19	0.53	0.47	2.2	3.8	2.7
Inter-row						
Tilled	3.0	6.8 **a**	3.7	32	104 **a**	83 **a**
Sod	2.7	5.2 **b**	2.5	33	70 **b**	50 **b**
SEM	0.19	0.53	0.47	2.2	3.8	2.7
Grand Mean	2.8	6.0	3.1	32	93	60
SEM	0.12	0.45	0.39	1.5	3.4	2.8

[1] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.
[2] Standard error of the mean

Table 3.15 Significance of test factors and their interactions on shoots per plant and plant spread for experiment #2 (May and September, 2005; n = 48), using a General Linear Model analysis of variance.

Factor	Degrees of Freedom	Shoots per Plant, May	Shoots per Plant, Sept	Change in Shoots per Plant, May-Sept	Plant Spread (cm), May	Plant Spread (cm), Sept	Change Plant Spread (cm), May-Sept
Block	3	-	-	-	-	-	-
Mulch	2	-	-	-	-	*	**
Fertility	1	-	**	**	-	*	**
Inter-row	1	-	*	-	-	***	***
Mulch x Fertility	2	-	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-	-
Fertility x Inter-row	1	-	-	-	-	-	-
Mulch x Fertility x Inter-row	2	-	*	*	-	-	-
Error	33	-	-	-	-	-	-
Total	47	-	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

than did plants in the sod treatments (Table 3.14). In-row mulch, in-row fertility, and inter-row treatments significantly affected the increase in plant spread from May to September, 2005 (Table 3.15).

3.2.3 Rose Hip Yields

In 2005, approximately 85% of rose plants in experiment #2 produced flowers and consequently, rose hips. The flowering period (when a minimum of 5% of rose plants in both experiments had open flowers) began in the second week of July and lasted until mid-August. Total biological yield of rose hips per plant in experiment #2 was 73 ± 5.1 g, of which 86% was deemed marketable (Table 3.16). Yield per plant was higher in plots with the tilled treatments than in plots with the sod inter-row treatments (Table 3.16). Yields were significantly affected by inter-row treatments, but not by in-row mulch or fertility treatments (Table 3.17).

3.2.4 Soil Analysis

Soil pH was significantly affected by in-row mulch and in-row fertility treatments in experiment #2 (Table 3.18). Soil pH was higher for bark mulch (5.0) than for no mulch (4.8) or straw mulch (4.8). Soil pH was lower for fertilizer (4.7) than for the no fertilizer treatments (5.0) (Figure 3.4). Soil concentrations of Potassium (K) were also significantly affected by in-row fertility treatments; higher concentrations of K were found for the fertilizer treatments than for the no fertilizer treatments (Figure 3.4). Concentrations of Phosphorus (P), Calcium (Ca) and Magnesium (Mg) were not significantly affected by

Table 3.16 Mean values for rose hip yield variables for experiment #2 (October, 2005; n = 48), separated by treatments using a General Linear Model analysis of variance followed by Tukey's method of multiple comparisons.

	Biological Yield (g)	Marketable Yield (g)	Total Hips	Percent Rotten	Percent Failed
In-row Mulch					
None	62	53	39	5.2	0.0
Straw	69	59	52	7.5	0.5
Bark	87	76	62	5.8	0.7
SEM[1]	11.0	10.3	7.3	0.89	0.20
In-row Fertility					
None	67	58	47	3.7	0.3
Fertilizer	79	67	55	8.6	0.5
SEM	9.0	8.4	6.0	0.73	0.16
Inter-row					
Tilled	88 **a**[2]	76 **a**	58	8.0	0.6
Sod	58 **b**	50 **b**	44	4.4	0.2
SEM	9.0	8.4	6.0	0.73	0.16
Grand Mean	73	63	63	7.5	0.4
SEM	5.1	4.7	5.5	0.80	0.13

[1] Standard error of the mean

[2] Symbols *a* and *b* denote values of statistical significance between treatments within a test factor (Mulch, Fertility, and Inter-row), where *a* is significantly different from *b* at $p < 0.05$. Symbol *ab* denotes a value that is neither significantly different than *a* or *b*.

Table 3.17 Significance of test factors and their interactions on rose hip yield variables for experiment #2 (October, 2005; n = 48), using a General Linear Model analysis of variance.

Test Factors	Degrees of Freedom	Biological Yield (g) of Hips per Plant	Marketable Yield (g) of Hips per Plant	Total Number of Hips per Plant	Percentage Rotten	Percentage Failed
Block	3	-	-	-	-	-
Mulch	2	-	-	-	-	-
Fertility	1	-	-	**	-	-
Inter-row	1	*	*	-	-	-
Mulch x Fertility	2	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-
Fertility x Inter-row	1	-	-	-	-	-
Mulch x Fertility x Inter-row	2	-	-	-	-	-
Error	33	-	-	-	-	-
Total	47	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

Table 3.18 Significance of test factors and their interactions on soil concentrations of macronutrients for experiment #2 (2005; n = 48), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	pH	Phosphorus (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
Block	3	-	-	-	-	-
Mulch	2	*	-	-	-	-
Fertility	1	***	-	***	-	-
Inter-row	1	-	-	-	-	-
Mulch x Fertility	2	-	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-
Fertility x Inter-row	1	-	-	-	-	-
Mulch x Fertility x Inter-row	2	-	-	-	-	-
Error	33	-	-	-	-	-
Total	47	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

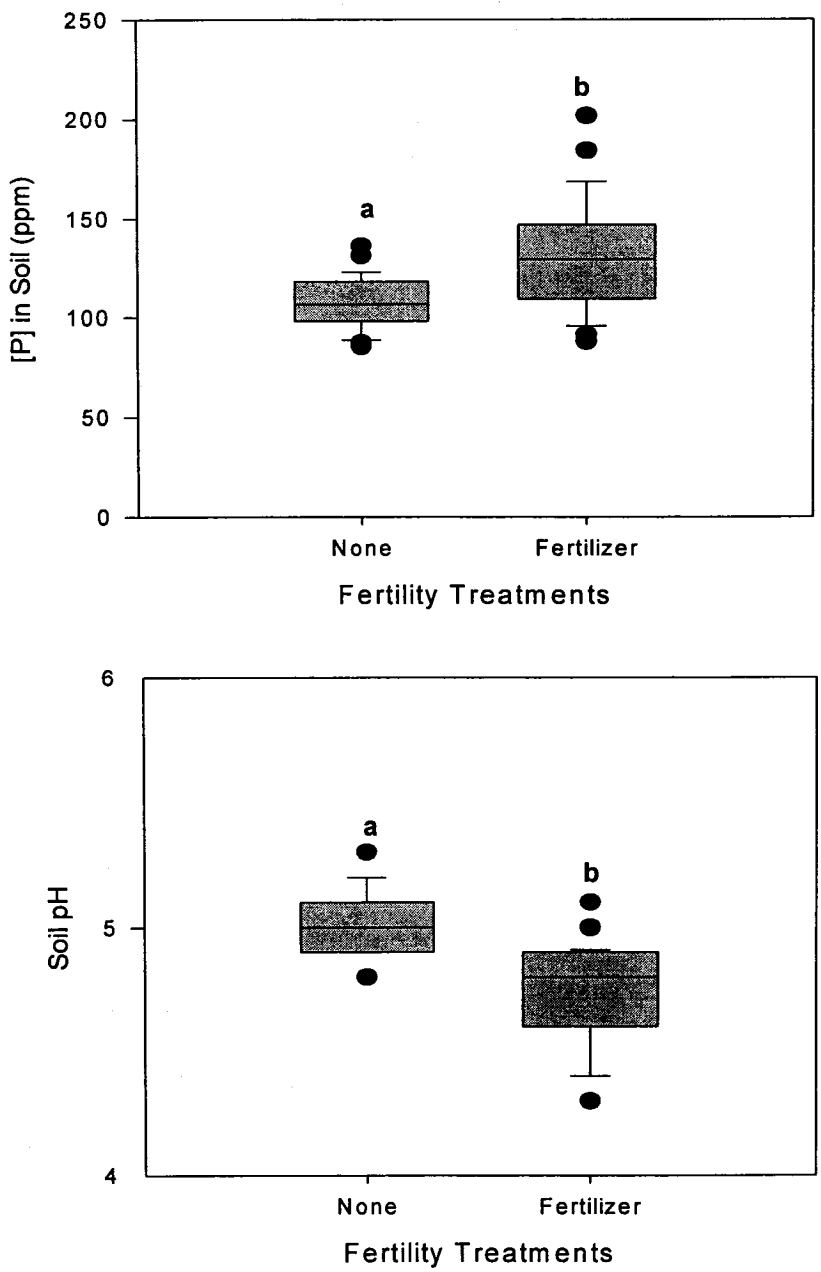

Figure 3.4 Soil pH and concentration of Potassium (K) in soil (ppm) for experiment #2 (2005; n = 48), separated by fertility treatments using Tukey's method of multiple comparisons. Symbols *a* and *b* denote values of statistical significance between treatments where *a* is significantly different from *b* at $p < 0.05$.

treatments in experiment #2 (Table 3.18).

3.2.5 Tissue Analysis

Concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in rose leaf tissue were significantly affected by treatment factors in experiment #2 (Table 3.19). N content was higher for plants with straw mulch (2.7%) than for those with bark mulch treatments (2.4%); the no mulch treatment was intermediate. N content was also higher for plants with fertilizer than for those with no fertilizer treatment (Figure 3.5). Leaf tissue concentrations of P were significantly affected by inter-row treatments; P content was higher for plants with the sod treatments (0.26%) than for those with the tilled treatments (0.23%). In-row mulch treatments had an effect on concentrations of K found in rose leaf tissue; plants growing with bark mulch (1.1%) had higher concentrations of K than those with no mulch (1.0%); straw mulch was intermediate. Concentrations of Ca and Mg in leaf tissue were significantly lower for plants with fertilizer than for those with no fertilizer (Figure 3.5).

3.3 Rose Hip Physical Qualities

The measured masses of rose hips sampled from experiment #1 ranged from 0.7 - 2.5 g, with a mean of 1.3 g (Table 3.20). Masses after desiccation at 80°C for 24 hours ranged from 0.31-1.00 g, with a mean of 0.54 g. The mean percentage of water in the rose hips was calculated to be 56%. Mean equatorial and polar lengths were 14 mm and 12 mm, respectively. Mean equatorial: polar length ratio was 1.15.

Table 3.19 Significance of test factors and their interactions on concentrations of macronutrients (%) in rose leaf tissue for experiment #2 (2005; n = 48), using a General Linear Model analysis of variance.

Test Factor	Degrees of Freedom	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
Block	3	-	-	-	-	-
Mulch	2	**	-	**	-	-
Fertility	1	***	-	-	**	**
Inter-row	1	-	*	-	-	-
Mulch x Fertility	2	*	-	-	-	-
Mulch x Inter-row	2	-	-	-	-	-
Fertility x Inter-row	1	*	-	-	-	-
Mulch x Fertility x Inter-row	2	-	-	-	-	-
Error	33	-	-	-	-	-
Total	47	-	-	-	-	-

- = no significant effect
* = $0.05 < p < 0.01$
** = $0.01 \leq p < 0.001$
*** = $p \leq 0.001$

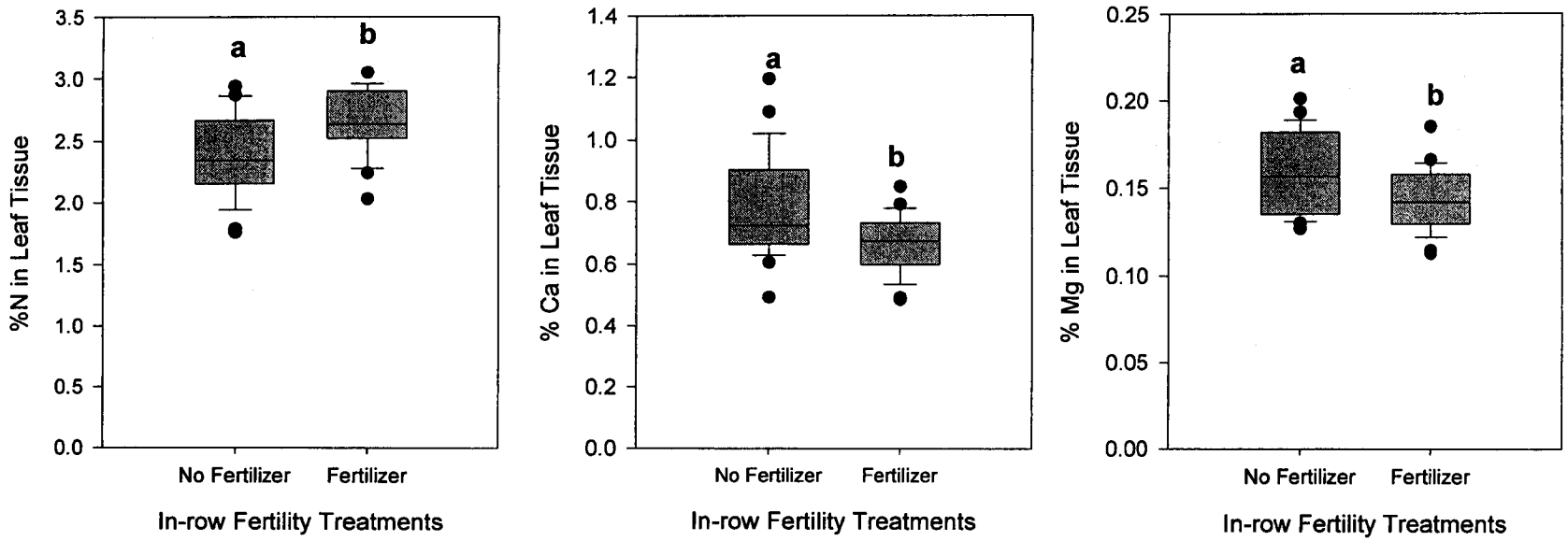

Figure 3.5 Percentage (%) of Nitrogen (N), Calcium (Ca), and Magnesium (Mg) in rose leaf tissue in experiment #2 (2005; n=48) separated by fertility treatments using Tukey's method of multiple comparisons. Symbols *a* and *b* denote values of statistical significance between treatments where *a* is significantly different from *b* at $p < 0.05$.

Table 3.20 Mean values for rose hip physical properties from hips in experiment #1. Each sample consisted of 10 ripened rose hips (n = 72) that were measured and weighed, then dried at 80°C and weighed again.

Response	Mean	Standard. Deviation	Minimum	Maximum
Whole Mass (g)	1.3	0.30	0.7	2.5
Dried Mass (g)	0.54	0.120	0.31	1.00
% Dry Weight	44	4.2	36	59
Equatorial Length (mm)	14	1.7	11	24
Polar Length (mm)	12	1.2	9	16
Equatorial: Polar Length	1.2	0.13	0.9	1.9

CHAPTER 4:

Discussion

4.0 DISCUSSION

4.1 Introduction

In general, the results from this study showed that wild roses responded very well to agricultural management. There was excellent survival of wild plants after transplanting, with only 2 deaths from the more than 1300 rose plants grown in these experiments. Regardless of the original collection source of wild plants, all plants displayed a similar growth pattern with few phenotypic differences when planted in agricultural fields in Prince Edward Island. When these wild plants were removed from their natural habitat and grown in an agricultural setting, they established well and most began rose hip production in their second season, earlier than in published reports from other countries. In 2005, flowering of rose plants in both experiments started during the second week of July and lasted until the second week of August. The majority of rose plants ($\approx$ 85%) in both experiments produced flowers, and most flowers developed into marketable rose hips.

Although there are no published reports on the longevity of wild rose species, the creation of a rose hip plantation is undoubtedly a long-term venture. The rose plants used in this study are expected to reach full yielding potential only after four or more years of non-irrigated growth (Joublan and Rios 2005; Uggla and Martinsson 2005). The results of this study should be considered with this in mind; treatment effects on rose hip yield might be more or less appreciable in subsequent years. The knowledge gained from this research will be a part of a long term project for establishing wild roses as an alternative agricultural crop for Atlantic Canada.

4.2 Comparing Results from Experiments #1 and #2

An important difference to note when comparing the results from each experiment was the greater number of rose selections used in experiment #2 (31), than in experiment #1 (8). This larger number of rose selections may explain why experiment #2 had higher values for variability (SEM) for almost all measured responses when compared to experiment #1. The smaller sample size for experiment #2 (n = 48) than for experiment #1 (n = 72) may have also contributed to the difference. The location of the experiments was also different; experiment #1 was located inland, in a sheltered field while experiment #2 was located in a coastal area, open on all sides and exposed to the wind. Soil conditions and microclimates at each site are expected to have influenced rose plant growth and development.

To gain a clearer perspective of how the soil conditions in each experiment differed from each other and from conditions found in wild rose natural habitats, soil analyses from untreated plots in experiments #1 and #2 were compared with those from 10 wild rose collection sites. The soil from the collection sites was tested for pH and nutrient content in a previous study of wild roses in Prince Edward Island by Victoria MacPhail (2004). Plant material from these same collection sites was also used to plant the experiments in this study. Statistics were not used for comparisons as only four samples were available from each of the experiments. Soil pH and macronutrient levels were classified as low, medium , or high, using soil ratings developed by the provincial Soil and Feed Testing Laboratory (PEI Department of Agriculture and Forestry, Charlottetown) for strawberries, raspberries, and trees.

There was a difference in soil pH between the two experiment sites; mean soil pH in experiment #2 was 5.0, 0.8 units lower than the mean value for experiment #1 (Table 4.1). Mean soil pH in wild collection sites was intermediate at 5.4. Levels of P and K in both experiments were higher (high) than those found at wild collection sites (medium). Concentrations of Ca and Mg were roughly the same (low) in the experiments and at wild collection sites (Table 4.1). The high concentrations of P and K found in agricultural soils may offer a benefit to the growing rose plants not found in their natural habitat. The lower pH of the soil in experiment #2 could have been a by-product of recent potato production at that site in 2003. Soil pH of potato fields in Prince Edward Island are often lowered to reduce incidences of potato scab, a common agricultural problem. It is expected that the removal of competiton by weed species through regular field maintenance would be another boon for rose plant growth. Although the analysis of treatment effects on response variables for experiments #1 and #2 were analyzed separately, they are discussed together here.

4.3 Mulching

The benefits of mulching crops have been well documented. Mulches positively affect the growth and yield of crop plants by maintaining more uniform soil temperatures, increasing the amount of stored moisture, and decreasing competition by weed species (Darrow and Magness 1938; Unger 1988; Trinka and Pritts 1992; Kimak et al., 2001). It was hypothesized that straw and bark mulches would increase the size of rose plants (total number of shoots per plant, length and diameter of the shoots, number of branches

Table 4.1 Comparison of soil pH and soil nutrient levels (ppm) in untreated plots from experiment #1 (n = 4), and experiment #2 (n = 4), to mean values from 10 wild collection sites used in this study. Soil pH and macronutrient levels were classified using soil ratings developed for strawberries, raspberries, and trees.

Site	pH	P	K	Ca	Mg
Exp. #1	5.8	144 H	146 H	770 L	73 L
Exp. #2	5.0	212 H	108 H	500 L	74 L
Wild Sites	5.4	68 M	86 M	592 L	108 L

L = Low
M = Medium
H = High

per shoot, and overall plant spread) used in both experiments. An increase in plant size during the establishment year might reasonably be expected to result in an earlier maturation of rose plants in mulched versus unmulched plots, resulting in higher yields of rose hips in the first production year.

Mulching had a positive impact on several aspects of rose plant growth, resulting in larger shoots (length, diameter, and number of branches) and greater plant spreads for rose plants than no mulch. Mulching did not increase the number of shoots per plant, and in some instances had the opposite effect, as mulched plants in experiment #1 had fewer shoots than un-mulched plants after the first growing season. The mulch may have acted as a barrier to new shoot formation, or may have caused the new shoots to spread laterally before breaking the mulch surface, thus avoiding detection until 2005. This lateral spreading is common in rose plants, and shoots that do so are often referred to as "runners" (Crockett 1971). Throughout the course of the study, runners were commonly observed rising from the edges of mulched plots into the inter-row areas. These shoots were not recorded and were either tilled or mown during regular inter-row maintenance.

Straw mulch was the most effective in-row mulch treatment for promoting plant vegetative growth in experiment #1, while bark mulch was the most effective in experiment #2. The results from the leaf tissue analyses indicate that the phosphorus content of bark-mulched plants was significantly higher than that of plants with no mulch or straw mulch. Increased phosphorus uptake could contribute to increased root, flower and rose hip development. It is possible that increased levels of phosphorus caused by bark mulch may have increased root growth and inhibited new shoot production in rose

plants. Similar effects have been reported in studies on various crops (e.g. in alfalfa by Berg et al. 2005; and in grapevine by Pinamonti 1988). Although the bark mulch proved effective at promoting plant growth in experiment #2, evidence from the tissue analyses suggest that straw mulch was more effective at promoting nitrogen uptake in the rose plants. Nitrogen levels in both experiments were higher in plants that were mulched with straw than in those with no mulch or bark mulch. Related studies have attributed higher levels of N with straw mulch to more favourable soil conditions due to adequate soil moisture and temperature, optimum for N-mineralization (e.g. Patra et al. 1993). Straw mulch may also be more favourable than bark mulch as it costs much less to apply per hectare.

Although mulching effectively increased rose plant growth, it did not significantly affect the yields of rose hips in 2005. Mulches have been used to increase fruit yield in many crops such as raspberry (Darrow and Magness 1938; Clark 1940; Childs 1941; Trinka and Pritts 1992), tomato (Abdul-baki et al. 1992, 1996; Agele et al. 2000), and strawberry (Kimak et al., 2001; Laugale et al., 2000). Although rose plants did produce rose hips in 2005, they are not yet old enough to achieve maximum rose hip yields. In several reports, maximum yields of rose hips are not seen until four or more years after establishment (e.g. in Chile, Joublan and Rios 2005). A mulching effect on yield might be observed in subsequent years. Alternatively, mulching may enhance plant vegetative growth, but have little or no observable effect on rose hip yield.

Although the effects of in-row mulch treatments on weed suppression were not formally assessed, it was generally noted that the bark mulch was the most effective

treatment for preventing weed establishment. This could be because of the dense nature of the mulch which would not easily permit weed species to access the soil. Straw mulched plots were slightly difficult to weed without disturbing the mulch, but appeared to offer better weed suppression than no mulch.

4.4 Compost and Fertilizer

Although nutrients exist naturally in the soil and atmosphere, they do not always occur in forms that are accessible by plants. Fertilizers are often used to provide plants with a source of accessible nutrients for optimal growth. The fertilizers used in both experiments were granular formulations (5-20-20 and 10-10-10) of three primary nutrients: nitrogen, phosphorus, and potassium (N-P-K). These nutrients each contribute to plant growth and development; nitrogen promotes leaf growth and forms proteins and chlorophyll; phosphorus contributes to root, flower and fruit development; potassium contributes to stem and root growth and the synthesis of proteins.

In experiment #1, fertilized plants had greater vegetative growth (significantly higher values for shoot length, branches per shoot, and plant spread) than plants with compost or no fertilizer. Fertilized plants in experiment #2 had more shoots and greater plant spreads than did plants with no fertilizer. Soil analyses from both experiments showed higher levels of K in fertilized plots than in plots with no fertilizer treatments. Potassium has been shown to increase vegetative growth, particularly shoot lengths in various crops (e.g. wheat, Shirazi et al. 2005). When observing the effects of fertilizer in the two experiments, it is important to note that fertilizer was incorporated into

experiment #2 in 2005. Therefore, plants in experiment #1 had one more growing season with fertilizer than those in experiment #2. Also, the lower soil pH in experiment #2 (5.0) may have negated the beneficial influence of the fertilizer treatments; in most soils, N, P, and K are most available for uptake by plants when pH values are above 6.0 and below 8.0 (Donahue 1971).

Organic fertilizers may include properly managed barnyard manure, green manure, and compost. Although composts are relatively low in essential nutrients (N, P, and K) they are known to increase soil organic matter through mineralization of elements into plant-accessible forms (Entry et al. 1997). The use of compost is also beneficial to various physical properties of soils, including increased porosity, structural stability, available water content, and reduction of erosion (Sartori et al. 1985; Guidi et al. 1988; Ballif et al. 1991; Roe et al. 1993). Composts also suppress plant pathogens, and provide a slow-release source of nutrients (Entry et al. 1997). Soil pH in experiment #1 was highest in plots with the in-row compost treatments. Nutrients in soils may become more available for uptake by plants at higher pH levels. Soil concentrations of P, Ca, and Mg in experiment #1 were also highest with compost treatments. In a study of grapevine by Pinamonti (1988) it was found that application of compost in-row resulted in a greater abundance of roots near the soil surface. Although leaf tissue analysis did not reveal any relationship between plant nutrient uptake and compost in experiment #1, an effect of compost on uptake may be seen in subsequent years.

The positive effect of fertilizer on the yield of rose hips was apparent in experiment #1. Plants that received fertilizer produced about twice the mass of hips per

plant as those with compost or no fertilizer. A similar effect was seen in a study of fertilizer effects on black chokeberry (*Aronia melanocarpa*) where plant height and yield were both greater in plots fertilized with a combined N-P-K fertilizer (Jeppsson 2000). Rose hip yields in experiment #2 were not significantly influenced by the use of fertilizer in-row. In-row fertilizer had an overall positive effect on plant vegetative growth and rose hip yield. While the compost used in this experiment did increase soil pH and soil macronutrients in experiment #1, it did not appear to offer any immediate advantage to rose plants.

Mean rose hip yields (measured in grams per plant) were higher for plants growing in experiment #2 than for those growing in experiment #1, with plants in experiment #2 yielding about 43% more than plants in experiment #1. More efficient pollination in experiment #2 is one possible explanation for this difference, but this was not formally assessed. Soil analyses reveal that the pH of the soil was 5.0 for experiment #2 and 5.8 for experiment #1. Natural habitats of wild rose plants on PEI that were tested in a previous study by MacPhail (2004) had mean pH values of 5.4, intermediate to the two experiments in this study. The rose plants used in both experiments may therefore favour soil with a relatively low pH. While plants in experiment #2 did have greater yields of rose hips than those in experiment #1, they also had a larger proportion of rotten or unmarketable rosehips. The cause of this was not investigated in this study, but may be related to a higher incidence of pests or disease in experiment #2 relative to experiment #1.

4.5 Inter-row Sod

The most consistent treatment effect in both experiments was the positive influence of tilled inter-row areas on rose plant growth and yield of rose hips. The mean increase (from May to September, 2005) in shoot lengths, diameters, and plant spreads was significantly higher for tilled inter-row treatments than for the sod inter-row treatments. Sod inter-row was not without some benefit though, as leaf tissue analysis revealed increased levels of P in rose plants with sod treatments compared to those with the tilled treatments. It is generally accepted that uptake of phosphorus is reduced in dry soil (Cornish and Myers 1977; Pinkerton and Simpson 1986), and sod inter-row may have increased the moisture retention of the soils, particularly during the hot summer months.

Biological yield of rose hips was also significantly lower with sod inter-row than with tilled inter-row treatments in experiment #2. Yield of rose hips was 22% lower for the sod inter-row treatments than for the tilled treatments in experiment #1, but the difference was not significant. A similar reduction in yield associated with the use of sod inter-row has been reported for various crops (e.g. for raspberry, Sanderson and Cutcliffe 1988). Grasses in the inter-row areas may have competed with the rose plants for water and nutrients, negatively affecting rose plant growth and yield. The effects of inter-row sod might only hinder rose plant establishment, and might lessen as the rose plants mature and send their roots deeper into the soil substrate.

4.6 Rose Hip Physical Qualities

Physical rose hip characteristics that should be considered for selection improvement include the size and mass of hips, dry weight of hips, and the ratio of flesh-to-achenes. The rose hips sampled from experiment #1 were small in size, slightly wider than long, and more than half made up of water. Small rose hips are expected to be more difficult to harvest by hand than the larger hips of cultivated varieties (Ercisli and Esitken 2004). One possible implication of this relatively small rose hip size is that commericialization of rose hips as a crop for Atlantic Canada might require a mechanized method of harvesting. Alternatively, future breeding programs might select for plants that produce larger rose hips. As mentioned previously, this study is only a small part of a much larger research effort, the goal of which is to produce a local source of high quality rose hip powder. An ideal rose selection would therefore be one which produces large hips with a high dry matter and bioactive (carotenoid) content.

In the present study, the percentage of rose hip yield graded as "marketable" from both experiments was high, with only 6% of hips from experiment #1 and 14% of hips from experiment #2 classified as "rotten" or "failed". Although the cause of rose hips that failed to set properly or that appeared rotten was not investigated in this study, communications with Dr. Christine Nornoha (entomologist) and Dr. Richard Martin (plant pathologist) of the AAFC (Charlottetown, PEI) gave some insight as to the potential causes. Both researchers conducted observations in 2005 using the site for experiment #1 of this study. Rose leafhoppers, sawfly larvae, aphids, and a lepidopteran leafroller were observed on randomly sampled rose plants in experiment #1. The number

of insects recorded was relatively low, and it seems likely that any rose hip damage that may have been caused by insects in this experiment would be minor as well.

The layout of the plants in experiment #1 (0.9 m between plants, 4 m between rows) was not considered conducive to the spread of disease. Thus, what was observed was a variable disease response, with individual plants displaying symptoms and adjacent plants remaining relatively disease-free. Black spot (asexual stage: *Marssonina rosae*) was perhaps the most common disease noted in the experiment. Leaves infected with black spot produce large quantites of ethylene, causing the plants to defoliate. Black spot is not known to affect rose hip fruit quality. Anthracnose (*Sphaceloma rosarum*), *Cercospora* leaf spot, and *Atlernaria* leaf spot were also noted, but were relatively rare. Botrytis blight (caused by *Botrytis cinerea*) is fungal disease which can negatively affect rose hip quality (Elad 1997). Although Botrytis blight was not observed on plants in experiment #1, observations were not recorded during flowering when the disease is most visible, and this disease may have gone undetected.

4.7 Suggestions for Future Research

Now that this preliminary study into field management protocols has been completed, additional research will be needed to assess treatments effects on rose hip production in the years to come. The fields used in this study might be productive for many years, as the longevity of a rose plantation is reported to be high if plants are cut back when necessary (Uggla and Martinsson 2005). This study focused on several rose plant characters to determine management effects on rose plant growth and rose hip

yields. Many different response variables might now be studied to give a more comprehensive picture of rose plant growth and provide insights for crop development. For example, studying the relationships between internode lengths, positioning of floral buds, and flower production in rose plants might lead to the development of more compact plants that are easier to harvest, with greater numbers of rose hips.

Research into associated aspects of rose hip production should now be undertaken. The results from this study indicate that wild roses respond well to mulching and fertilizer application; different mulches might now be tested to determine their effects on rose plant growth and development. Mulches vary widely in material type and price, as well their suitability for a given cropping system. Organic mulches (straw and bark) were selected for use in this study, but synthetic mulch materials (e.g. plastic) might also be useful. Plastic mulches are relatively inexpensive and have been used successfully in Swedish rose plantations (Uggla and Martinsson 2005).

Different fertilizer types, concentrations, and application rates could now be tested to determine optimum levels for rose plant growth, and develop responsible nutrient management programs for growers. Fertilizers have been shown to affect the antioxidant profiles of other fruit crops (e.g. in tomatoes, Toor et al. 2006), and could be expected to have similar effects on rose hips. Antioxidant profiling could be coupled with fertilizer testing in rose hip production, with the aim of developing more effective fertilizers and rose hips with maximum bioactive content.

Efficient pollination is vital to most fruit production programs. It is now known that species recorded by Erlanson (1934) as highly self-pollinating (*R. setigera* and *R.*

rugosa Thunb.), require cross-pollination by insects to set fruit (Kevan 2003). Both *R. carolina* and *R. virginiana* are tetraploids and so may often self-fertilize in natural populations, resulting in lower rates of fruit set than might be expected with cross-pollination. For example, it is possible that *R. carolina* requires cross-pollination in order to ensure fruit set and honeybees might be required for marketable rose hip yields. The maximum yields of rose hips that wild rose plants might potentially produce are not yet known. It will become necessary to clarify the breeding system of local species so that we may fully realize yield potentials, and widen the genetic basis for sustainable cultivar improvement. Continued research into these and other related issues will help to create a solid foundation for rose hip production in Atlantic Canada.

CHAPTER 5:

Literature Cited

5.0 LITERATURE CITED

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APPENDIX A:

Glossary of Botanical Terms

GLOSSARY OF BOTANICAL TERMS

The following definitions are taken from: Little R.J. and C.E. Jones. 1980. *A Dictionary of Botany*. Van Nostrand Reinhold, Toronto, Canada. 400pp.

Achenes: a simple, dry, one-seeded, indehiscent fruit; seed coat is not attached to the pericarp.

Axillary: in an axil; a term applied to buds, branches, or meristems, which occur in the axil of a leaf; e.g. axillary buds.

Basal: located at or near the base of a structure.

Bract: a modified, often much reduced leaf subtending a flower or inflorescence; morphologically a foliar organ.

Disc: a somewhat fleshy structure developed from the receptacle at the base of the ovary, or from coalesced nectarines or stamens around the pistil.

Habit: the general appearance or characteristic form of a plant, e.g. erect, prostrate, climbing, etc.

Hypanthium: a floral tube formed by the fusion of the basal portions of the sepals, petals and stamens, and from which the rest of the floral parts emanate.

Inflorescence: the arrangement of flowers on a floral axis; a floral cluster.

Pedicel: the stalk of an individual flower in an inflorescence.

Peduncle: the stalk of an inflorescence or the stalk of a solitary flower.

Perennial: a plant which lives for more than two years; woody perennials, e.g. trees and shrubs, have aerial stems which may live for many years.

Petal: one of the members of the corolla of a flower. Frequently conspicuously coloured.

Pinnate: shaped like a feather; e.g. having leaflets of a compound leaf arranged on opposite sides of a common axis or rachis.

Sepal: one of the outermost, sterile appendages of a flower which normally encloses the other floral parts in the bud; one of the separate parts of the calyx.

Stipule: a small structure or appendage found at the base of some leaf petioles; usually present in pairs; they are morphologically variable and appear as scales, spines, glands or leaflike structures.

APPENDIX B:

General Linear Model Tables

KEY TO TERMS USED IN GENERAL LINEAR MODEL TABLES

Source = the Source of variation

DF = Degrees of Freedom

Seq SS = Sequential Sum of Squares

Adj SS = Adjusted Sum of Squares

F = F statistic, used to determine P.

P = the probability that you would have obtained samples as extreme (or more extreme) if the indicated term (factor or interaction) had no effect on the response variable.

S = S^2 is an estimate of the variance in the data after the linear relationship between the response and the predictor has been taken into account. S is the square root of the mean standard error, S^2.

R^2 = describes the amount of variation in the observed response values that is explained by the model.

R^2 (adjusted) = a modified R^2 that has been adjusted for the number of terms in the model.

Table B-1. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #1 (July 2004; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	10.522	10.522	3.507	0.43	0.735
Mulch	2	20.605	20.605	10.303	1.25	0.295
Fertility	2	48.494	48.494	24.247	2.94	0.062
Inter-row	1	31.128	31.128	31.128	3.78	0.057
Mulch x Fertility	4	60.136	60.136	15.034	1.83	0.138
Mulch x Inter-row	2	5.782	5.782	2.891	0.35	0.706
Fertility x Inter-row	2	68.999	68.999	34.500	4.19	0.021
Mulch x Fertility x Inter-row	4	7.599	17.599	4.400	0.53	0.711
Error	51	420.096	420.096	8.237		
Total	71	683.362				

$S = 2.87005$ $R^2 = 38.53\%$ $R^2(\text{adjusted}) = 14.42\%$

Table B-2. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #1 (September 2004; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	276.73	276.73	92.24	2.12	0.109
Mulch	2	122.57	122.57	61.28	1.41	0.254
Fertility	2	12.71	12.71	6.36	0.15	0.864
Inter-row	1	100.41	100.41	100.41	2.31	0.135
Mulch x Fertility	4	130.73	130.73	32.68	0.75	0.562
Mulch x Inter-row	2	47.67	47.67	23.83	0.55	0.582
Fertility x Inter-row	2	119.69	119.69	59.84	1.38	0.262
Mulch x Fertility x Inter-row	4	170.71	170.71	42.68	0.98	0.426
Error	51	2219.47	2219.47	43.52		
Total	71	3200.68				

$S = 6.59690$ $R^2 = 30.66\%$ $R^2(\text{adjusted}) = 3.46\%$

Table B-3. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #1 (July 2004; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.6371	0.6371	0.2124	1.01	0.396
Mulch	2	0.6480	0.6480	0.3240	1.54	0.224
Fertility	2	0.4992	0.4992	0.2496	1.19	0.314
Inter-row	1	0.5167	0.5167	0.5167	2.46	0.123
Mulch x Fertility	4	0.1294	0.1294	0.0324	0.15	0.960
Mulch x Inter-row	2	0.5119	0.5119	0.2559	1.22	0.305
Fertility x Inter-row	2	0.0735	0.0735	0.0367	0.17	0.840
Mulch x Fertility x Inter-row	4	2.3015	2.3015	0.5754	2.74	0.039
Error	51	10.7283	10.7283	0.2104		
Total	71	16.0456				

S = 0.458649 R^2 = 33.14% R^2(adjusted) = 6.92%

Table B-4. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #1 (September 2004; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	3.6162	3.6162	1.2054	1.86	0.148
Mulch	2	14.1821	14.1821	7.0910	10.96	0.000
Fertility	2	0.5430	0.5430	0.2715	0.42	0.660
Inter-row	1	0.0846	0.0846	0.0846	0.13	0.719
Mulch x Fertility	4	3.1609	3.1609	0.7902	1.22	0.313
Mulch x Inter-row	2	1.5373	1.5373	0.7686	1.19	0.313
Fertility x Inter-row	2	1.9851	1.9851	0.9925	1.53	0.225
Mulch x Fertility x Inter-row	4	2.7941	2.7941	0.6985	1.08	0.376
Error	51	32.9983	32.9983	0.6470		
Total	71	60.9016				

S = 0.804379 R^2 = 45.82% R^2(adjusted) = 24.57%

Table B-5. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #1 (July 2004; n = 72) using adjusted sum of squares for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1.5704	1.5704	0.5235	2.80	0.049
Mulch	2	1.4853	1.4853	0.7426	3.98	0.025
Fertility	2	0.1103	0.1103	0.0551	0.30	0.746
Inter-row	1	0.0113	0.0112	0.0112	0.06	0.807
Mulch x Fertility	4	0.4914	0.4914	0.1228	0.66	0.624
Mulch x Inter-row	2	0.0208	0.0208	0.0104	0.06	0.946
Fertility x Inter-row	2	0.1908	0.1908	0.0954	0.51	0.603
Mulch x Fertility x Inter-row	4	0.8558	0.8558	0.2140	1.15	0.346
Error	51	9.5271	9.5271	0.1868		
Total	71	14.2632				

S = 0.432210 R^2 = 33.21% R^2(adjusted) = 7.01%

Table B-6. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #1 (September 2004; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2.8271	2.8271	0.9424	2.36	0.083
Mulch	2	3.9336	3.9336	1.9668	4.92	0.011
Fertility	2	0.2186	0.2186	0.1093	0.27	0.762
Inter-row	1	0.3068	0.3068	0.3068	0.77	0.385
Mulch x Fertility	4	1.3347	1.3347	0.3337	0.83	0.510
Mulch x Inter-row	2	0.0836	0.0836	0.0418	0.10	0.901
Fertility x Inter-row	2	0.7803	0.7803	0.3901	0.98	0.384
Mulch x Fertility x Inter-row	4	1.1781	1.1781	0.2945	0.74	0.571
Error	51	20.3904	20.3904	0.3998		
Total	71	31.0532				

$S = 0.632307$ $R^2 = 34.34\%$ $R^2(\text{adjusted}) = 8.59\%$

Table B-7. General Linear Model for the effects of test factors and their interactions on the change in the number of shoots per plant in experiment #1 (July-September 2004; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1.1678	1.1678	0.3893	2.46	0.073
Mulch	2	0.7344	0.7344	0.3672	2.32	0.109
Fertility	2	0.0544	0.0544	0.0272	0.17	0.843
Inter-row	1	0.2006	0.2006	0.2006	1.27	0.266
Mulch x Fertility	4	0.7289	0.7289	0.1822	1.15	0.344
Mulch x Inter-row	2	0.0878	0.0878	0.0439	0.28	0.759
Fertility x Inter-row	2	0.4411	0.4411	0.2206	1.39	0.258
Mulch x Fertility x Inter-row	4	0.3456	0.3456	0.0864	0.55	0.703
Error	51	8.0772	8.0772	0.1584		
Total	71	11.8378				

$S = 0.397966$ $R^2 = 31.77\%$ $R^2(\text{adjusted}) = 5.01\%$

Table B-8. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #2 (July 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	144.04	144.04	48.01	4.47	0.010
Mulch	2	28.12	28.12	14.06	1.31	0.284
Fertility	1	0.06	0.06	0.06	0.01	0.939
Inter-row	1	0.35	0.35	0.35	0.03	0.858
Mulch x Fertility	2	4.79	4.79	2.39	0.22	0.801
Mulch x Inter-row	2	41.35	41.35	20.67	1.92	0.162
Fertility x Inter-row	1	2.78	2.78	2.78	0.26	0.614
Mulch x Fertility x Inter-row	2	0.82	0.82	0.41	0.04	0.963
Error	33	354.44	354.44	10.74		
Total	47	576.75				

$S = 3.27728$ $R^2 = 38.55\%$ $R^2(\text{adjusted}) = 12.47\%$

Table B-9. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #2 (September 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1477.8	1477.8	492.6	1.84	0.159
Mulch	2	1383.1	1383.1	691.6	2.58	0.091
Fertility	1	367.7	367.7	367.7	1.37	0.250
Inter-row	1	127.6	127.6	127.6	0.48	0.495
Mulch x Fertility	2	171.7	171.7	85.8	0.32	0.728
Mulch x Inter-row	2	878.2	878.2	439.1	1.64	0.209
Fertility x Inter-row	1	200.5	200.5	200.5	0.75	0.393
Mulch x Fertility x Inter-row	2	425.7	425.7	212.8	0.79	0.460
Error	33	8836.3	8836.3	267.8		
Total	47	13868.6				

$S = 16.3636$ $R^2 = 36.29\%$ $R^2(\text{adjusted}) = 9.25\%$

Table B-10. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #2 (July 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1.7959	1.7959	0.5986	0.69	0.565
Mulch	2	1.2118	1.2118	0.6059	0.70	0.505
Fertility	1	0.3020	0.3020	0.3020	0.35	0.559
Inter-row	1	0.2644	0.2644	0.2644	0.30	0.585
Mulch x Fertility	2	0.2834	0.2834	0.1417	0.16	0.850
Mulch x Inter-row	2	1.5531	1.5531	0.7766	0.89	0.418
Fertility x Inter-row	1	1.0643	1.0643	1.0643	1.23	0.276
Mulch x Fertility x Inter-row	2	4.8054	4.8054	2.4027	2.77	0.077
Error	33	28.6400	28.6400	0.8679		
Total	47	39.9204				

$S = 0.931600$ $R^2 = 28.26\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-11. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #2 (September 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.2440	0.2440	0.0813	0.08	0.969
Mulch	2	0.3194	0.3194	0.1597	0.16	0.851
Fertility	1	0.9185	0.9185	0.9185	0.93	0.342
Inter-row	1	0.7538	0.7538	0.7538	0.76	0.388
Mulch x Fertility	2	0.3450	0.3450	0.1725	0.17	0.840
Mulch x Inter-row	2	1.4256	1.4256	0.7128	0.72	0.493
Fertility x Inter-row	1	1.2805	1.2805	1.2805	1.30	0.263
Mulch x Fertility x Inter-row	2	0.8778	0.8778	0.4389	0.44	0.645
Error	33	32.5543	32.5543	0.9865		
Total	47	38.7190				

S = 0.993224 R^2 = 15.92% R^2(adjusted) = 0.00%

Table B-12. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #2 (July 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.7604	0.7604	0.2535	0.65	0.591
Mulch	2	0.2917	0.2917	0.1458	0.37	0.693
Fertility	1	0.0052	0.0052	0.0052	0.01	0.909
Inter-row	1	0.2552	0.2552	0.2552	0.65	0.426
Mulch x Fertility	2	0.4479	0.4479	0.2240	0.57	0.571
Mulch x Inter-row	2	0.0104	0.0104	0.0052	0.01	0.987
Fertility x Inter-row	1	0.0833	0.0833	0.0833	0.21	0.648
Mulch x Fertility x Inter-row	2	0.0417	0.0417	0.0208	0.05	0.948
Error	33	12.9583	12.9583	0.3927		
Total	47	14.8542				

$S = 0.626639$ $R^2 = 12.76\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-13. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #2 (September 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2.6810	2.6810	0.8937	1.35	0.274
Mulch	2	1.8776	1.8776	0.9388	1.42	0.255
Fertility	1	0.0013	0.0013	0.0013	0.00	0.965
Inter-row	1	0.0638	0.0638	0.0638	0.10	0.758
Mulch x Fertility	2	0.5026	0.5026	0.2513	0.38	0.686
Mulch x Inter-row	2	0.5807	0.5807	0.2904	0.44	0.648
Fertility x Inter-row	1	0.0013	0.0013	0.0013	0.00	0.965
Mulch x Fertility x Inter-row	2	0.9870	0.9870	0.4935	0.75	0.481
Error	33	21.7721	21.7721	0.6598		
Total	47	28.4674				

$S = 0.812257$ $R^2 = 23.52\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-14. General Linear Model for the effects of test factors and their interactions on the change in the number of shoots per plant in experiment #2 (July-September 2004; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.7747	0.7747	0.2582	1.54	0.222
Mulch	2	1.2214	1.2214	0.6107	3.65	0.037
Fertility	1	0.0013	0.0013	0.0013	0.01	0.930
Inter-row	1	0.0638	0.0638	0.0638	0.38	0.541
Mulch x Fertility	2	0.0495	0.0495	0.0247	0.15	0.863
Mulch x Inter-row	2	0.4714	0.4714	0.2357	1.41	0.259
Fertility x Inter-row	1	0.1055	0.1055	0.1055	0.63	0.433
Mulch x Fertility x Inter-row	2	0.7266	0.7266	0.3633	2.17	0.130
Error	33	5.5221	5.5221	0.1673		
Total	47	8.9362				

$S = 0.409069$ $R^2 = 38.20\%$ $R^2(\text{adjusted}) = 11.99\%$

Table B-15. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #1 (May 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	36.05	36.05	12.02	0.58	0.629
Mulch	2	2.92	2.92	1.46	0.07	0.932
Fertility	2	2.65	2.65	1.32	0.06	0.938
Inter-row	1	42.17	42.17	42.17	2.04	0.159
Mulch x Fertility	4	55.35	55.35	13.84	0.67	0.615
Mulch x Inter-row	2	20.18	20.18	10.09	0.49	0.616
Fertility x Inter-row	2	41.48	41.48	20.74	1.01	0.373
Mulch x Fertility x Inter-row	4	49.89	49.89	12.47	0.60	0.661
Error	51	1051.98	1051.98	20.63		
Total	71	1302.66				

S = 4.54171 R^2 = 19.24% R^2(adjusted) = 0.00%

Table B-16. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #1 (September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	159.08	159.08	53.03	1.04	0.383
Mulch	2	426.23	426.23	213.11	4.18	0.021
Fertility	2	502.28	502.28	251.14	4.92	0.011
Inter-row	1	433.65	433.65	433.65	8.50	0.005
Mulch x Fertility	4	539.22	539.22	134.81	2.64	0.044
Mulch x Inter-row	2	0.47	0.47	0.23	0.00	0.995
Fertility x Inter-row	2	142.45	142.45	71.22	1.40	0.257
Mulch x Fertility x Inter-row	4	253.11	253.11	63.28	1.24	0.306
Error	51	2601.15	2601.15	51.00		
Total	71	5057.63				

$S = 7.14164$ $R^2 = 48.57\%$ $R^2(\text{adjusted}) = 28.40\%$

Table B-17. General Linear Model for the effects of test factors and their interactions on the change in shoot length in experiment #1 (May-September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	279.77	279.77	93.26	3.18	0.032
Mulch	2	363.37	363.37	181.68	6.19	0.004
Fertility	2	535.41	535.41	267.70	9.12	0.000
Inter-row	1	746.27	746.27	746.27	25.41	0.000
Mulch x Fertility	4	417.64	417.64	104.41	3.56	0.012
Mulch x Inter-row	2	19.34	19.34	9.67	0.33	0.721
Fertility x Inter-row	2	288.23	288.23	144.11	4.91	0.011
Mulch x Fertility x Inter-row	4	254.99	254.99	63.75	2.17	0.085
Error	51	1497.55	1497.55	29.36		
Total	71	4402.56				

$S = 5.41883$ $R^2 = 65.98\%$ $R^2(\text{adjusted}) = 52.65\%$

Table B-18. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #1 (May 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2.9793	2.9793	0.9931	1.96	0.132
Mulch	2	2.1436	2.1436	1.0718	2.11	0.132
Fertility	2	1.0678	1.0678	0.5339	1.05	0.357
Inter-row	1	0.3612	0.3612	0.3612	0.71	0.403
Mulch x Fertility	4	0.7906	0.7906	0.1976	0.39	0.815
Mulch x Inter-row	2	0.3558	0.3558	0.1779	0.35	0.706
Fertility x Inter-row	2	0.8233	0.8233	0.4117	0.81	0.450
Mulch x Fertility x Inter-row	4	3.0183	3.0183	0.7546	1.49	0.220
Error	51	25.9032	25.9032	0.5079		
Total	71	37.4432				

S = 0.712675 R^2 = 30.82% R^2(adjusted) = 3.69%

Table B-19. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #1 (September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	31.90	31.90	10.63	0.78	0.511
Mulch	2	71.02	71.02	35.51	2.60	0.084
Fertility	2	41.13	41.13	20.57	1.51	0.231
Inter-row	1	77.92	77.92	77.92	5.71	0.021
Mulch x Fertility	4	63.12	63.12	15.78	1.16	0.341
Mulch x Inter-row	2	1.81	1.81	0.91	0.07	0.936
Fertility x Inter-row	2	2.74	2.74	1.37	0.10	0.905
Mulch x Fertility x Inter-row	4	41.96	41.96	10.49	0.77	0.550
Error	51	695.40	695.40	13.64		
Total	71	1027.00				

S = 3.69259 R^2 = 32.29% R^2(adjusted) = 5.73%

Table B-20. General Linear Model for the effects of test factors and their interactions on the change in shoot diameter in experiment #1 (May-September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	38.24	38.24	12.75	1.10	0.356
Mulch	2	97.68	97.68	48.84	4.23	0.020
Fertility	2	45.78	45.78	22.89	1.98	0.148
Inter-row	1	88.89	88.89	88.89	7.70	0.008
Mulch x Fertility	4	63.02	63.02	15.75	1.36	0.260
Mulch x Inter-row	2	1.12	1.12	0.56	0.05	0.953
Fertility x Inter-row	2	6.56	6.56	3.28	0.28	0.754
Mulch x Fertility x Inter-row	4	29.49	29.49	7.37	0.64	0.638
Error	51	589.12	589.12	11.55		
Total	71	959.89				

$S = 3.39874$ $R^2 = 38.63\%$ $R^2(\text{adjusted}) = 14.56\%$

Table B-21. General Linear Model for the effects of test factors and their interactions on the number of branches per shoot in experiment #1 (May 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.21375	0.21375	0.07125	0.90	0.450
Mulch	2	0.38111	0.38111	0.19056	2.39	0.101
Fertility	2	0.69528	0.69528	0.34764	4.37	0.018
Inter-row	1	0.08681	0.08681	0.08681	1.09	0.301
Mulch x Fertility	4	0.21806	0.21806	0.05451	0.68	0.606
Mulch x Inter-row	2	0.12444	0.12444	0.06222	0.78	0.463
Fertility x Inter-row	2	0.82028	0.82028	0.41014	5.15	0.009
Mulch x Fertility x Inter-row	4	0.13472	0.13472	0.03368	0.42	0.791
Error	51	4.05875	4.05875	0.07958		
Total	71	6.73319				

$S = 0.282105$ $R^2 = 39.72\%$ $R^2(\text{adjusted}) = 16.08\%$

Table B-22. General Linear Model for the effects of test factors and their interactions on the number of branches per shoot in experiment #1 (September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	7.558	7.558	2.519	0.56	0.645
Mulch	2	4.554	4.554	2.277	0.50	0.607
Fertility	2	59.808	59.808	29.904	6.62	0.003
Inter-row	1	26.040	26.040	26.040	5.76	0.020
Mulch x Fertility	4	30.972	30.972	7.743	1.71	0.161
Mulch x Inter-row	2	6.474	6.474	3.237	0.72	0.493
Fertility x Inter-row	2	5.564	5.564	2.782	0.62	0.544
Mulch x Fertility x Inter-row	4	24.927	24.927	6.232	1.38	0.254
Error	51	230.374	230.374	4.517		
Total	71	396.273				

$S = 2.12536$ $R^2 = 41.86\%$ $R^2(\text{adjusted}) = 19.07\%$

Table B-23. General Linear Model for the effects of test factors and their interactions on the change in the number of branches per shoot in experiment #1 (May-September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	5.374	5.374	1.791	0.42	0.741
Mulch	2	2.423	2.423	1.212	0.28	0.755
Fertility	2	73.136	73.136	36.568	8.54	0.001
Inter-row	1	29.134	29.134	29.134	6.80	0.012
Mulch x Fertility	4	28.753	28.753	7.188	1.68	0.169
Mulch x Inter-row	2	5.008	5.008	2.504	0.58	0.561
Fertility x Inter-row	2	9.587	9.587	4.793	1.12	0.335
Mulch x Fertility x Inter-row	4	25.729	25.729	6.432	1.50	0.216
Error	51	218.496	218.496	4.284		
Total	71	397.640				

$S = 2.06984$ $R^2 = 45.05\%$ $R^2(\text{adjusted}) = 23.50\%$

Table B-24. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #1 (May 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	3.6494	3.6494	1.2165	2.67	0.058
Mulch	2	6.1119	6.1119	3.0560	6.70	0.003
Fertility	2	0.1303	0.1303	0.0651	0.14	0.867
Inter-row	1	0.4356	0.4356	0.4356	0.95	0.333
Mulch x Fertility	4	2.7006	2.7006	0.6751	1.48	0.222
Mulch x Inter-row	2	0.1019	0.1019	0.0510	0.11	0.895
Fertility x Inter-row	2	1.5636	1.5636	0.7818	1.71	0.191
Mulch x Fertility x Inter-row	4	1.8239	1.8239	0.4560	1.00	0.417
Error	51	23.2756	23.2756	0.4564		
Total	71	39.7928				

S = 0.675562 R^2 = 41.51% R^2(adjusted) = 18.57%

Table B-25. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #1 (September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	29.518	29.518	9.839	4.88	0.005
Mulch	2	9.370	9.370	4.685	2.32	0.108
Fertility	2	1.277	1.277	0.638	0.32	0.730
Inter-row	1	1.473	1.473	1.473	0.73	0.397
Mulch x Fertility	4	2.162	2.162	0.541	0.27	0.897
Mulch x Inter-row	2	2.125	2.125	1.063	0.53	0.593
Fertility x Inter-row	2	3.087	3.087	1.543	0.77	0.470
Mulch x Fertility x Inter-row	4	7.831	7.831	1.958	0.97	0.431
Error	51	102.809	102.809	2.016		
Total	71	159.653				

$S = 1.41981$ $R^2 = 35.60\%$ $R^2(\text{adjusted}) = 10.35\%$

Table B-26. General Linear Model for the effects of test factors and their interactions on the change in the number of shoots per plant in experiment #1 (May-September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	12.5749	12.5749	4.1916	4.65	0.006
Mulch	2	2.2633	2.2633	1.1317	1.25	0.294
Fertility	2	0.6400	0.6400	0.3200	0.35	0.703
Inter-row	1	0.3068	0.3068	0.3068	0.34	0.562
Mulch x Fertility	4	3.9392	3.9392	0.9848	1.09	0.371
Mulch x Inter-row	2	3.1244	3.1244	1.5622	1.73	0.187
Fertility x Inter-row	2	2.1378	2.1378	1.0689	1.18	0.314
Mulch x Fertility x Inter-row	4	4.7147	4.7147	1.1787	1.31	0.280
Error	51	46.0076	46.0076	0.9021		
Total	71	75.7088				

S = 0.949795 R^2 = 39.23% R^2(adjusted) = 15.40%

Table B-27. General Linear Model for the effects of test factors and their interactions on plant spread in experiment #1 (May 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	196.53	196.53	65.51	1.18	0.326
Mulch	2	90.18	90.18	45.09	0.81	0.449
Fertility	2	45.26	45.26	22.63	0.41	0.667
Inter-row	1	14.05	14.05	14.05	0.25	0.617
Mulch x Fertility	4	308.18	308.18	77.04	1.39	0.251
Mulch x Inter-row	2	35.49	35.49	17.74	0.32	0.728
Fertility x Inter-row	2	55.58	55.58	27.79	0.50	0.609
Mulch x Fertility x Inter-row	4	87.62	87.62	21.91	0.39	0.811
Error	51	2830.17	2830.17	55.49		
Total	71	3663.04				

$S = 7.44939$ $R^2 = 22.74\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-28. General Linear Model for the effects of test factors and their interactions on plant spread in experiment #1 (September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2060.9	2060.9	687.0	3.73	0.017
Mulch	2	1065.1	1065.1	532.5	2.89	0.065
Fertility	2	1736.9	1736.9	868.5	4.72	0.013
Inter-row	1	3146.9	3146.9	3146.9	17.09	0.000
Mulch x Fertility	4	1911.2	1911.2	477.8	2.59	0.047
Mulch x Inter-row	2	1163.0	1163.0	581.5	3.16	0.051
Fertility x Inter-row	2	567.8	567.8	283.9	1.54	0.224
Mulch x Fertility x Inter-row	4	1824.7	1824.7	456.2	2.48	0.056
Error	51	9391.2	9391.2	184.1		
Total	71	22867.6				

$S = 13.5699$ $R^2 = 58.93\%$ R^2(adjusted) = 42.83%

Table B-29. General Linear Model for the effects of test factors and their interactions on the change in plant spread in experiment #1 (May-September 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1435.1	1435.1	478.4	3.99	0.012
Mulch	2	1482.6	1482.6	741.3	6.19	0.004
Fertility	2	1459.2	1459.2	729.6	6.09	0.004
Inter-row	1	2740.5	2740.5	2740.5	22.88	0.000
Mulch x Fertility	4	2462.7	2462.7	615.7	5.14	0.001
Mulch x Inter-row	2	1450.5	1450.5	725.2	6.05	0.004
Fertility x Inter-row	2	609.4	609.4	304.7	2.54	0.089
Mulch x Fertility x Inter-row	4	1401.3	1401.3	350.3	2.92	0.030
Error	51	6109.1	6109.1	119.8		
Total	71	19150.3				

$S = 10.9447$ $R^2 = 68.10\%$ $R^2(\text{adjusted}) = 55.59\%$

Table B-30. General Linear Model for the effects of test factors and their interactions on the total biological yield of rose hips per plant in experiment #1 (October 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	953.5	953.5	317.8	0.41	0.749
Mulch	2	1406.2	1406.2	703.1	0.90	0.413
Fertility	2	16051.8	16051.8	8025.9	10.27	0.000
Inter-row	1	3253.7	3253.7	3253.7	4.16	0.047
Mulch x Fertility	4	4711.0	4711.0	1177.8	1.51	0.214
Mulch x Inter-row	2	1445.4	1445.4	722.7	0.92	0.403
Fertility x Inter-row	2	1267.4	1267.4	633.7	0.81	0.450
Mulch x Fertility x Inter-row	4	9573.4	9573.4	2393.4	3.06	0.025
Error	51	39857.1	39857.1	781.5		
Total	71	78519.7				

$S = 27.9555$ $R^2 = 49.24\%$ R^2(adjusted) = 29.33%

Table B-31. General Linear Model for the effects of test factors and their interactions on the total marketable yield of rose hips per plant in experiment #1 (October 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	847.8	847.8	282.6	0.39	0.760
Mulch	2	991.8	991.8	495.9	0.69	0.509
Fertility	2	13350.9	13350.9	6675.5	9.23	0.000
Inter-row	1	3248.5	3248.5	3248.5	4.49	0.039
Mulch x Fertility	4	5215.3	5215.3	1303.8	1.80	0.143
Mulch x Inter-row	2	1734.8	1734.8	867.4	1.20	0.310
Fertility x Inter-row	2	988.9	988.9	494.4	0.68	0.509
Mulch x Fertility x Inter-row	4	10063.2	10063.2	2515.8	3.48	0.014
Error	51	36902.4	36902.4	723.6		
Total	71	73343.7				

$S = 26.8994$ $R^2 = 49.69\%$ $R^2(\text{adjusted}) = 29.95\%$

Table B-32. General Linear Model for the effects of test factors and their interactions on the total number of rose hips per plant in experiment #1 (October 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	463.5	463.5	154.5	0.24	0.865
Mulch	2	724.7	724.7	362.4	0.57	0.567
Fertility	2	8542.0	8542.0	4271.0	6.77	0.002
Inter-row	1	4384.1	4384.1	4384.1	6.95	0.011
Mulch x Fertility	4	4158.3	4158.3	1039.6	1.65	0.177
Mulch x Inter-row	2	1794.5	1794.5	897.2	1.42	0.251
Fertility x Inter-row	2	626.9	626.9	313.5	0.50	0.611
Mulch x Fertility x Inter-row	4	6563.8	6563.8	1641.0	2.60	0.047
Error	51	32189.3	32189.3	631.2		
Total	71	59447.2				

$S = 25.1229$ $R^2 = 45.85\%$ $R^2(\text{adjusted}) = 24.62\%$

Table B-33. General Linear Model for the effects of test factors and their interactions on the percentage of rotten rose hips per plant in experiment #1 (October 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.005322	0.005322	0.001774	1.02	0.391
Mulch	2	0.015862	0.015862	0.007931	4.57	0.015
Fertility	2	0.002193	0.002193	0.001096	0.63	0.536
Inter-row	1	0.003577	0.003577	0.003577	2.06	0.157
Mulch x Fertility	4	0.003995	0.003995	0.000999	0.58	0.682
Mulch x Inter-row	2	0.007105	0.007105	0.003553	2.05	0.140
Fertility x Inter-row	2	0.004980	0.004980	0.002490	1.43	0.248
Mulch x Fertility x Inter-row	4	0.033426	0.033426	0.008356	4.81	0.002
Error	51	0.088542	0.088542	0.001736		
Total	71	0.165001				

$S = 0.0416668$ $R^2 = 46.34\%$ $R^2(\text{adjusted}) = 25.29\%$

Table B-34. General Linear Model for the effects of test factors and their interactions on the percentage of failed rose hips per plant in experiment #1 (October 2005; n = 72) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.017156	0.017156	0.005719	0.75	0.529
Mulch	2	0.006746	0.006746	0.003373	0.44	0.646
Fertility	2	0.015253	0.015253	0.007626	1.00	0.376
Inter-row	1	0.008580	0.008580	0.008580	1.12	0.295
Mulch x Fertility	4	0.020849	0.020849	0.005212	0.68	0.608
Mulch x Inter-row	2	0.002385	0.002385	0.001193	0.16	0.856
Fertility x Inter-row	2	0.000548	0.000548	0.000274	0.04	0.965
Mulch x Fertility x Inter-row	4	0.014162	0.014162	0.003540	0.46	0.763
Error	51	0.390293	0.390293	0.007653		
Total	71	0.475973				

S = 0.0874803 R^2 = 18.00% R^2(adjusted) = 0.00%

Table B-35. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #2 (May 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	140.99	140.99	47.00	2.07	0.124
Mulch	2	170.30	170.30	85.15	3.74	0.034
Fertility	1	1.80	1.80	1.80	0.08	0.780
Inter-row	1	0.15	0.15	0.15	0.01	0.935
Mulch x Fertility	2	4.20	4.20	2.10	0.09	0.912
Mulch x Inter-row	2	79.17	79.17	39.59	1.74	0.191
Fertility x Inter-row	1	15.53	15.53	15.53	0.68	0.415
Mulch x Fertility x Inter-row	2	62.72	62.72	31.36	1.38	0.266
Error	33	750.30	750.30	22.74		
Total	47	1225.16				

$S = 4.76827$ $R^2 = 38.76\%$ $R^2(\text{adjusted}) = 12.78\%$

Table B-36. General Linear Model for the effects of test factors and their interactions on shoot length in experiment #2 (September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1096.40	1096.40	365.47	10.34	0.000
Mulch	2	62.59	62.59	31.30	0.89	0.422
Fertility	1	47.40	47.40	47.40	1.34	0.255
Inter-row	1	400.79	400.79	400.79	11.34	0.002
Mulch x Fertility	2	44.15	44.15	22.08	0.62	0.542
Mulch x Inter-row	2	585.13	585.13	292.56	8.28	0.001
Fertility x Inter-row	1	1.24	1.24	1.24	0.03	0.853
Mulch x Fertility x Inter-row	2	17.30	17.30	8.65	0.24	0.784
Error	33	1166.14	1166.14	35.34		
Total	47	3421.14				

$S = 5.94455$ $R^2 = 65.91\%$ $R^2(\text{adjusted}) = 51.45\%$

Table B-37. General Linear Model for the effects of test factors and their interactions on the change in shoot length in experiment #2 (May-September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1068.03	1068.03	356.01	15.28	0.000
Mulch	2	88.18	88.18	44.09	1.89	0.167
Fertility	1	30.72	30.72	30.72	1.32	0.259
Inter-row	1	416.54	416.54	416.54	17.88	0.000
Mulch x Fertility	2	22.42	22.42	11.21	0.48	0.622
Mulch x Inter-row	2	234.75	234.75	117.38	5.04	0.012
Fertility x Inter-row	1	8.00	8.00	8.00	0.34	0.562
Mulch x Fertility x Inter-row	2	60.09	60.09	30.05	1.29	0.289
Error	33	769.00	769.00	23.30		
Total	47	2697.74				

$S = 4.82731$ $R^2 = 71.49\%$ $R^2(\text{adjusted}) = 59.40\%$

Table B-38. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #2 (May 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1.0700	1.0700	0.3567	0.91	0.446
Mulch	2	0.9779	0.9779	0.4890	1.25	0.300
Fertility	1	0.1875	0.1875	0.1875	0.48	0.494
Inter-row	1	0.0533	0.0533	0.0533	0.14	0.714
Mulch x Fertility	2	0.1287	0.1287	0.0644	0.16	0.849
Mulch x Inter-row	2	1.4904	1.4904	0.7452	1.90	0.165
Fertility x Inter-row	1	0.0408	0.0408	0.0408	0.10	0.749
Mulch x Fertility x Inter-row	2	1.3079	1.3079	0.6540	1.67	0.203
Error	33	12.9100	12.9100	0.3912		
Total	47	18.1667				

S = 0.625470 R^2 = 28.94% R^2(adjusted) = 0.00%

Table B-39. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #2 (September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	19.627	19.627	6.542	5.65	0.003
Mulch	2	17.551	17.551	8.776	7.58	0.002
Fertility	1	1.367	1.367	1.367	1.18	0.285
Inter-row	1	14.410	14.410	14.410	12.45	0.001
Mulch x Fertility	2	7.614	7.614	3.807	3.29	0.050
Mulch x Inter-row	2	5.888	5.888	2.944	2.54	0.094
Fertility x Inter-row	1	0.010	0.010	0.010	0.01	0.926
Mulch x Fertility x Inter-row	2	0.830	0.830	0.415	0.36	0.701
Error	33	38.185	38.185	1.157		
Total	47	105.483				

S = 1.07570 R^2 = 63.80% R^2(adjusted) = 48.44%

Table B-40. General Linear Model for the effects of test factors and their interactions on the change in shoot diameter in experiment #2 (May-September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	13.9956	13.9956	4.6652	5.32	0.004
Mulch	2	12.4067	12.4067	6.2033	7.08	0.003
Fertility	1	2.5669	2.5669	2.5669	2.93	0.096
Inter-row	1	12.7102	12.7102	12.7102	14.50	0.001
Mulch x Fertility	2	7.5050	7.5050	3.7525	4.28	0.022
Mulch x Inter-row	2	2.3217	2.3217	1.1608	1.32	0.280
Fertility x Inter-row	1	0.0102	0.0102	0.0102	0.01	0.915
Mulch x Fertility x Inter-row	2	0.4317	0.4317	0.2158	0.25	0.783
Error	33	28.9319	28.9319	0.8767		
Total	47	80.8798				

$S = 0.936335$ $R^2 = 64.23\%$ $R^2(\text{adjusted}) = 49.05\%$

Table B-41. General Linear Model for the effects of test factors and their interactions on the number of branches per shoot in experiment #2 (May 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.2540	0.2540	0.0847	0.42	0.740
Mulch	2	0.4829	0.4829	0.2415	1.20	0.314
Fertility	1	0.2552	0.2552	0.2552	1.27	0.269
Inter-row	1	0.0919	0.0919	0.0919	0.46	0.504
Mulch x Fertility	2	0.4129	0.4129	0.2065	1.02	0.370
Mulch x Inter-row	2	0.0537	0.0537	0.0269	0.13	0.876
Fertility x Inter-row	1	0.2852	0.2852	0.2852	1.42	0.243
Mulch x Fertility x Inter-row	2	0.0204	0.0204	0.0102	0.05	0.951
Error	33	6.6485	6.6485	0.2015		
Total	47	8.5048				

$S = 0.448855$ $R^2 = 21.83\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-42. General Linear Model for the effects of test factors and their interactions on shoot diameter in experiment #2 (September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.782	0.782	0.261	0.08	0.968
Mulch	2	62.732	62.732	31.366	10.07	0.000
Fertility	1	2.475	2.475	2.475	0.79	0.379
Inter-row	1	1.367	1.367	1.367	0.44	0.512
Mulch x Fertility	2	1.972	1.972	0.986	0.32	0.731
Mulch x Inter-row	2	21.105	21.105	10.553	3.39	0.046
Fertility x Inter-row	1	0.060	0.060	0.060	0.02	0.890
Mulch x Fertility x Inter-row	2	6.252	6.252	3.126	1.00	0.377
Error	33	102.770	102.770	3.114		
Total	47	199.515				

S = 1.76472 R^2 = 48.49% R^2(adjusted) = 26.64%

Table B-43. General Linear Model for the effects of test factors and their interactions on the change in the number of branches per shoot in experiment #2 (May-September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1.458	1.458	0.486	0.15	0.932
Mulch	2	52.216	52.216	26.108	7.81	0.002
Fertility	1	1.141	1.141	1.141	0.34	0.563
Inter-row	1	2.167	2.167	2.167	0.65	0.426
Mulch x Fertility	2	0.943	0.943	0.471	0.14	0.869
Mulch x Inter-row	2	20.116	20.116	10.058	3.01	0.063
Fertility x Inter-row	1	0.083	0.083	0.083	0.02	0.876
Mulch x Fertility x Inter-row	2	6.758	6.758	3.379	1.01	0.375
Error	3	110.317	110.317	3.343		
Total	47	195.200				

$S = 1.82837$ $R^2 = 43.49\%$ $R^2(\text{adjusted}) = 19.51\%$

Table B-44. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #2 (May 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	3.9842	3.9842	1.3281	1.61	0.206
Mulch	2	0.5713	0.5713	0.2856	0.35	0.710
Fertility	1	0.4033	0.4033	0.4033	0.49	0.490
Inter-row	1	1.5408	1.5408	1.5408	1.87	0.181
Mulch x Fertility	2	0.4829	0.4829	0.2415	0.29	0.748
Mulch x Inter-row	2	0.2554	0.2554	0.1277	0.15	0.857
Fertility x Inter-row	1	0.3333	0.3333	0.3333	0.40	0.530
Mulch x Fertility x Inter-row	2	0.3854	0.3854	0.1927	0.23	0.793
Error	33	27.2558	27.2558	0.8259		
Total	47	35.2125				

$S = 0.908809$ $R^2 = 22.60\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-45. General Linear Model for the effects of test factors and their interactions on the number of shoots per plant in experiment #2 (September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	14.105	14.105	4.702	0.69	0.566
Mulch	2	1.286	1.286	0.643	0.09	0.910
Fertility	1	53.341	53.341	53.341	7.80	0.009
Inter-row	1	32.341	32.341	32.341	4.73	0.037
Mulch x Fertility	2	29.385	29.385	14.693	2.15	0.133
Mulch x Inter-row	2	26.330	26.330	13.165	1.93	0.162
Fertility x Inter-row	1	1.763	1.763	1.763	0.26	0.615
Mulch x Fertility x Inter-row	2	63.333	63.333	31.666	4.63	0.017
Error	33	225.615	225.615	6.837		
Total	47	447.500				

$S = 2.61473$ $R^2 = 49.58\%$ $R^2(\text{adjusted}) = 28.19\%$

Table B-46. General Linear Model for the effects of test factors and their interactions on the change in the number of shoots per plant in experiment #2 (May-September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	6.221	6.221	2.074	0.44	0.725
Mulch	2	1.149	1.149	0.574	0.12	0.885
Fertility	1	44.468	44.468	44.468	9.47	0.004
Inter-row	1	19.763	19.763	19.763	4.21	0.048
Mulch x Fertility	2	23.741	23.741	11.871	2.53	0.095
Mulch x Inter-row	2	21.430	21.430	10.715	2.28	0.118
Fertility x Inter-row	1	0.563	0.563	0.563	0.12	0.731
Mulch x Fertility x Inter-row	2	55.808	55.808	27.904	5.94	0.006
Error	33	154.909	154.909	4.694		
Total	47	328.053				

$S = 2.16661$ $R^2 = 52.78\%$ $R^2(\text{adjusted}) = 32.75\%$

Table B-47. General Linear Model for the effects of test factors and their interactions on plant spread in experiment #2 (May 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	508.8	508.8	169.6	1.47	0.242
Mulch	2	176.1	176.1	88.1	0.76	0.475
Fertility	1	202.1	202.1	202.1	1.75	0.195
Inter-row	1	0.9	0.9	0.9	0.01	0.931
Mulch x Fertility	2	59.2	59.2	29.6	0.26	0.776
Mulch x Inter-row	2	343.1	343.1	171.6	1.48	0.242
Fertility x Inter-row	1	28.4	28.4	28.4	0.25	0.624
Mulch x Fertility x Inter-row	2	166.5	166.5	83.3	0.72	0.494
Error	33	3817.9	3817.9	115.7		
Total	47	5303.0				

S = 10.7561 R^2 = 28.01% R^2(adjusted) = 0.00%

Table B-48. General Linear Model for the effects of test factors and their interactions on plant spread in experiment #2 (September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	157.7	157.7	52.6	0.15	0.930
Mulch	2	2483.7	2483.7	1241.8	3.51	0.041
Fertility	1	2141.3	2141.3	2141.3	6.06	0.019
Inter-row	1	5401.8	5401.8	5401.8	15.28	0.000
Mulch x Fertility	2	165.8	165.8	82.9	0.23	0.792
Mulch x Inter-row	2	2172.5	2172.5	1086.2	3.07	0.060
Fertility x Inter-row	1	276.5	276.5	276.5	0.78	0.383
Mulch x Fertility x Inter-row	2	1494.6	1494.6	747.3	2.11	0.137
Error	33	11666.4	11666.4	353.5		
Total	47	25960.3				

$S = 18.8024$ $R^2 = 55.06\%$ $R^2(\text{adjusted}) = 36.00\%$

Table B-49. General Linear Model for the effects of test factors and their interactions on the change in plant spread in experiment #2 (May-September 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1165.5	1165.5	388.5	2.11	0.118
Mulch	2	3459.1	3459.1	1729.5	9.37	0.001
Fertility	1	1027.7	1027.7	1027.7	5.57	0.024
Inter-row	1	5540.6	5540.6	5540.6	30.03	0.000
Mulch x Fertility	2	205.5	205.5	102.7	0.56	0.578
Mulch x Inter-row	2	893.7	893.7	446.9	2.42	0.104
Fertility x Inter-row	1	482.0	482.0	482.0	2.61	0.116
Mulch x Fertility x Inter-row	2	776.7	776.7	388.4	2.11	0.138
Error	33	6088.0	6088.0	184.5		
Total	47	19638.7				

S = 13.5825 R^2 = 69.00% R^2(adjusted) = 55.85%

Table B-50. General Linear Model for the effects of test factors and their interactions on the total biological yield of rose hips per plant in experiment #2 (October 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	3227	3227	1076	0.54	0.659
Mulch	2	13792	13792	6896	3.45	0.044
Fertility	1	2218	2218	2218	1.11	0.300
Inter-row	1	24203	24203	24203	12.11	0.001
Mulch x Fertility	2	5413	5413	2707	1.35	0.272
Mulch x Inter-row	2	16685	16685	8342	4.18	0.024
Fertility x Inter-row	1	1250	1250	1250	0.63	0.435
Mulch x Fertility x Inter-row	2	10590	10590	5295	2.65	0.086
Error	33	65934	65934	1998		
Total	47	143311				

$S = 44.6991$ $R^2 = 53.99\%$ $R^2(\text{adjusted}) = 34.47\%$

Table B-51. General Linear Model for the effects of test factors and their interactions on the total marketable yield of rose hips per plant in experiment #2 (October 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2206	2206	735	0.41	0.745
Mulch	2	11769	11769	5884	3.30	0.049
Fertility	1	1162	1162	1162	0.65	0.425
Inter-row	1	18037	18037	18037	10.11	0.003
Mulch x Fertility	2	5283	5283	2642	1.48	0.242
Mulch x Inter-row	2	13435	13435	6717	3.77	0.034
Fertility x Inter-row	1	1427	1427	1427	0.80	0.378
Mulch x Fertility x Inter-row	2	9016	9016	4508	2.53	0.095
Error	33	58876	58876	1784		
Total	47	121211				

$S = 42.2390$ $R^2 = 51.43\%$ R^2(adjusted) = 30.82%

Table B-52. General Linear Model for the effects of test factors and their interactions on the total number of rose hips per plant in experiment #2 (October 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2342	2342	781	0.75	0.531
Mulch	2	10325	10325	5162	4.95	0.013
Fertility	1	1289	1289	1289	1.24	0.274
Inter-row	1	6834	6834	6834	6.55	0.015
Mulch x Fertility	2	3416	3416	1708	1.64	0.210
Mulch x Inter-row	2	5518	5518	2759	2.64	0.086
Fertility x Inter-row	1	1003	1003	1003	0.96	0.334
Mulch x Fertility x Inter-row	2	4081	4081	2041	1.96	0.157
Error	33	34429	34429	1043		
Total	47	69238				

S = 32.3001 R^2 = 50.27% R^2(adjusted) = 29.18%

Table B-53. General Linear Model for the effects of test factors and their interactions on the percentage of rotten rose hips per plant in experiment #2 (October 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.011400	0.011400	0.003800	2.06	0.124
Mulch	2	0.005607	0.005607	0.002804	1.52	0.234
Fertility	1	0.023496	0.023496	0.023496	12.74	0.001
Inter-row	1	0.025522	0.025522	0.025522	13.84	0.001
Mulch x Fertility	2	0.006496	0.006496	0.003248	1.76	0.188
Mulch x Inter-row	2	0.006389	0.006389	0.003194	1.73	0.193
Fertility x Inter-row	1	0.001380	0.001380	0.001380	0.75	0.393
Mulch x Fertility x Inter-row	2	0.003498	0.003498	0.001749	0.95	0.398
Error	33	0.060847	0.060847	0.001844		
Total	47	0.144635				

$S = 0.0429401$ $R^2 = 57.93\%$ $R^2(\text{adjusted}) = 40.08\%$

Table B-54. General Linear Model for the effects of test factors and their interactions on the percentage of failed rose hips per plant in experiment #2 (October 2005; n = 48) using adjusted sum of squares for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.0001159	0.0001159	0.0000386	0.60	0.618
Mulch	2	0.0005057	0.0005057	0.0002528	3.95	0.029
Fertility	1	0.0000464	0.0000464	0.0000464	0.72	0.401
Inter-row	1	0.0003107	0.0003107	0.0003107	4.85	0.035
Mulch x Fertility	2	0.0004236	0.0004236	0.0002118	3.31	0.049
Mulch x Inter-row	2	0.0001626	0.0001626	0.0000813	1.27	0.295
Fertility x Inter-row	1	0.0000000	0.0000000	0.0000000	0.00	0.985
Mulch x Fertility x Inter-row	2	0.0000611	0.0000611	0.0000306	0.48	0.625
Error	33	0.0021149	0.0021149	0.0000641		
Total	47	0.0037410				

$S = 0.00800542$ $R^2 = 43.47\%$ $R^2(\text{adjusted}) = 19.48\%$

Table B-55. General Linear Model for the effects of test factors and their interactions on [P] in soil, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	16804.4	16804.4	5601.5	17.02	0.000
Mulch	2	1750.1	1750.1	875.0	2.66	0.080
Fertility	2	5080.2	5080.2	2540.1	7.72	0.001
Inter-row	1	1382.3	1382.3	1382.3	4.20	0.046
Mulch x Fertility	4	3546.2	3546.2	886.5	2.69	0.041
Mulch x Inter-row	2	260.5	260.5	130.3	0.40	0.675
Fertility x Inter-row	2	1831.1	1831.1	915.5	2.78	0.071
Mulch x Fertility x Inter-row	4	391.3	391.3	97.8	0.30	0.878
Error	51	16780.1	16780.1	329.0		
Total	71	47826.3				

$S = 18.1389$ $R^2 = 64.91\%$ $R^2(\text{adjusted}) = 51.16\%$

Table B-56. General Linear Model for the effects of test factors and their interactions on [K] in soil, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	2482.4	2482.4	827.5	1.98	0.129
Mulch	2	890.9	890.9	445.5	1.07	0.352
Fertility	2	32687.3	32687.3	16343.7	39.08	0.000
Inter-row	1	206.8	206.8	206.8	0.49	0.485
Mulch x Fertility	4	8359.2	8359.2	2089.8	5.00	0.002
Mulch x Inter-row	2	285.4	285.4	142.7	0.34	0.713
Fertility x Inter-row	2	1773.7	1773.7	886.9	2.12	0.130
Mulch x Fertility x Inter-row	4	332.0	332.0	83.0	0.20	0.938
Error	51	21331.3	21331.3	418.3		
Total	71	68349.1				

$S = 20.4514$ $R^2 = 68.79\%$ $R^2(\text{adjusted}) = 56.55\%$

Table B-57. General Linear Model for the effects of test factors and their interactions on [Ca] in soil, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	175802	175802	58601	2.20	0.099
Mulch	2	109446	109446	54723	2.05	0.139
Fertility	2	3042360	3042360	1521180	57.10	0.000
Inter-row	1	9499	9499	9499	0.36	0.553
Mulch x Fertility	4	237048	237048	59262	2.22	0.079
Mulch x Inter-row	2	181215	181215	90607	3.40	0.041
Fertility x Inter-row	2	21542	21542	10771	0.40	0.670
Mulch x Fertility x Inter-row	4	327362	327362	81841	3.07	0.024
Error	51	1358669	1358669	26641		
Total	71	5462944				

$S = 163.219$ $R^2 = 75.13\%$ $R^2(\text{adjusted}) = 65.38\%$

Table B-58. General Linear Model for the effects of test factors and their interactions on [Mg] in soil, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	962.78	962.78	320.93	3.89	0.014
Mulch	2	203.11	203.11	101.56	1.23	0.300
Fertility	2	5116.78	5116.78	2558.39	31.04	0.000
Inter-row	1	2.72	2.72	2.72	0.03	0.857
Mulch x Fertility	4	788.14	788.14	197.03	2.39	0.063
Mulch x Inter-row	2	580.78	580.78	290.39	3.52	0.037
Fertility x Inter-row	2	96.78	96.78	48.39	0.59	0.560
Mulch x Fertility x Inter-row	4	1351.47	1351.47	337.87	4.10	0.006
Error	51	4203.22	4203.22	82.42		
Total	71	13305.78				

$S = 9.07833$ $R^2 = 68.41\%$ $R^2(\text{adjusted}) = 56.02\%$

Table B-59. General Linear Model for the effects of test factors and their interactions on soil pH in experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.04153	0.04153	0.01384	0.46	0.711
Mulch	2	0.11861	0.11861	0.05931	1.98	0.149
Fertility	2	2.78778	2.78778	1.39389	46.43	0.000
Inter-row	1	0.03125	0.03125	0.03125	1.04	0.312
Mulch x Fertility	4	0.50722	0.50722	0.12681	4.22	0.005
Mulch x Inter-row	2	0.10083	0.10083	0.05042	1.68	0.197
Fertility x Inter-row	2	0.01000	0.01000	0.00500	0.17	0.847
Mulch x Fertility x Inter-row	4	0.37167	0.37167	0.09292	3.10	0.023
Error	51	1.53097	1.53097	0.03002		
Total	71	5.49986				

$S = 0.173260$ $R^2 = 72.16\%$ $R^2(\text{adjusted}) = 61.25\%$

Table B-60. General Linear Model for the effects of test factors and their interactions on %N in leaf tissue, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.32272	0.32272	0.10757	2.12	0.109
Mulch	2	0.96114	0.96114	0.48057	9.47	0.000
Fertility	2	1.07102	1.07102	0.53551	10.56	0.000
Inter-row	1	0.00056	0.00056	0.00056	0.01	0.917
Mulch x Fertility	4	0.28611	0.28611	0.07153	1.41	0.244
Mulch x Inter-row	2	0.01119	0.01119	0.00559	0.11	0.896
Fertility x Inter-row	2	0.01202	0.01202	0.00601	0.12	0.889
Mulch x Fertility x Inter-row	4	0.16484	0.16484	0.04121	0.81	0.523
Error	51	2.58748	2.58748	0.05073		
Total	71	5.41706				

$S = 0.225244$ $R^2 = 52.23\%$ $R^2(\text{adjusted}) = 33.50\%$

Table B-61 General Linear Model for the effects of test factors and their interactions on %Ca in leaf tissue, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.55671	0.55671	0.18557	4.54	0.007
Mulch	2	0.01003	0.01003	0.00501	0.12	0.885
Fertility	2	0.08047	0.08047	0.04023	0.99	0.380
Inter-row	1	0.03507	0.03507	0.03507	0.86	0.358
Mulch x Fertility	4	0.10698	0.10698	0.02674	0.65	0.626
Mulch x Inter-row	2	0.04476	0.04476	0.02238	0.55	0.581
Fertility x Inter-row	2	0.02999	0.02999	0.01500	0.37	0.695
Mulch x Fertility x Inter-row	4	0.17954	0.17954	0.04489	1.10	0.367
Error	51	2.08306	2.08306	0.04084		
Total	71	3.12660				

$S = 0.202100$ $R^2 = 33.38\%$ $R^2(\text{adjusted}) = 7.25\%$

Table B-62. General Linear Model for the effects of test factors and their interactions on %Mg in leaf tissue, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.012969	0.012969	0.004323	3.33	0.027
Mulch	2	0.000187	0.000187	0.000094	0.07	0.931
Fertility	2	0.006460	0.006460	0.003230	2.49	0.093
Inter-row	1	0.000020	0.000020	0.000020	0.02	0.901
Mulch x Fertility	4	0.003985	0.003985	0.000996	0.77	0.552
Mulch x Inter-row	2	0.003587	0.003587	0.001793	1.38	0.261
Fertility x Inter-row	2	0.001818	0.001818	0.000909	0.70	0.501
Mulch x Fertility x Inter-row	4	0.005669	0.005669	0.001417	1.09	0.371
Error	51	0.066261	0.066261	0.001299		
Total	71	0.100957				

S = 0.0360450 R^2 = 34.37% R^2(adjusted) = 8.63%

Table B-62. General Linear Model for the effects of test factors and their interactions on %P in leaf tissue, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.019161	0.019161	0.006387	1.65	0.189
Mulch	2	0.004895	0.004895	0.002448	0.63	0.535
Fertility	2	0.014120	0.014120	0.007060	1.83	0.171
Inter-row	1	0.042108	0.042108	0.042108	10.90	0.002
Mulch x Fertility	4	0.004732	0.004732	0.001183	0.31	0.872
Mulch x Inter-row	2	0.012699	0.012699	0.006350	1.64	0.203
Fertility x Inter-row	2	0.013057	0.013057	0.006529	1.69	0.195
Mulch x Fertility x Inter-row	4	0.017122	0.017122	0.004280	1.11	0.363
Error	51	0.196961	0.196961	0.003862		
Total	71	0.324856				

$S = 0.0621448$ $R^2 = 39.37\%$ $R^2(\text{adjusted}) = 15.59\%$

Table B-63. General Linear Model for the effects of test factors and their interactions on %K in leaf tissue, experiment #1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.40494	0.40494	0.13498	2.52	0.068
Mulch	2	0.05226	0.05226	0.02613	0.49	0.617
Fertility	2	0.09979	0.09979	0.04990	0.93	0.401
Inter-row	1	0.00007	0.00007	0.00007	0.00	0.971
Mulch x Fertility	4	0.21755	0.21755	0.05439	1.02	0.408
Mulch x Inter-row	2	0.11405	0.11405	0.05702	1.06	0.352
Fertility x Inter-row	2	0.05631	0.05631	0.02816	0.53	0.594
Mulch x Fertility x Inter-row	4	0.22033	0.22033	0.05508	1.03	0.402
Error	51	2.73240	2.73240	0.05358		
Total	71	3.89770				

$S = 0.231466$ $R^2 = 29.90\%$ $R^2(\text{adjusted}) = 2.41\%$

Table B-64. General Linear Model for the effects of test factors and their interactions on [P] in soil, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	11695.6	11695.6	3898.5	11.87	0.000
Mulch	2	1897.8	1897.8	948.9	2.89	0.070
Fertility	1	984.3	984.3	984.3	3.00	0.093
Inter-row	1	1202.4	1202.4	1202.4	3.66	0.064
Mulch x Fertility	2	334.8	334.8	167.4	0.51	0.605
Mulch x Inter-row	2	43.9	43.9	21.9	0.07	0.936
Fertility x Inter-row	1	3.6	3.6	3.6	0.01	0.917
Mulch x Fertility x Inter-row	2	127.8	127.8	63.9	0.19	0.824
Error	33	10840.5	10840.5	328.5		
Total	47	27130.7				

$S = 18.1246$ $R^2 = 60.04\%$ $R^2(\text{adjusted}) = 43.09\%$

Table B-65. General Linear Model for the effects of test factors and their interactions on [K] in soil, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	1590.6	1590.6	530.2	1.16	0.341
Mulch	2	2731.3	2731.3	1365.6	2.98	0.065
Fertility	1	6442.7	6442.7	6442.7	14.05	0.001
Inter-row	1	281.3	281.3	281.3	0.61	0.439
Mulch x Fertility	2	2195.6	2195.6	1097.8	2.39	0.107
Mulch x Inter-row	2	553.0	553.0	276.5	0.60	0.553
Fertility x Inter-row	1	405.1	405.1	405.1	0.88	0.354
Mulch x Fertility x Inter-row	2	354.4	354.4	177.2	0.39	0.683
Error	33	15136.2	15136.2	458.7		
Total	47	29690.2				

$S = 21.4167$ $R^2 = 49.02\%$ $R^2(\text{adjusted}) = 27.39\%$

Table B-66. General Linear Model for the effects of test factors and their interactions on [Ca] in soil, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	11290	11290	3763	0.68	0.573
Mulch	2	3838	3838	1919	0.34	0.711
Fertility	1	936	936	936	0.17	0.684
Inter-row	1	2214	2214	2214	0.40	0.533
Mulch x Fertility	2	2496	2496	1248	0.22	0.800
Mulch x Inter-row	2	16735	16735	8368	1.50	0.237
Fertility x Inter-row	1	3502	3502	3502	0.63	0.433
Mulch x Fertility x Inter-row	2	1158	1158	579	0.10	0.902
Error	33	183715	183715	5567		
Total	47	225885				

S = 74.6132 R^2 = 18.67% R^2(adjusted) = 0.00%

Table B-67. General Linear Model for the effects of test factors and their interactions on [Mg] in soil, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	469.42	469.42	156.47	1.61	0.207
Mulch	2	45.50	45.50	22.75	0.23	0.793
Fertility	1	5.33	5.33	5.33	0.05	0.816
Inter-row	1	114.08	114.08	114.08	1.17	0.287
Mulch x Fertility	2	15.17	15.17	7.58	0.08	0.925
Mulch x Inter-row	2	366.17	366.17	183.08	1.88	0.169
Fertility x Inter-row	1	108.00	108.00	108.00	1.11	0.300
Mulch x Fertility x Inter-row	2	2.00	2.00	1.00	0.01	0.990
Error	33	3215.58	3215.58	97.44		
Total	47	4341.25				

$S = 9.87127$ $R^2 = 25.93\%$ $R^2(\text{adjusted}) = 0.00\%$

Table B-68. General Linear Model for the effects of test factors and their interactions on soil pH in experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.15750	0.15750	0.05250	1.99	0.135
Mulch	2	0.25042	0.25042	0.12521	4.74	0.016
Fertility	1	0.90750	0.90750	0.90750	34.32	0.000
Inter-row	1	0.00083	0.00083	0.00083	0.03	0.860
Mulch x Fertility	2	0.04875	0.04875	0.02438	0.92	0.408
Mulch x Inter-row	2	0.03792	0.03792	0.01896	0.72	0.496
Fertility x Inter-row	1	0.02083	0.02083	0.02083	0.79	0.381
Mulch x Fertility x Inter-row	2	0.00292	0.00292	0.00146	0.06	0.946
Error	33	0.87250	0.87250	0.02644		
Total	47	2.29917				

$S = 0.162602$ $R^2 = 62.05\%$ $R^2(\text{adjusted}) = 45.95\%$

Table B-69. General Linear Model for the effects of test factors and their interactions on %N in leaf tissue, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.44804	0.44804	0.14935	2.63	0.066
Mulch	2	0.78668	0.78668	0.39334	6.93	0.003
Fertility	1	0.86135	0.86135	0.86135	15.17	0.000
Inter-row	1	0.02385	0.02385	0.02385	0.42	0.521
Mulch x Fertility	2	0.52793	0.52793	0.26396	4.65	0.017
Mulch x Inter-row	2	0.09543	0.09543	0.04771	0.84	0.441
Fertility x Inter-row	1	0.29610	0.29610	0.29610	5.22	0.029
Mulch x Fertility x Inter-row	2	0.06588	0.06588	0.03294	0.58	0.565
Error	33	1.87334	1.87334	0.05677		
Total	47	4.97860				

$S = 0.238260$ $R^2 = 62.37\%$ $R^2(\text{adjusted}) = 46.41\%$

Table B-70. General Linear Model for the effects of test factors and their interactions on %Ca in leaf tissue, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.09447	0.09447	0.03149	1.86	0.155
Mulch	2	0.03402	0.03402	0.01701	1.01	0.376
Fertility	1	0.16827	0.16827	0.16827	9.96	0.003
Inter-row	1	0.06206	0.06206	0.06206	3.67	0.064
Mulch x Fertility	2	0.02554	0.02554	0.01277	0.76	0.478
Mulch x Inter-row	2	0.05818	0.05818	0.02909	1.72	0.194
Fertility x Inter-row	1	0.02034	0.02034	0.02034	1.20	0.280
Mulch x Fertility x Inter-row	2	0.00702	0.00702	0.00351	0.21	0.813
Error	33	0.55746	0.55746	0.01689		
Total	47	1.02736				

$S = 0.129972$ $R^2 = 45.74\%$ $R^2(\text{adjusted}) = 22.72\%$

Table B-71. General Linear Model for the effects of test factors and their interactions on %Mg in leaf tissue, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.0022784	0.0022784	0.0007595	2.08	0.122
Mulch	2	0.0021700	0.0021700	0.0010850	2.97	0.065
Fertility	1	0.0033450	0.0033450	0.0033450	9.16	0.005
Inter-row	1	0.0009074	0.0009074	0.0009074	2.49	0.124
Mulch x Fertility	2	0.0002739	0.0002739	0.0001370	0.38	0.690
Mulch x Inter-row	2	0.0021577	0.0021577	0.0010789	2.95	0.066
Fertility x Inter-row	1	0.0002266	0.0002266	0.0002266	0.62	0.436
Mulch x Fertility x Inter-row	2	0.0002305	0.0002305	0.0001152	0.32	0.732
Error	33	0.0120495	0.0120495	0.0003651		
Total	47	0.0236391				

S = 0.0191085 R^2 = 49.03% R^2(adjusted) = 27.40%

Table B-72. General Linear Model for the effects of test factors and their interactions on %P in leaf tissue, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.014719	0.014719	0.004906	3.76	0.020
Mulch	2	0.001673	0.001673	0.000836	0.64	0.533
Fertility	1	0.000398	0.000398	0.000398	0.31	0.584
Inter-row	1	0.008177	0.008177	0.008177	6.26	0.017
Mulch x Fertility	2	0.005706	0.005706	0.002853	2.19	0.128
Mulch x Inter-row	2	0.006316	0.006316	0.003158	2.42	0.105
Fertility x Inter-row	1	0.005463	0.005463	0.005463	4.18	0.049
Mulch x Fertility x Inter-row	2	0.007831	0.007831	0.003915	3.00	0.064
Error	33	0.043086	0.043086	0.001306		
Total	47	0.093370				

S = 0.0361338 R^2 = 53.85% R^2(adjusted) = 34.28%

Table B-73. General Linear Model for the effects of test factors and their interactions on %K in leaf tissue, experiment #2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Block	3	0.186491	0.186491	0.062164	7.10	0.001
Mulch	2	0.097257	0.097257	0.048629	5.55	0.008
Fertility	1	0.033444	0.033444	0.033444	3.82	0.059
Inter-row	1	0.017595	0.017595	0.017595	2.01	0.166
Mulch x Fertility	2	0.012761	0.012761	0.006380	0.73	0.490
Mulch x Inter-row	2	0.008878	0.008878	0.004439	0.51	0.607
Fertility x Inter-row	1	0.000173	0.000173	0.000173	0.02	0.889
Mulch x Fertility x Inter-row	2	0.005882	0.005882	0.002941	0.34	0.717
Error	33	0.288948	0.288948	0.008756		
Total	47	0.651428				

$S = 0.0935736$ $R^2 = 55.64\%$ $R^2(\text{adjusted}) = 36.83\%$