AMERICAN UNIVERSITY OF BEIRUT

REDUCED RATES OF METRIBUZIN AND HILLING TIME FOR WEED MANAGEMENT IN POTATO

by
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A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science
to the Department of Agriculture
of the Faculty of Agricultural and Food Sciences
at the American University of Beirut

Beirut, Lebanon
September 2015

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ACKNOWLEDGMENTS

It should be acknowledged at the outset that this project's materialization would not have been possible without the kind support and help of many individuals. I would like to extend my sincere gratitude to all of them.

Foremost, I am highly indebted to Dr. Mustapha Haidar, my advisor, professor, and academic father for his support, patience, encouragement and immense knowledge. His guidance and unceasing supervision have helped me throughout the research and writing of this thesis. I genuinely could not have imagined having a better advisor and mentor.

In addition, I would like to thank the rest of my thesis committee: Dr. Isam Bashour, Dr. Nadim Farajalla, and Dr. Salwa Tohme Tawk, for serving as my committee members and for their insightful comments and advice, which have helped me widen my research from various perspectives.

I would also like to express my gratitude towards the AREC staff, particularly Mr. Nicolas Haddad, for their kind cooperation. They provided me with all the necessary facilities for my research, and gave me plenty attention and time.

I would like to thank my parents, my sister, my brother, and my family for all of the sacrifices they made on my behalf. Their indefatigable support was what sustained me thus far.

My thanks and appreciations also go to my friends and colleagues in developing the project and to all the people who have willingly helped me with their abilities.

Finally but importantly, my special and deepest gratitude goes to the engineer Ali Mroweh. Words cannot express how grateful I am for having him as a friend. In addition to being an excellent research assistant, who helped me physically, from the very beginning to the very last minute of the research, he supported me spiritually in writing the thesis and pushed me to constantly strive towards my goal.

AN ABSTRACT OF THE THESIS OF

Walaa Siblani for Master of Science
Major: Plant Science

Title: Reduced Rates of Metribuzin and Increased Hilling Time for Weed Management in Potato

The current emphasis on reducing herbicide applications has led to an increase in alternative weed control measures. Field and greenhouse experiments were conducted in the spring and fall semesters of 2014-2015 to examine the effect of hilling-time and reduced- rates of metribuzin and their combinations on weed infestation in potato, and to determine their impact on potato yield. Metribuzin at 0.18, 0.35, 0.65, or 0.75kg ai/ha with or without hilling 6, 7, and 8 weeks after planting (WAP) were used. Weed count, weed control visual rating, weed dry weight, potato plant height, number of shoots and leaves, dry weight, phytotoxicity visual rating, and potato yield (number and weight of marketable and nonmarketable) were collected. Results of the field experiment showed that metribuzin, at all tested rates, with or without hilling significantly reduced weed infestation after 50, 70, and 110 days after planting (DAP) compared to the check. However, the effect of hilling alone on weed infestation was not significantly different from the check. All treatments (metribuzin or hilling) significantly reduced weed dry weight compared to the check. Best results considering long season weed management, selectivity, and marketable yield of potato were obtained by a combination of metribuzin at all tested rates with hilling 6, 7, and 8 WAP. Results of the greenhouse experiment showed that metribuzin at all tested rates significantly reduced all weeds early in the season, compared to the check. However, late in the season, only metribuzin at 0.56 and 0.75kg ai/ha were effective against weeds in comparison to the check. None of the metribuzin treatments was toxic to potato plants compared to the hand-weeded plots. The results suggest that long season weed control could be suppressed by metribuzin at 0.35kg ai/ha (53% reduction in metribuzin) supplemented with hilling (6 and 8 WAP).

Keywords: Weeds, metribuzin, hilling, potato

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ABBREVIATIONS

&	And
°C	Degrees Celsius
$	Dollar
/	Per
%	Percentage of Hundred
>	Greater than
<	Less than
α	Alpha (significant level)
#	Number
ai	Active Ingredient
ANOVA	Analysis of Variance
AREC	Advancing Research Enabling Communities Center
ASAE	The American Society of Association Executives
AUB	American University of Beirut
CIP	Centro Internacional de la Papa (International Potato Center)
cm	Centimeter
CNS	Central Nervous System
CO_2	Carbon Dioxide
DAP	Days After Planting
DF	Dry Flowables
DNA	Deoxyribonucleic Acid
dS/m	Deci Siemens per meter
du	Dunum
EC	Electrical Conductivity
EPA	Environmental Protection Agency
EPTC	S-ethyl dipropylcarbamothioate
et al.	et alia (means "and others")
etc	et cetera (means "and so forth")
F	Flowable
FAO	Food and Agriculture Organization of the United Nations
FAFS	Faculty of Agricultural and Food Sciences
ha	Hectare
IARC	International Agency for Research on Cancer
IWM	Integrated Weed Management
g	Gram
g com/ha	Gram commercial per hectare
K	Potassium
Kg	Kilogram
kPa	Kilopascal
l	Liter

L	Liquid
L/ha	Liter per hectare
M	Metribuzin
m	Meter
m^2	Square Meters
ml	Milliliter
N	Nitrogen
P	Phosphorous
pH	Potential Hydrogen
ppm	Parts per million
PRE	Pre Emergence
psi	Pounds per square inch
PTO	Power Take-Off
PVR	Phytotoxicity Visual Rating
®	Registered Trademark
RCBD	Randomised Complete Block Design
Rep	Replicate
S	Sulfur
SO_3	Sulfur Trioxide
Spp.	Species
TCDD	2,3,7,8- Tetrachlorodibenzodioxin
t/ha	Ton per Hectare
TPS	True Potato Seed
UK	United Kingdom
U.S.	United States
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
VAM	Vesicular- Arbuscular Mychorrhizae
WAP	Weeks After Planting
WCVR	weed count visual rating
WP	Wettable Powder

CHAPTER I

INTRODUCTION

Solanum tuberosum, commonly known as potato is considered one of the most important strategic crops in the Mediterranean region. In Lebanon, the Beq'aa and Akkar provinces are the main potato producing areas in the country, with about 68% and 19% of the total production, respectively (Abou-Jawdah *et al*., 2001). Potato is susceptible to several pests among them are weeds that compete for resources with summer, spring, and autumn planted potatoes across Lebanon and the Mediterranean region.

Weeds are a major problem in potato production in Lebanon. They can cause significant loss of yields through direct competition for light, moisture, and nutrients, as well as harbor insects and diseases that attack potato. They also present a problem at harvest by increasing mechanical damage to tubers, reducing harvesting efficiency, and slowing down harvesting operations. In Lebanon, potato production involves using conventional tillage method, mechanical planting, and hilling within one month from planting. Hilling is accomplished mainly with a locally manufactured plow to aerate the soil, enhances tuber development, and prevents exposure of tubers to sunlight. Also, weed management involves hand weeding and the use of pre or post application of herbicide Metribuzin (Sencor®) at 0.75 kg ai/ha. However, the globally rising public concern about the use of herbicides has shifted trends towards reduction in their use. The reliance on herbicides poses environmental and economic threat, since herbicides are expensive and can leach in the soil contaminating groundwater, especially when farmers apply high dosage to achieve maximum control instead of just satisfactory management (Bellinder *et al.*, 1994); Some weeds are becoming resistant to herbicides (Binning *et al.*, 1991; Burgard *et al.*, 1994). Therefore, many researchers are investigating the benefits of integrated mechanical and herbicide techniques for weed management practices (Chitsaz and Nelson, 1983; Sieczka and Creighton, 1984; Eberlein *et al.*, 1997).

In order to reduce chemical load on the environment without significant loss in yield, the time and number of hilling operations and herbicide application rates must be optimized. Excessive tillage is costly and can increase soil compaction and lower tuber production, while herbicides pose a potential hazard to the environment. Taking into consideration the environmental and economic aspects posed by these practices, proper hilling times and herbicide rates should be maintained. Accordingly, the objective of this study was to examine weed control with, and potato tolerance to, various combinations of hilling-time and reduced-rates of metribuzin.

CHAPTER II

LITERATURE REVIEW

Potato (*Solanum tuberosum*) in the family *Solanaceae* is a cash crop, with high dietary qualities and numerous uses (Survase and Singhal, 2009). It is grown globally and considered to be number one tuber crop and comes after rice, wheat, and corn. Until 1900s, potato growers breed seeds that can adapt day-length, resist pests, and give high quality and quantity. Along these characteristics, today breeds search for other characteristics, such as enhanced processing value, high nutritional values, early ripeness, better tuber shapes, etc. (Douches *et al*., 1996; Love *et al*., 1998). But the total potato yields have not increased during the last years (Jansky, 2009).

A. Origin

The first potato was found in 1537 in Colombia (Hawkes, 1990). Then it was exported, in 1567, to Belgium, Antwerp, from the Canary Islands, mainly Gran Canaria (Hawkes and Francisco- Ortega, 1993), and then it was transported to Spain markets in 1573 after it was detected by Hawkes and Francisco-Ortega (1992), in the archives of Seville's Hospital de La Sangre. Finally, it was introduced to Europe in 1562, grown for research and pharmaceutical purposes (Hawkes and Francisco-Ortega, 1993). It was first used as food in the 17th and 18th centuries in Ireland due to its suitable environmental and socio-economical motivations (Burton, 1989), which led to tremendous increase in the Irish population (Reader, 2008). But the over consumption of potatoes led to 1845 and 1846 famine in Ireland due to the outbreak of late blight caused by the fungus *Phytophthora infestans*.

Later on, it was cultivated in British as a field crop to supply the requirements of the low-priced laborers who migrate from Ireland and supported the Industrial Revolution (Reader, 2008). Then potato was planted to empower European men for wars in the 18th century. And when Europe invades the world through colonization and missionaries in the 16th century, potato was among the foods that was transported with them (Burton, 1989), where Spanish brought it to the Philippines at the end of the 17th century, Dutch introduced it to East and South East Asia in the 18th century, British to India, Portuguese to Africa, French and Britain to islands of the tropical Pacific Ocean, and it was cultivated in USA, old Virginia, in 1621, after it was grown in Bermuda in 1613. Also, Russian traders introduced potato plantation to central China in the 17th century, after it was initiated by the European missionaries in China coasts and Taiwan (Pandey and Kaushik, 2003), afterwards spreading globally in the 19th century. Nowadays, China is considered the first and India the third potato producers worldwide, counting for almost 33% of potato production in the world, since the 20th century (Navarre *et al.*, 2009).

B. Uses

Potatoes are primarily used as a food crop. And this vegetable needs to be cooked either by boiling, baking, or frying since the starch it contains is not gelatinized which makes it indigestible if eaten raw (Burton, 1989). In North America and several countries in Europe, 50-60% of potato production goes for processing as French fries and chips. And some other countries use dried potatoes for the production of starch (Kirkman, 2007; Li *et* *al.*, 2006). Potato pulps can be also used as silage that is fermented, high in moisture animal forage for winter (Lisinka and Leszczynski, 1989). Moreover, potato can be used for pharmaceutical purposes in many medicines and vaccines against cancers, diabetes, cholera, enteric virus, hepatitis B, mouth and foot disease virus, Norwalk virus, rabbit hemorrhagic virus, and against many bacteria (Li *et al.*, 2006). Recently, potato skins, removed in potato industry, are used in food synthesis (Rodriguez de Sotillo *et al.*, 1994a, 1994b) as a natural antioxidant that can protect from many chronic diseases and free radicals, since it contains phenolics (Lisinka and Leszczynski, 1989).

C. Nutritional value

Potato is a very important crop and the most consumed vegetable in the world for its high nutritional values and caloric yields, which are currently needed to supply the growing populations' demand for fortified foods with low prices instead of biofuel crops invading the agricultural lands (Navarre *et al.*, 2009).

A potato tuber consists of 20% solid matter and 80% water, which vary according to each potato variety. Water-extractable starch consists 65-75% out of the tuber's dry matter (Burton, 1989). This starch is valuable for many industrial purposes, after its adjustment physically and chemically. For instance, potato starch can be used for gel, coats, and capsules manufacturing, for coagulation in alcohol industry, as adhesive and sizing agent in fabric and paper industry, as food constituent, and as biodegradable plastics with starch base (Li *et al.*, 2006).

Part of the potatoes' starch is "resistant starch". Resistant starch is important as a prebiotic, helps in the anticipation of colon cancer, improves glycemia by controlling metabolism in type II diabetes, reduces cholesterol and triglycerides levels in blood, restrains fat buildup in the body, decreases gall stone development, enhances satiety, and improves minerals' absorption (Cummings *et al*., 1996; Hylla *et al*., 1998; Raban *et al*., 1994).

Potatoes also contain considerable quantity of protein, with fine amino acid equilibrium, that is stored mainly as patitins in tubers, consisting 40% of the total soluble proteins in potatoes (Prat *et al.*, 1990). Also, it contains few nitrogenous compounds of non-protein origin, like amides and free amino acids (Steward and Durzan, 1965; Steward *et al*., 1981).

Moreover, potatoes are good source of dietary fibers when consumed with the peel and almost free of fat and cholesterol. And due to its high consumption, potato supplies vitamins and minerals (Navarre *et al.*, 2009). It provides B1, B6, C, and folate as vitamins, calcium, potassium, magnesium, and phosphorus as minerals, and zinc and iron as micronutrients (Storey, 2007).

D. Plantation

Potato is a cool season crop that can grow ideally in a temperature range between 5 and 21°C where it is neither cold nor hot either rain-fed or irrigated (Govindakrishan and Haverkort, 2006). However, growth is influenced differently according to temperature and photoperiod. Tuber formation is stimulated during short days with high temperatures, while long days cause flowering and formation of lateral branches (Moreno, 1985).

Good seedbed preparation is of primary importance to insure a high yield. Thus, good seedbed preparation ensures quick emergence, deep penetration of the roots, and welldrained loose soil. As for plant depth, potatoes planted near top surface will germinate earlier in the growing season but this has no significant effect on total yields (Bohl and Love, 2005; Lewis and Rowberry, 1973; Moore, 1937; Moursi, 1953; Stalham *et al.*, 2001). Besides, yields can be improved by effective interception of light maintained by consistent and fast haulm growth, especially in the Mediterranean region, where foliage growth can take advantage of the weather state until the beginning of winter in November. But the most important factor for higher yields and higher potato quality is the use of seed tubers with excellent quality free from diseases at the correct physiological age.

1. Potato Tuber

Tubers are enlarged stolon laterals, where the apex of the stolon or the tuber's end is called "bud" or "rose" end, and the other end is called "stem" or "heel" end, as illustrated by Peterson *et al*. (1985).

Leaves of the stolons with its spiral phyllotaxy and the axillary buds connected to them are called "eyes" (Reeve, 1954), thus each eye is a node of the stem formed from axillary bud connected to two leaves produced by a larger main axillary bud that has a scale leaf enfolding it (Adams, 1975; Cutter, 1978) and sprouts appear first from this central bud when the tuber germinates. Eyes appear at different depth with respect to the tuber's surface (Burton, 1966). Also, the external surface of the tuber has small white specks called "lenticels" (Artschwager, 1924). The shape of the potato tuber vary from variety to the other, the peel can be smooth or rough with a color range from white, yellow to dark purple (Burton, 1966).

After a period of dormancy, potato tubers can be recultivated for a second and third time whenever climatic state is suitable, even though some cultivars may produce deformed tubers (Bodlaender *et al*., 1964).

2. True Potato Seeds (TPS)

Since seed potato tubers, which reproduce asexually producing uniform and identical seedlings, are known to transmit diseases, true potato seeds are collected from natural berries and propagated (Bradshaw and Ramsay, 2009) in the sake of consistent vegetative growth and higher production. First, it was produced by the International Potato Center (CIP) in Lima, Peru, in 1972, after then it spreads in many countries, such as China, India, Nicaragua, Philippines, Vietnam, Egypt, Indonesia, Peru, and southern Italy (Almekinders *et al*., 1996; Chilver *et al*., 2005; Ortiz, 1997; Simmonds, 1997).

Even though TPS show high genetic variability, delayed maturity, and inconsistent growth, they are inexpensive with lower inputs required, viable all over the season so farmers can plant at any time, and disease-free in spite of some seed-borne diseases (Golmirzaie *et al*., 1994).

E. Harvesting

Potato tubers are considered physiologically mature when they reach perfect size with maximum starch amounts, minimum soluble sugars, and well-developed skin that has condensed periderm under its epidermis preventing skin injuries or “feathering” caused when harvesting (Brecht, 2003).

However, many reasons can affect this morphological and physiological process known as maturity including dry matter, carbohydrate modifications, respiration, and water content levels that are affected by skin formation, sprouting, and dormancy. For instance, immature tubers respires four to five folds more than mature tubers (Pinhero *et al.,* 2009).

Tubers can be harvested mature, late in the season, or immature, early in the season while the new tubers are still growing. Tubers harvested earlier in the season are fragile, more prone to injures, have undeveloped peels, but more tender, utilized for industrial purposes or sold at high costs when potato market is demanding. Late-harvested tubers are either processed or stored.

Marketable tubers should be firm, with consistent light color and good shape, free from sticky soil particles, sprouting, bruising, greening, infections, and any factor that may affect its physiological functions, like damage due to freezing, sugar-end browning, blackspot, hollow and black heart, and necrotic center (Pinhero *et al.,* 2009).

F. Handling

When harvested, potato tubers should be collected immediately and cleaned dry from adhering soils without damaging them before exposure to sunlight since it can result in overheating and greening of the tubers thus boosting toxic glycoalkaloids levels and sometimes leading to blackening and cell death. Also, attention should be taken when handling potatoes, since around 75% of tuber injury occurs during grading, upon packaging and transportation.

External bruising varies in tubers of the same cultivar according to tuber’s turgidity, dry matter, and maturity, for instance skinning occurs in early-harvested tubers.

To decrease injury occurrences, tubers should remain cooled when harvested (Lewis, 2007), then, prior to grading, their temperature can be increased (Pinhero *et al.*, 2009).

G. Pests

Various pests infest potato fields and cause major losses in yields and deterioration in quality of production, include insects, pathogens, nematodes, viruses, and weeds. The latter, which includes parasitic weeds, is considered the major pests in potato.

1. Weeds

Weeds compete with plants for nutrients, water, space, light, and are possible vectors for pests. For instance, one corn crop needs around 167 liters of water to yield approximately a pound of corn, while for the production of one pound dry matter of weeds, a *Chenopodium album* requires 363 liters of water and *Ambrosia* spp. requires 430 liters (USDA, 1965). This competition is due to the weeds' high growth rate over different environments in addition to high seed production that allow them to live for long periods and occupy more spaces at the detriment of crops (Ashton and Monaco, 1991). For example, one *Amaranthus retroflexus* can produce around 117,400 seeds; one *Ambrosia artemisiifolia* can produce around 3,380 seeds, and one *Chenopodium album* can produce around 72,450 seeds (Anderson, 1983). Also, the seeds' special characteristics like wings, hooks, and spines, help them to be moved by water, wind, equipment, humans, and animals (Gianessi and Sankula, 2003).

This competition is also affected by the type of weeds infesting the field, where by monocot weeds are less competitive than dicots, since the leaves of dicot weeds have lager surface area thus can capture more light, for instance, the soil surface area occupied by one *Xanthium strumarium* is around 4-8 square feet, thus limiting the area provided for plants. Also, crop yields are affected by this competition, for example, 9 plants of the broadleaved *Xanthium strumarium* per square meter can decrease 80% of yield in a crop field, where as 6 plants of the grass *Setaria faberii* per square meter reduces crop yields by 10% only (Stoller *et al*., 1987).

Furthermore, weeds can facilitate the spread of diseases and insects either by being a barrier that blocks pesticide from reaching the planted crops (King, 1966; Klingman, 1961), or through being a host or reservoirs for many pathogens, insects, and disease vectors, mainly herbaceous annual weeds (Norris and Kogan, 2005). Hence, weeds should be controlled in order to limit viral epidemiology (Baldwin and Pereton, 1999). Moreover, weed seeds can contaminate crop seeds upon harvesting resulting in product refusal in the markets. For instance, lima beans or peas products will be rejected when contaminated with *Solanum nigrum* seeds since they look alike in color, size, and shape. Also, spinach or mint contaminated with weeds will have off flavor and low prices at the market (Gianessi and Sankula, 2003). This type of interference may result in poor crop yield and quality. Unfortunately, the weed infestation has been increasing due to improved irrigation, fertilizers, and pest management, and sometimes lack of crop rotations (Fricke, 1969; Fricke and Dallyn, 1970; Klingman, 1961; Sawyer and Dallyn, 1965).

a. Major weeds in Potatoes

Major weeds in potatoes in Lebanon are *Amaranthus retroflexus, Chenopodium album, Solanum nigrum, Datura stramonium, Xanthium strumarium, Malva* spp., *Portulaca* *oleracea*, *Convolvulus arvensis, Galium tricorne, Setaria viridis, Cyperus rotendus, Sorghum halepens, Cynodon dactylon, Digitria filiformes, Poa balbusa* (Jafar *et al*., 2013), *Orobanche ramosa* and *Cuscuta* spp. (Haidar and Sabra, 2012).

b. Influence of weeds on potato growth

Potato tubers number, weight, and size, thus total yields are reduced due to weeds competing for nutrients, water, and light (Caldiz and Panelo, 1985; Eberlein *et al.*, 1997; Saghir and Markoullis, 1974; Sweet, 1986; Wall and Friesen, 1990a, 1990b). Hence, more weeds infesting a field means more resources absorbed by weeds and the result is less resources availability for crops (Lehoczky *et al*., 2003; Żurawski and Sienkiewicz, 1981).

A broad spectrum of weeds can infest potato fields having direct economic impact, due to their competition for light, water, space, and nutrients thus yield reduction. Researches show that 30-40% of the potato yields were reduced due to weed competition (Hutchinson *et al*., 2011) and sometimes can reach 80% (Hashim, 2003; Jaiswal and Lal, 1996; Knezevic *et al*., 1995; Lal and Gupta, 1984). Also, there are the indirect costs of weeds which include costs of management- cultivation, labors, and herbicides. For instance, in Australia, the total costs of weed management and losses of yields due to weeds that are not controlled or not well controlled, according to Combellack (1987), were estimated at $2 billion. Whereas, in U.S. potato farms, herbicide use per acre replaced 10 hours of hand weeding and 5 tillage trips, where it is calculated that hand weeding costs $8.75/hour and cultivation costs $4.50/trip, thus a total cost of $110, whereas a herbicide costing $40 can be used instead, therefore $70 net gain in the presence of herbicide and

$654 production loss and $726 total impact in the absence of herbicides (Gianessi and Sankula, 2003).

The most significant period for weeds to compete with potatoes is from planting date to full foliage growth, between week 9 and 12 after sowing (Dallyn, 1971; Saghir and Markoullis, 1974). Besides, weeds that emerge late in the growing season can reduce the effectiveness of harvesting (VanGessel and Renner, 1990a), thus raising production costs (Nation, 1961; USDA, 1965). And this is the period of high seed production which aids in increasing the weed seed bank in soil (Gianessi and Sankula, 2003), but they are less threatening since they will be shaded by the crops. A 12% yield decrease in potato was observed when weed population increased by 10%, according to a report by Nelson and Thoreson (1981). For instance, if only one *Amaranthus retroflexus* plant emerged in a meter-potato- row for the whole season, yields will decease 19% (Vangessel and Renner, 1990b).

Therefore, weeds should be well controlled mainly from sowing until week 4 to 6 to avoid tremendous reduction in crop production. This critical period of weed-free may differ among weeds, crops, soil types, growing states, and can be affected by weather conditions and some practices like cultivation (Zimdahl, 1988).

c. Weed management

The main building block for an effective and economical weed management strategy is prevention (Norris *et al*., 2003). This involves attentive monitoring of new weed sources as well as weed vectors, declaring practical governmental decrees and laws that manage the entry of contaminated non indigenous crops and equipment, eliminating vegetative organs of perennial weeds, reducing weed seed banks in the soil, using weed-free plant seeds, avoiding weed seed set in the field, avoiding weed dispersal by machinery or other tools, eradicating weed seeds from animal manure and feed through composting or fermentation, and avoiding contamination of water and irrigation systems with weed seeds (Rizzardi *et al*., 2004). Later on, several strategies should be implemented, which includes cultural, biological, mechanical, and chemical weed management practices.

i. Biological Control

An economically feasible and environmentally friendly method to manage weeds in agricultural fields is using living herbivores. There are more than 350 herbivores used to control around 133 plant species in the world; insects constitute the majority. Other biocontrol agents are birds, bacteria, viruses, nematodes, slugs, snails, mammals, marsupials, fish, and crustaceans (Julien and Griffiths, 1998). However, their use as bio-agents is limited, since there are no efficient studies of the long-term effects and specifications of herbivores (Parker *et al*., 2006). For instance, implementing mammals as bio-agents was not encouraged by many researchers (Holst *et al*., 2004; Stanley *et al*., 2000). However, few studies show that *Rhinocyllus conicus* (the seed head feeding weevil) was found successful against *Carduus nutans*, *Sesbania punicea*, *Euphorbia esula*, *Azolla filiculoides*, *Senecio jacobaea*, *Acacia saligna*, and *Lythrum salicaria* (McConnachie *et al*., 2004; McFadyen, 2000). Moreover, some herbivores have been noted as biological control agents against some species that were considered difficult to be managed, such as *Chromolaena odorata*, *Cirsium arvense*, and *Cyperus rotundus* (Crawley, 1989).

Biocontrol agents should be host-specific in order to successfully control target weeds. However, prediction of host specificity is complicated (Blossey *et al*., 2001; Louda *et al*., 2003; McFadyen, 1998; Pemberton, 2000) since biological control agents may affect non-target weeds directly or after they became less host-specific (Louda *et al*., 1997; Simberloff and Stiling, 1996).

Biological weed control can be well implemented in the future if the economic and ecological effects of herbivores on weeds are sufficiently documented, and if successful selection of herbivores as well as monitoring after their release is available. However, there are no known bioagents for weed management in potatoes.

ii. Cultural Control

There are various cultural methods to eliminate the establishment of weeds and reduce their competition in the potato fields over long- term.

- Crop Rotation

Weeds and crops, that have same life cycle, tend to grow at the same period. So rotating with crops having varied planting or harvesting dates can reduce establishment of weeds or the production of weed seeds later after their establishment (Derksen *et al*., 2002; Karlen *et al*., 1994). Thus crop rotation can deplete weed seed bank since viable seeds, especially annuals, are reduced directly through germination, desiccation due to natural conditions, or consumption by microorganisms (Roberts, 1981). In potato field, rotation with a winter wheat or canola or other winter annual crops, or with alfalfa crops will help in the reduction of summer annual weed populations (Hutchinson and Eberlein, 2003).

- Crop Competition

Neighboring plants compete with each other when the resources- light, nutrients, and water, are limited or when their demand is higher than these supplied resources (Harper, 1977). Crops are considered competitive when they can either suppress weeds and deplete their seed bank, or "tolerate" them and produce high yields in their presence (Goldberg, 1990), but an ideal competitive crop will optimize yields while suppressing weeds (Jordon, 1993). Thus, crop competition is important as an economically feasible part of integrated weed management, as examined in the past 15 years (Lemerle *et al*., 2001; Mohler, 2001a).

Early crop sowing with good quality and disease-free seeds, using good machinery, can enhance rapid germination, root expansion, higher stems, larger leaf area, more closed canopy, and more tillering or branching, hence better crop competition. However, these agronomic practices can be affected by the crop cultivar, characteristics, seeding rate and depth, spacing between rows and between seeds, fertilization, soil and environmental conditions. For instance, the new semi-dwarf crop cultivars are less competitive than the conventional taller cultivars (Gibson and Fischer, 2004; Lindquist *et al*., 1998). In potatoes, Russet Burbank cultivar was considered better competitor than Superior cultivar since it can form denser canopy early and for longer period, which allows for more competition with weeds that germinate late in the season (Connell *et al*., 1999; Raby, 1988). As for yields, tuber yields of Red Norland was reduced 65% in the presence of weeds while the more competitor cultivar, Red Pontiac, was reduced by 45% only in the presence of weeds as reported by Nelson and Giles (1989).

Moreover, shallow or too deep seed sowing in inappropriate soils can decrease seed germination and deplete its reserve. Lower yields were reported when planting depth for the Russet potato cultivars was increased from 8 to 23cm, and when Shepody potatoes were sown at 8cm due to greening of shallow tubers (Bohl and Love, 2005). In addition, closer spaces between rows can increase competitiveness of crops with weeds (Jordon, 1993; Lemerle *et al*., 2001; Mohler, 2001a), since more crops are being sown thus higher light interception, nutrient, and water uptake by crops not by weeds (Fischer and Miles, 1973), even though higher crop density can increase susceptibility to diseases and reduce yields. For example, intra-row space wider than 38cm significantly increased the oversized tubers numbers, reduced specific gravity, and increased hollow heart incidences, as reported by Halderson *et al.* (1992) and Rex *et al.* (1987).

- Crop Fertilization

Even though soil fertilization is required for higher crop yields, timing, rate, and methods of application can influence weed-crop competition (DiTomaso, 1995). For instance, substituting surface fertilizer broadcasting by narrow band application in-soil can better control weeds and maintain crop yields (Blackshaw *et al*., 2004b; Rasmussen *et al*., 1996). In fact, Agenbag and Villiers (1989) had reported the effect of nitrogen application on breaking some weed seeds dormancy, thus enhancing weed infestations (Supasilapa *et al*., 1992). And since weeds are more receptive to soil nitrogen, in some cases to phosphorus as well (Blackshaw *et al*., 2003, 2004a), they can consume higher nitrogen amounts making it unavailable for crops (Qasem, 1992), consequently reducing yields (Dhima and Eleftherohorinos, 2001). However, nitrogen application was reported to reduce weed density efficiently when its rates are doubled (Tulikov and Sugrobov, 1984) since it improves the canopy of the potato plants thus preventing light interception restraining weed emergence, also it enhances the competitive ability of potatoes causing mortality of weed seedlings (Azeez, 2009; Evans *et al*., 2003a; Williams, 2006).

- Silage, Green Manure, and Cover Crops

Including silage and cover crops and green manure into the cropping system can result in weed management by several ways (Caamal-Maldonado *et al*., 2001). Silage can deplete weed seed bank when they are harvested prior to weed seed set. Cover crops compete with weeds for light, water, and nutrients when alive, and in some cases, develop "vesicular-arbuscular mychorrhizae" (VAM) that help crops capture their nutrients (Teasdale, 1996). However, cover crop residues can suppress weed growth physically or chemically, through the secretion of allelopathic compounds (Hartwig and Ammon, 2002; Weston, 1996). For example, rapeseed green manure was reported to reduce weed population up to 85% when incorporated in the loamy sand potato fields of Washington (Boydston and Hang, 1995).

- Intercropping

Intercropping is the practice of growing more than one crop together- annuals together, perennials together, or annuals with perennials (Vandermeer, 1989). Intercropping can reduce weed infestation since more crops are competing with weeds for space, water, nutrients (Hauggaard-Nielsen *et al*., 2001), and light (Itulya and Aguyoh, 1998), or by the production of some allelopathic chemicals (Liebman and Dyck, 1993). Thus, this practice can manage weeds up to 90% and consequently increases the main crop yields (Liebman and Dyck, 1993). For example, intercropping of potatoes with sugarcane was experimented at Marathwada Agricultural University, India. Results showed 80% weed reduction in addition to 4.6% tuber greening reduction compared to 15% greening in tubers harvested from potato monoculture (Nankar, 1990).

- Timing of Weed Control

Even though some crops can tolerate weeds; however, they need to be “weed-free” for one-third their life cycle (Zimdahl, 1988). Therefore, the time of weed management or weed control critical period is important to prevent any losses in the yields, especially if weeds are controlled early in the season whereby crop tolerance to weeds will increase. The critical period for weed control was between 4 and 6 weeks after planting for the dry season potato in Angola, for example. Weeding once after 2 to 8 weeks of planting in UK was efficient to avoid significant losses in yields (Monteiro *et al*., 2011). In Brazil, it was reported that the critical period is 20-21 days after planting (Costa *et al*., 2008b). While in western Iran, for instance, this period ranges from 19-24 to 43-51 days after emergence (Ahmadvand *et al*., 2009). Thus, famers must control weeds in this period to obtain maximum yield. But this period may change according to time of weed germination and their density, and according to potato planting date and density or fertilization program used or other practices (Evans *et al.,* 2003b; Williams, 2006).

- Combining Cropping Practices

Integrated weed management involves implementing multi-cultural practices, such as crop rotation, fertilization, cover crops, or intercropping as a substitution of high rates of herbicides (Anderson, 2003), in order to manage weeds before seed set and weed development, and to deplete weed seed banks in the soil (Anderson, 2005). For instance, intercropping potatoes with rapeseed in the fall or incorporating it as a cover crop in spring can suppress weeds early in the season (Boydston and Hang, 1995).

iii. Mechanical Control

Several mechanical techniques are adapted by farmers in order to manage weeds effectively such as seed bed preparation, hand weeding, hoeing, mowing, hilling, and tractor-driven mechanized equipment. Though the use of most of the above techniques have been reduced since the introduction of herbicides, but they remain economically feasible technique and supplies season-long management of weeds, especially when combined with other weed management systems (Leblanc and Cloutier, 2001b; Mohler, 2001b; Peruzzi *et al*., 2005a,b; Wicks *et al*., 1995).

- Pulling

Weed pullers can be used in order to control weeds after weeds maturity and growth above the crops, where two rubber tires rotate opposite to each other uprooting weed stems or breaking them depending on soil moisture level. This method is better than hand pulling; however, it may cause crop damage by tractors passing in the field late in the season. So, it must not be implemented as a sole weed management practice but as a means to control weeds that were not killed by other control methods (Anonymous, 1979; Wicks *et al*., 1995).

- Cutting and mowing

Implemented with another control measures, mowing weeds can decrease leaf area index, thus minimizing weed volume, restrict its growth, and diminish seed set; hence, crop-weed competition will be reduced enhancing crop development (Donald, 2006; Frick, 2005; Kempen and Greil, 1985; Lampkin, 1990; Ross and Lembi, 1985; Schreiber, 1973; Smith, 1995). But this practice is more efficient against broad leaf annual weeds than perennial monocots and creeping weeds. One of the tools used to reduce inter-row weeds development and production of seeds, while saving energy and minimizing herbicide use, is weed cutting by laser (Heisel *et al*., 2002). But weeds may re-grow if they are not cut from the bottom of their stem near the surface of the soil below the meristems (Heisel *et al*., 2001). Another method for weed control is by cutting using 5-21 liters of water per minute at 2000-3000 bars through water-jet cutting (Fogelberg, 2004).

- Tillage

Tillage is used to enhance production of crops through altering the conditions of soil, as defined by the American Society of Agricultural Engineers (2005). Tillage is divided into primary, secondary, and cultivating tillage (ASAE, 2004; Wicks *et al*., 1995).

- Primary tillage

Primary tillage is the first practice for soil preparation prior to planting. It loosens the soil, reorganizes its aggregates, and buries plant residues (ASAE, 2005), and most importantly for weed control through burying some weed seeds and perennial propagule deep in the soil (Kouwenhoven, 2000), or through bringing them up to the surface of the soil making them prone to desiccation and bad environmental conditions (Cloutier and Leblanc, 2001; Mohler, 2001b). Primary tillage can be achieved using moldboard plows, disc plows, chisel plows, powered rotary plows, and diggers (Barthelemy *et al*., 1987; Peruzzi and Sartori, 1997).

- Secondary tillage

Secondary tillage is used to grind, level, and compact soil as well as to allow fertilizers, pesticides, manure, and other amendments to be mixed with the soil. Also, this tillage can be used to close air spaces in the soil, manage weeds (ASAE, 2004), and improve crop and production (Bàrberi, 2002; Mohler, 2001b).

Several tools are used for secondary tillage including radial blade, spring tine, rolling, disc harrows, cultivators, and PTO powered equipment. Some of these equipment can be used as a substitute to primary tillage equipment to invert soil 10-15cm deep, thus maintaining organic matter, saving money and time (Barthelemy *et al*., 1987; Peruzzi and Sartori, 1997).

- Seedbed preparation

Cultivators with flexible or rigid tines are used for seedbed preparation. The curved flexible tines can disintegrate the top 5-10cm soil intensively with less drawbar pull, thus mixing the residues of weeds and crops with the soil when the tractor moves forward causing the vibration of the tines. Whereas, the partially or totally curved rigid tines are used to elevate soil and break its clods at a depth of 15-25cm, as well as controlling weeds, mainly reproductive propagules of perennials, by pulling them up to the surface exposing them to hot or cold weather. These tines might have tips set with teeth of several shapes like goosefoot. But in general, all cultivators control weeds, even though it may enhance the germination of weed seeds (ASAE, 2004; Bàrberi, 2002; Barthelemy *et al*., 1987; Mohler, 2001b; Peruzzi and Sartori, 1997).

- Stale seedbed and false seedbed

This technique involves tilling the soil to enhance weed seeds germination while setting up the seedbed for the crops, then delaying crop sowing (Mohler, 2001b). Later on, weeds are damaged without disrupting soil by either applying herbicides, as the conventional way, or by burning them using propane flamers which reduces weeds by 30%, according to Rasmussen (2003), up to 60% as reported by Balsari *et al*. (1994) after 16 days of flaming, as in the stale seedbed. Otherwise, weeds can be controlled after about a week from their germination by shallow plowing. Then, if optimal environmental conditions are maintained before crop seeding, the first plowing can be followed by several cultivations at the same depth in order to prevent weed seed emergence if they reach the soil surface. This technique caused 63-85% weed reductions (Gunsolus, 1990; Leblanc and Cloutier, 1996) when practiced in organic farming (Mohler, 2001b), even though it reduced crop yields due to delay in sowing (Rasmussen, 2004). Flex-tine harrows or rolling harrows can be implemented to manage weeds by uprooting them and break soil clods, whereby rolling harrow was more effective than flex-tine harrow reducing weeds 20% more. Also, these harrows can allow weeds to germinate thus exhausting the weed seed bank in the soil, after incorporating the false seedbed technique (Peruzzi *et al*., 2005a).

- Cultivating tillage

Cultivating tillage, or as previously called tertiary tillage, is done post crop emergence to enhance its growth through loosening of soil crust and stopping evaporations from the soil, under unfavorable conditions, by blocking its water capillaries, enhancing infiltration rates of water, and accelerating organic matter mineralization (Blake and Aldrich, 1955; Buhler *et al*., 1995; Cloutier and Leblanc, 2001; Leblanc *et al*., 1998; Souty and Rode, 1994; Steinmann, 2002); consequently increasing crop yields (Buckingham, 1984; Leblanc and Cloutier, 2001a, b). Moreover, cultivators, or cultivating tillage tools, can be implemented to control weeds by partly or totally burying them (Cavers and Kane, 1990; Kurstjens and Perdok, 2000; Rasmussen, 1991), or by removing their roots from soil- "uprooting" (Kurstjens and Kropff, 2001; Kurstjens *et al*., 2000; Rasmussen, 1992; Weber and Meyer, 1993), or by simply destroying their stems and shredding them mechanically (Toukura *et al*., 2006). Note that dry soils are required to facilitate these weed control methods; else, soil structure is destroyed spreading more perennials (Cloutier and Leblanc, 2001).

Weeds can be controlled between crop rows or within the row using broadcast cultivators, only between the rows using inter-row cultivators, and within the row only using intra-row cultivators (Cloutier and Leblanc, 2001; Leblanc and Cloutier, 2001b; Melander *et al*., 2005).

Broadcast or "blind cultivation" is the plowing of the entire field, between crop rows and within rows, pre and post-crop emergence. Chain harrows, flex-tine harrows, and rotary hoes can be implemented in broadcast cultivation. But these cultivators may enhance weed emergence directly after plowing due to cracking of the soil crust, which usually prevent weed emergence (Leblanc *et al*., 1998), or allow minimal weed emergence after seed germination- 5% emergence as reported by Cloutier *et al*. (1996).

Inter-row cultivators, rolling cultivators, rotary cultivators, rolling harrows, basket weeders, brush weeders, and discs can be used to control weeds between crop rows while reducing herbicide use and crop injury. It is better to be applied early in the growing season when the growth stage and crop height are suitable to avoid plant damage or burial, or plugging the cultivators with either large weeds or expanded crop foliage. Tent, rolling, wheel, and panel cultivator shields may be utilized to avoid any crop destruction on the sides of each row (Bowman, 1997; Cloutier and Leblanc, 2001).

Many tools can be used to control intra-row weeds, mainly Finger weeders, Torsion weeders, Spring-hoe weeders. Finger weeders remove young weeds within the row of deep-rooted crops. Torsion weeders are effective against weeds within well-rooted and anchored crops after emergence if applied in one direction. Spring-hoe weeders are used to control intra-row weeds between deep-rooted crops since blades will be inserted under soil surface and uproot the weeds (Bowman, 1997).

- Hilling

Hilling or ridging is the most important weed management practice applied in potato production, besides its various other advantages. It controls weeds between the crop row by burying them completely with soil thrown by the wings, ridgers, blades, or discs used. Rotary hoes can be used to cultivate weeds from the ridges tops, intra-row cultivation, in the presence of high residues, then inter-row cultivation may be done for taller weeds and when crops are more tolerant to partial burial by soil or shields that protect crop rows should be used. Later on, special ridging equipment should be used to reconstruct the ridge.

Hilling at potato emergence and early growth 5-7 weeks after planting when plants' height is 10-20cm (Crosvier, 1970) and when tubers are formed (Everett, 1964) can suppress weeds (Thornton and Sieczka, 1980) especially annuals that germinate early in the season (Callihan and Bellinder, 1993), aerate soil (Chitsaz and Nelson, 1983), enhance tuber growth and prevent sunburn (Blake *et al.*, 1962; Moursi, 1955; Strand, 1986), frost bites, and late blight (Dallyn and Sweet, 1970), and in some cases it is cheaper than herbicides (Chitsaz and Nelson, 1983). However, late hilling 3 to 5 weeks after potato emergence and intense hilling can decease yields by 3 and 21% for successive years as reported by Nelson and Giles (1986) and weights of marketable tubers (Beveridge *et al.*, 1964), by affecting soil structure (Bell and Kenyon, 1966-1967; Bell and Tisdell, 1958; Sommerfeldt and Knutson, 1968), compacting soil (Chitsaz and Nelson, 1983), increasing soil erosion, damaging potato shoots and leaves (Aldrich *et al.*, 1954; Blake *et al.*, 1960;

Flocker, 1964; Flocker *et al.*, 1960; Moursi, 1954; Struchtemeyer *et al.*, 1963; Thompson *et al.*, 1931), trimming crops' roots (Beveridge *et al.*, 1964; Nelson and Giles, 1989), and injuring tubers (Nowacki, 1983). Consequently it aids in spreading pests (Dallyn, 1971), while carrying weed seeds to the top of the soil (Rioux *et al.*, 1979). Thus, hilling is a must in potato plantation and without hilling, yields will decrease. But hilling time and frequency should be considered for better weed management without affecting crops' growth and yields.

iv. Chemical control

Several types of soil and foliar applied herbicides can be used against weeds in potato such as Dimethenamid, EPTC (Eptam®), Glyphosate (Roundup®), Paraquat (Gramoxone Inteon®), Pendimethalin (Prowl®), Sethoxydim (Poast®), Rimsulfuron (Matrix®), Metolachlor (Dual II Magnum®), and Metribuzin (Sencor®). But in general, farmers prefer to apply selective herbicides for better weed management in potatoes (Rodriguez and Jones, 1978).

- Metribuzin

Metribuzin, is the commonly used asymmetric herbicide for weed control in potato fields. It is the active ingredient of the triazine group, sold as Sencor®, Lexone®, and other trade names. It is formulated as 70% or 75% ai wettable powder (WP) or dry flowables (DF), or as flowable (F) or liquid (L). It is a broad spectrum herbicide that acts on many dicots and monocots in potato (Ackley *et al.*, 1996; Hutchinson and Eberlein, 2003; Robinson *et al*., 1996). It is soil-incorporated as well as foliar applied herbicide, pre- or post- emergence. It can be applied pre-potato emergence at low rates as 280g ai/ha (Anonymous, 2001).

Metribuzin is a Photosystem II Inhibitor. It inhibits the transmission of electrons in photosynthesis (Corbett, 1994) then a series of reactions is caused when metribuzin binds to a certain protein in the photosystem II complex, where highly reactive free radicals attack and oxidize plant lipids and proteins. Chlorosis occurs when pigments like chlorophyll are damaged causing cell desiccation and degeneration.

Metribuzin is degraded in the soil mainly due to microbial activity, which increases when soil temperature and moisture increase (Smith and Walker, 1989). And as mentioned by Ladlie *et al.* (1976), pH can be one of the factors causing metribuzin degradation whereby herbicide degradation is more observed at higher pH when it is less adsorbed to soil particles. Also, it is reported that the level it leaches into the soil can be means of metribuzin breakdown in the soil, where it cannot move in clayey soils rich in organic matter since it can highly adsorb to it (Bouchard *et al.,* 1982). Metribuzin can moderately leach in soils with medium texture, while it leaches rapidly in sandy-loam and sandy soils with low organic matter. It moves in the soil due to its high solubility in water, slow absorption, and short to moderate persistence (USEPA, 1988), especially under heavy rains, thus affecting ground water. Moreover, volatilization or photo-degradation can cause slight loss of metribuzin. So, low soil temperature and water content are needed for better metribuzin persistence or its half-life will be 14 to 28 days due to microbial and chemical degradation.

The herbicide can harm some potato cultivars if not applied at recommended rates and at optimum conditions, especially when applied post-emergence, for instance potato varieties with white and red skin are most vulnerable to foliar application (Friesen and Wall, 1984). In susceptible potato cultivars, metribuzin is metabolized slowly or it is not metabolized at all causing chlorosis, inter-veinal chlorosis, stunted growth, necrosis, and after 2 to 5 days, leaves become brown and dry out, then the whole plant dies, thus yield and tuber quality deterioration. However, in metribuzin-tolerant cultivars, injury does not occur unless the plant is stressed, but this slowed metabolism will recover after a week or two. And the level of tolerance differs from variety to another and varies with the mode of herbicide application; usually plants are more susceptible to post-emergence applications.

Even though metribuzin is inexpensive and efficient in controlling weeds early in the season, it is not effective in managing weeds that emerge late in the season because of its short residues in soil. And because of its excessive and frequent use, many weeds are becoming tolerant to metribuzin (Eberlein *et al.*, 1992), like *Solanum triflorum*, *Chenopodium album,* and *Amaranthus retroflexus* (Eberlein *et al*., 1994). So, a combination of metribuzin and hilling should be adopted (Roder *et al.,* 2009).

- Effects of pesticides on human health

Herbicides have been recognized as the most contaminants of the environment recently, even though they are added to the environment intentionally to control pests. And due to the long-term and extensive use of new highly effective active ingredients and toxic formulations, body organs and immune, nervous, cardiovascular, endocrine, renal, respiratory, and reproductive systems are disturbed, and several chronic diseases, such as Alzheimer, birth defects, Parkinson, diabetes, cancer, multiple sclerosis, kidney, and cardiovascular diseases can affect human health (Abdollahi *et al.*, 2004; de Souza *et al*., 2011; Mostafalou and Abdollahi, 2012). For example, a study based on 10 years survey, released in 2010, showed that people who live around agricultural lands, especially elders, are susceptible to Alzheimer after displaying high rates of mental performance (Jones, 2010). Also, Alzheimer can be developed upon direct work-related exposure to pesticides affecting CNS specifically, such as organophosphates (Hayden *et al*., 2010). Another study, done by Parron *et al*. (2011), confirmed that increased use of pesticides had increased risks of this disease.

Some herbicides are considered teratogens causing birth defects, which are congenital disorders, physiological, or morphological deformities that occur during pregnancy or after birth leading to minor incapacities and, sometimes, fatal failures at early ages (Rogers and Kavlock, 2008). Many reports refer to toxicity and birth defects due to exposure of parents to phenoxy defoliant herbicides or Agent Orange that contains the highly toxic byproduct dioxin, TCDD, in Vietnam in 1960 (Ngo *et al*., 2006). For instance, exposure to herbicides by parents can lead to higher hypospadias incidences as mentioned by Rocheleau *et al.* (2009) after his meta-analysis from 1966 until 2008. Also, animals exposed to some herbicides, under laboratory experiments, had developed skeletal and visceral abnormalities, in uterus retardation of growth and intrauterine fatality (Cavieres, 2004). Several meta-analysis studies showed that the risk of developing Parkinson's diseases is higher upon exposure to herbicides (Bonetta, 2002; Freire and Koifman, 2012; Van Maele-Fabry *et al*., 2012). And this was proven by four cohort, three cross-sectional, and 39 case-control studies reviewed by van der Mark *et al*. (2012). Further tests on patients with Parkinson showed high levels of pesticides in their serum (Richardson *et al*., 2009). More researches and "designed developmental models" were done to relate incidences of Parkinson disease to herbicide exposure (Cory-Slechta *et al*., 2005), especially organophosphates and carbamates since these neurotoxic herbicides can disturb ion channels and neurotransmission of the nervous system (Costa *et al*., 2008a). Other studies linked the herbicides exposure to obesity, which is one of the main factors leading to diabetes, since pesticides can alter adipocytes differentiation or disrupt the neural routes or circuits, which are known to regulate feeding activities (Thayer *et al*., 2012).

Many agricultural, health, and epidemiological studies have reported the effect of pesticide exposure on the incidence of several malignancies (Penel and Vansteene, 2007). Other cohort and population-based researches, done by the International Agency for Research on Cancer (IARC), have reported the exposure to pesticides in people with several types cancers (Baldi and Lebailly, 2007), such as brain, skin, esophageal, pancreatic, stomach, breast, and testicular cancers (Alavanja and Bonner, 2012; Jaga and Dharmani, 2005; Weichenthal *et al*., 2010). Moreover, leukemia and prostate cancer were found to be more common in people working in manufacturing herbicides according to risk meta-analysis provided by Van Maele-Fabry *et al*. (2006-2008). Lee *et al*. (2004a,b, 2007) reported lymphohematopoietic cancers when exposed to alachlor, while others reported colon, rectum, pancreatic, lung, and bladder cancers when people are exposed to different types of herbicides (table 1).

Table 1: Different pesticides with their associated type of cancer according to some epidemiological studies (Mostafalou and Abdollahi, 2013)

Type of cancer	Herbicide
Leukemia	EPTC
Prostate cancer	Methyl bromide
	Butylate
	Simazine
Colon cancer	Dicamba
	EPTC
	Imazethapyr
	Trifluralin
Rectum cancer	Pendimethalin
Pancreatic cancer	EPTC
	Pendimethalin
Lung cancer	Dicamba
	Metolachlor
	Pendimethalin
Bladder cancer	Imazethapyr

Herbicides are classified as carcinogenic when they can influence the genetic material indirectly through the distraction of the gene expression profile and homeostasis of cells by disrupting the endocrine network, nuclear receptors, endoplasmic reticulum, mitochondria, and other cell organelles, or directly by damaging the structure of DNA, Histone proteins, and chromosomes, and impairing their function (George and Shukla, 2011; Rakitsky *et al*., 2000). Recently, more than 70 pesticides were considered to have possible carcinogenic potential and are "probable carcinogens", sometimes at chronic low-dose, as mentioned in the 2010 list of Chemicals Evaluated for Carcinogenic Potential issued by EPA's Pesticide Program that analyzed data collected from many metabolism and animal studies, structural associations with another factors causing cancers, and available human epidemiological results. So, carcinogenicity tests, which are long-term bioassays on both male and female rodents, should be done prior to marketing new pesticides. Nevertheless, several factors, such as sex, age, susceptibility of the person, simultaneous exposure to other carcinogens, duration of exposure, and quantity of pesticides can influence pesticides carcinogenic potential.

v. Integrated Weed Management (IWM)

Weeds were first controlled by cultivating the land several times as the main management practice. In potato fields, 4 to 8 cultivations (Aldrich *et al*., 1954), with 6 summer tilling were used to control weeds (Maier and Loftsgard, 1964). Even though cultivation is considered a good practice for weed control, the frequent application of this practice was found to compact soil, injure the roots of potato crops (root pruning), and slow down their penetration (Aldrich *et al*., 1954). In addition, cultivation found to lower soil water content and decrease the air space in soil by 15% thus enhancing soil borne diseases and affecting yields negatively (Cadman, 1963; Pereira, 1941). In some cases, 3-21% yield reduction was observed (Nelson and Giles, 1986) and in other cases, losses reached 12-20% due to two tillage practices only (Callihan and Bellinder, 1993). Also, cultivation is considered ineffective in controlling in-row weeds i.e. weeds that emerge between the potato plants as well as weeds that emerge after the potato plants extend into the space between the rows which blocks the passage of cultivators (Callihan and Bellinder, 1993).

With the introduction of herbicides, frequent cultivations have decreased to one or two cultivations during the whole growing season (Aldrich and Campbell, 1952). Also, cultivation was delayed 4-5 weeks when early herbicide application is used (Aldrich *et al*., 1954). No yield increase was reported with the combination of herbicide and 3 cultivation (Blake *et al*., 1962), while a 29% increase was observed when weeds were controlled with a residual herbicide and one or two cultivations (Nelson and Giles, 1989). However, herbicides could be replaced by 5-6 cultivations per acre with 8-12 hand-weeding hours (Knutson *et al*., 1993).

Herbicides are used to reduce cultivation practices, on one hand, where hilling once can control weeds efficiently especially at harvesting (Bell and Kenyon, 1965); however, if hilling was achieved early in the season, it may reduce the efficiency of pre-plant and pre-emergence incorporated herbicides (Bellinder and Wallace, 1991; Collin and Phatack, 1970; Kain *et al*., 1986; Somody *et al*., 1978). On the other hand, the use of pre-emergence herbicides instead of tillage has caused reduction in uses of energy and soil erosions, eliminated present plants for better seed sowing, and altered weed species and their reaction with environment and herbicides (Froud-Williams, 1988). So, according to Wallace and Bellinder (1990), reduced rates of herbicides in potato production along with one hilling is an efficient practice to control weeds with reduced application of pesticides in agricultural lands. Yet, some farmers are still cultivating intensely even with the use of herbicides (Dallyn and Fricke, 1974).

CHAPTER III

MATERIALS AND METHODS

During the spring 2014 and fall 2014-2015 seasons, a field and greenhouse experiments were carried out at the American University of Beirut. The field experiment was carried out at the Advancing Research Enabling Communities Center (AREC), during April to September 2014. AREC is located in the Central Beq'aa plain with an altitude of around 1000m above sea level at 34° 54'' N latitude and 36° 45'' E longitude. While the green house experiment was carried out at the greenhouse area of the Faculty of Agricultural and Food Sciences (FAFS) at the Beirut coastal area, during October 2014 to February 2015. Standard certified potato seeds variety "Spunta" was obtained from Netherland through a certified local agent (stet Holland: Spunta, n.d.). Metribuzin (Sencor® 70% WP) was obtained from the local market.

A. Field Experiment

1. Experimental Site

The experiment was conducted on a 1375 m^2 field at AREC (Figure 1). The soil is clayey (48.08% clay, 35.85% silt, and 15.92% sand), basic (pH= 7.80), non-saline (EC= 0.00409dS/m), with 2.15% organic matter, 0.79% N, 16.9ppm P, 415ppm K, and 37.33% $CaCO_3$. Soil analysis was done according to Bashour and Sayegh (2007).

2. Experimental Design

Experimental plots were arranged in a randomised complete block design (RCBD) with four replicates. Blocks were separated by 2.5m aisles. Each block was divided into 22 plots, a total of 88 plots/experimental site. The area of each plot was 10.5m^2 (5m length × 2.1m width). Each plot consisted of 3 rows, 0.70m apart, for a total of 66 rows.

Figure 1: Experimental field throughout the season

Plots or replicates were divided according to the treatment applied to each plot (Table 2). Briefly, the table includes weedy check (control i.e. no metribuzin and no hilling), hand weeding, no hilling with different metribuzin rates: 0.18, 0.35, 0.56, and 0.75kg ai/ha, hilling with no metribuzin at different times: 6, 7, and 8 weeks after planting (WAP), and a combination of the mentioned metribuzin rates and hilling timing.

Table 2: Tretaments and their corresponding replicates

#	Treatments/Rates	Rep 1	Rep 2	Rep 3	Rep 4
1	Weedy check	101	222	303	403
2	Hand weeded	102	221	308	422
3	Standard application- Metribuzin at 0.75 kg ai/ha with one hilling 6 WAP	103	220	317	409
No Hilling-With Metribuzin					
4	0.18 kg ai/ha	104	219	307	410
5	0.35 kg ai/ha	105	218	302	408
6	0.56 kg ai/ha	106	217	309	418
7	0.75 kg ai/ha	107	216	316	411
Hilling-No Metribuzin					
8	6 WAP	108	215	318	419
9	7 WAP	109	214	306	404
10	8 WAP	110	213	310	412
Hilling-With Metribuzin					
11	6 WAP with 0.18kg ai/ha	111	212	301	402
12	7 WAP with 0.18kg ai/ha	112	211	311	413
13	8 WAP with 0.18kg ai/ha	113	210	305	420
14	6 WAP with 0.35kg ai/ha	114	209	312	407
15	7 WAP with 0.35kg ai/ha	115	208	322	421
16	8 WAP with 0.35kg ai/ha	116	207	319	414
17	6 WAP with 0.56kg ai/ha	117	206	313	417
18	7 WAP with 0.56kg ai/ha	118	205	304	401
19	8 WAP with 0.56kg ai/ha	119	204	320	415
20	6 WAP with 0.75kg ai/ha	120	203	321	406
21	7 WAP with 0.75kg ai/ha	121	202	314	416
22	8 WAP with 0.75kg ai/ha	122	201	315	405

3. Land preparation

All plots were tilled twice with a conventional moldboard plow, disked, and leveled two weeks prior to potato planting. The experimental area received a uniform application of 200kg of NPK (15:15:15) fertilizer one hour prior to potato sowing by a spreader, followed by shallow tillage. Another 50kg of NPK was band applied during potato sowing. Four hundred kilograms of small potato tubers (20 tubers/row) were planted on April 17, 2014 in the experimental area (except the aisles), using a commercial two-row potato planter (Figures 2 and 3). Urea-Ammonium sulphate 40-0-0 + (14 SO_3) were applied 60 days after planting by hand spreading at a rate of 100kg/experimental field (Table 3).

Figure 2: Potato tuber planter

Figure 3: Potato tank and tuber elevator of the potato planter

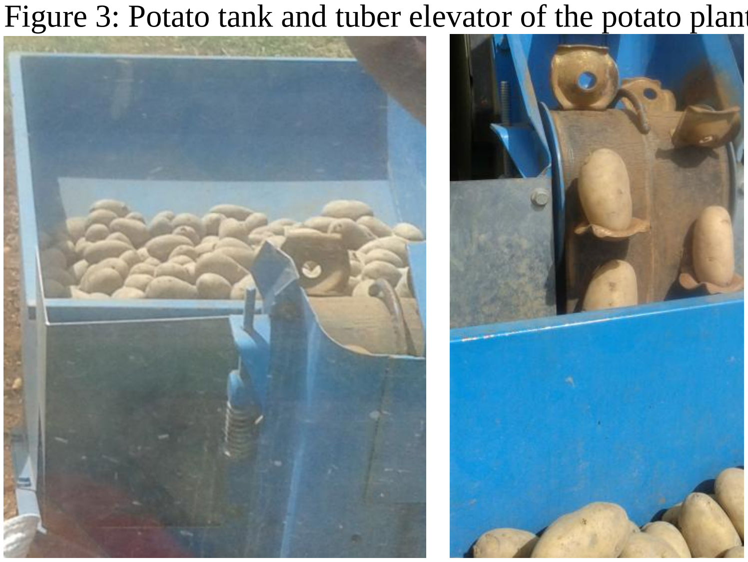


Table 3: Content of Urea- Ammonium Sulphate 40-0-0 + (14 SO_3), EC fertilizer

Ingredient	**%**
Total N	40
Ureic N	35
Ammoniacal N	5
Water soluble sulfur Trioxide (SO_3)	14
Water soluble sulfur (S)	5.6

4. Irrigation

Three pipelines, with 6 sprinklers/line, were inserted in the field between plots, one WAP, which delivered 8mm/hour at pressure of 4bars (58psi) for 5 hours and another 5 hours after 2 weeks in addition to the 22 mm rainfall after 6 days after planting (Figure 4). Water application was stopped several times for easy data collection and the whole irrigation system was removed from the field in order to undergo the hilling practice. The experimental field was irrigated for 2 hours every other day during the growing season. Irrigation was totally stopped 2 weeks before harvesting.

Figure 4: Irrigating the field with sprinklers

5. Metribuzin application

Metribuzin was applied prior to potato emergence (PRE, 4 WAP) at various rates as shown in table 4. Metribuzin was sprayed by a hand held CO_2-pressurized backpack sprayer that delivers 310 L/ha at 138 Kpa through a Teejet 8002 flat fan spray tips. Irrigation followed one day after spraying (Figure 5).

Table 4: Rates of metribuzin used

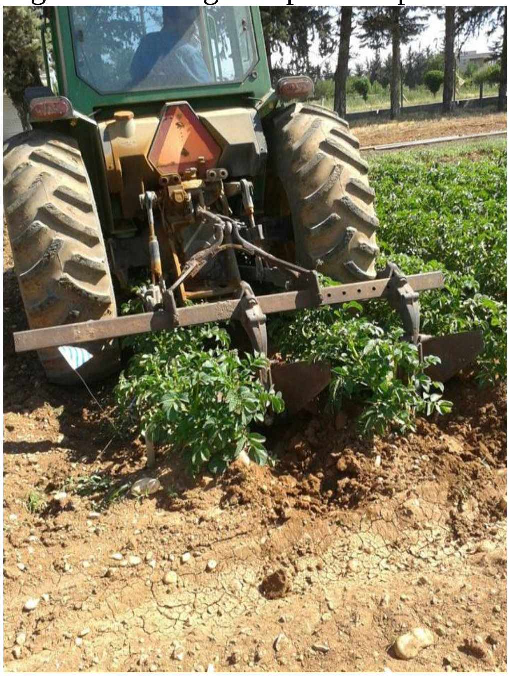
Rate in Kg ai/ha	Rate in g com/ha	Rate in 1 g com/4 blocks/1.26 l water
0.18	257	1.10
0.35	500	2.10
0.56	800	3.36
0.75	1071	4.50

Figure 5: Metribuzin application in the field

6. Hilling

Hilling was carried out 3 times during the season: 6, 7, and 8 WAP using John Deere rear-mounted, two row ridger with units spaced 90cm apart, which formed hills 40cm high in the middle row only in each selected plot (Figure 6).

Figure 6: Hilling the specified plots



7. Pesticide application

On July 10, 2014, 40ml of a mixture of pesticides were applied per 10L water (240ml pesticides) sprayed using CO_2-Pressurized Backpack sprayer described before. Table 5 shows the type, active ingredients, and rates of chemicals that were used over the whole experimental site during the growing season.

Table 5: Pesticides used during the growing season

Trade Name	Active Ingredient	Rate (g/10 liters of water)
Radiant 120	Spenetoram 12%	20
Actara WG	Thiamethoxam 250 G	10
Folio Gold SC	Mefenoxam 37,5 g Chlorothalonil 500 g	40
Agral	Emulsifier & Surfactant Agent	5
Gold fert	Micronutrients	25

8. Data Collection

Weed data included weed count/ 0.5m^2, weed count visual rating (WCVR) on a scale from 0-10 where 0 is highly infested and 10 no weeds, and weed dry weight. Common weed species found during the growing season in the experimental plots were *Amaranthus retroflexus*, *Convolvulus arvensis*, *Polygonum aviculare*, *Portulaca oleracea*, *Setaria verticillata, Solanum nigrum, Sorghum halepense,* and *Datura stramonium*.

Potato data included number of plants per middle row, phytotoxicity visual rating (PVR) on a scale from 0-10 where 0 is dead and 10 is healthy according to the European Weed Research Council scoring system, height/10 plants/plot, potato roots dry weight, non-marketable and marketable yield (weight and number).

First data collection was on June 3, 2014 (50 DAP), it includes potato plant number/ middle row, height in cm of 10 plants/ middle row/ plot, shoot number of 10 plants/ middle row/ plot, PVR, WCVR, and weed count/ 0.5m^2 (Figure 7).

Second data was collected on June 26 and 27, 2014 (70 DAP), it includes measuring height in cm of 10 plants/ middle row/ plot, shoot number of 10 plants/ middle row/ plot, PVR, WCVR, weed count/ 0.5m^2, and potato root dry weight, where two potato plants were collected from the two border rows of each plot, their shoots were counted, and their roots were oven dried for 48 hours at 70°C.

Third data collection was on August 5 and 6, 2014 (110 DAP), it includes measuring height in cm of 10 plants/ plot, shoot number of 10 plants/ plot, PVR, WCVR, and weed count/ 0.5m^2.

Figure 7: Measuring crop height and weed count

At harvest time (August 29, 2014), weeds were counted and then collected by cutting the upper vegetative parts and placed in jute bags to dry up in air for 25 days (Figure 8).

Figure 8: Collecting weeds and their air dry weight

9. Harvesting and Post Harvesting

On September 4, 2014, the whole experimental area was mowed with a heavy mower to remove existing weeds and potato shoots (Figure 9). Potato yield was determined by harvesting the middle row in each plot using Zahle plough cultivator and then collected by hands (Figure 10). Yield quality (Figure 11) was determined by separating harvested tubers into two classes: marketable (> 6cm diameter) and non-marketable tubers (< 5cm in diameter) according to Robinson *et al.* (1996).

Figure 9: Mowing of weeds in the aisles as well as potato top green parts

Figure 10: Potato harvesting

Figure 11: Potato grading and weighing

B. Green House Experiment (Boxes)

1. Experimental site

This experiment was carried out between October 2014 and February 2015. Potato seed tubers were placed in plastic trays and then covered with aluminum foil and kept moist in cold room at 15°C for two weeks prior to planting.

2. Planting potatoes

Sprouted tubers were planted on October 22, 2014 in plastic netted boxes 50× 34× 30cm (length× width× depth). Boxes were first filled with a 15 cm of potting soil consists of a mixture of terreau, perlite, and peat moss at a rate of 1:1:1. Two potato tubers (20cm apart) were placed on top of the soil (Figure 12) and then covered up with 20cm of the same soil mixture after being mixed with 12g of different weed seeds (*Amaranthus* *retroflexus, Datura stramonium, Lolium multiflorum,* and *Echinochloa crus-gali*). Boxes were lightly irrigated till the emergence of potato sprouts. Each box was then irrigated with one liter of tap water every two days, 20 DAP.

Figure 12: Potato tubers planted in the plastic box

3. Application of Metribuzin

Metribuzin was applied PRE 3 WAP at four rates: 0.18, 0.35, 0.56, and 0.75kg ai/ha using a small handheld Universal spray kit in a spray volume of 1000L/ha (Tables 6 and 7).

Table 6: Rates of metribuzin application in the greenhouse experiment

in Kg ai/ha	in g com/ ha	in g com/2m^2
0.18	257	0.52
0.35	500	0.1
0.56	800	0.16
0.75	1071	0.21

Table 7: Spray map

No	Treatments/Rates	Rep 1	Rep 2	Rep 3	Rep 4
1.	Weedy check	101	206	305	404
2.	Hand weeded	102	205	304	406
3.	0.18 kg ai/ha	103	204	301	401
4.	0.35 kg ai/ha	104	203	303	405
5.	0.56 kg ai/ha	105	202	302	402
6.	0.75 kg ai/ha	106	201	306	403

4. Experimental design

Randomized Complete Block Design (RCBD) was performed with 24 plastic netted boxes divided into 4 blocks; each block consists of 6 boxes. Each box is considered as a replicate (Figure 13).

Figure 13: Boxes containing potato at the beginning and end of the experiment

5. Pesticide application

Two applications of a mixture of Abamectin and Acetameprid at a rate of 1ml/ 5 liters of distilled water were sprayed 7 and 11 WAP to control white fly.

6. Data Collection

First reading was done on November 19, 2014 (30 days after planting-DAP), and it includes measuring weed count/box (monocot, dicot, and total weeds), potato height, shoot number/plant, and leaf number/plant. Second reading was done on December 22, 2014 (60 DAP), and it includes measuring weed count/box (monocot, dicot, and total weeds), potato height, shoot number/ plant, leaf number/ plant, and PVR at a scale of 0-10 where 0 means dead and 10 means healthy. Third reading was done on January 23, 2015 (90 DAP), and it includes measuring weed count/box (monocot, dicot, and total weeds), potato height, shoot number/plant, leaf number/plant, and PVR (Figure 14). Dry weight was measured for both weeds and potato shoots on February 18, 2015. Shoots were collected and placed in the oven at 70°C for 2 days (Figure 15).

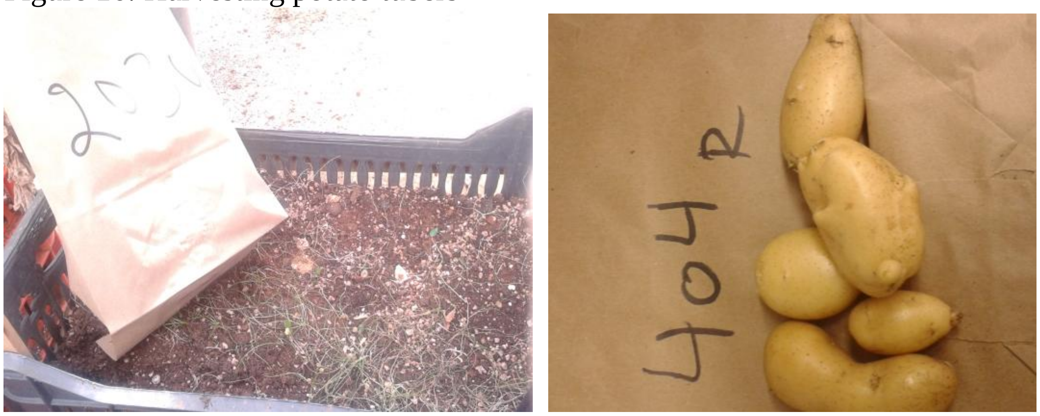
Figure 14: Weeds emerging in the boxes

Figure 15: Weed dry weight

7. Harvesting

Potato tubers were harvested on February 18, 2015, graded into marketable and non-marketable as described before (Figure 16).

Figure 16: Harvesting potato tubers



C. Statistical Analysis

Statistical analyses for both field and greenhouse experiments were performed using STATA (2012). Treatment means were compared using one way ANOVA (analysis of variance) and Tukey's range test. Differences were considered significant at $\alpha = 0.05$.

CHAPTER IV

RESULTS AND DISCUSSION

A. AREC Experiment

1. Effect on Weed Growth

Reduced rates of metribuzin, as a pre-emergence herbicide, were used with or without hilling to study their effect on weed infestation in potato compared to the check and the standard weed management strategy used by farmers (0.75kg ai/ha with hilling 6 WAP). Results in table 8 reveal that metribuzin alone at all tested rates (Figure 17) or combined with hilling 6, 7, or 8 WAP, with the exception of hilling alone 6, 7 and 8 WAP, significantly reduced weed infestation in potato after 50, 70, and 110 DAP compared to the check. In general, early hilling is more effective against weeds than late hilling in potato. Average weed count per $0.5m^2$ was 439.6, 104.6, and 140 weeds when plots were hilled 6 WAP compared to 580.6, 120.5, and 180 weeds when plots were hilled 7 WAP, while it recorded 535.6, 233.4, and 173.4 weeds when plots were hilled 8 WAP at 50, 70, and 110 DAP, respectively (Figure 18). Average weed count after 135 DAP varied among treatments. Yet, combination of metribuzin at 0.35kg ai/ha and hilling at 6 WAP was the most effective treatment against weeds compared to the check or standard application of metribuzin at 0.75kg ai/ha with hilling 6 WAP. This treatment gave an excellent control of *Amaranthus retroflexus*, *Chenopodium album*, and *Sorghum halepense*. Thus, weeds should be controlled at early stages especially when they emerge at crops germination since they are more deleterious than those emerging at later crop growth stages. Also, some weeds are difficult to control at later stages due to their morphology such as their deep root systems or underground storage parts as in perennial weeds; unless a herbicide with long residual activity is used or hilling late in season is applied leading to harmful consequences on the soil and on the crops themselves (Hager, 2009).

Table 8: Effect of metribuzin, hilling, and their combination on weed count per 0.5m^2, 50, 70, 110, and 135 days after planting potatoes (DAP)

Treatment	Rate (kg ai/ha)	Hilling (WAP*)	Weed count/ 0.5 m^2							
			50**		70		110		135	
Check	0	-	476.0	b	800.0	d	200.0	c	142.0	cd
Hand Weeding	0	-	0.0	a	0.0	a	0.0	a	0.0	a
Metribuzin (M)	0.18	-	64.0	a	35.0	a	30.0	ab	68.6	abcd
M	0.35	-	46.0	a	12.0	a	6.0	a	58.0	abc
M	0.56	-	12.6	a	10.6	a	8.6	a	19.6	ab
M	0.75	-	23.0	a	41.0	a	48.0	ab	67.6	abc
M	0	6	439.6	b	104.6	bc	140.0	bc	86.6	abcd
M	0.18	6	28.0	a	10.0	a	41.0	ab	64.6	abc
M	0.35	6	8.0	a	9.0	a	6.6	a	2.6	a
M	0.56	6	13.4	a	8.0	a	5.6	a	57.6	abc
M	0.75	6	9.4	a	5.0	a	6.0	a	0.6	a
M	0	7	580.6	b	120.6	c	180.0	c	173.6	d
M	0.18	7	61.0	a	56.0	ab	17.4	a	52.6	abc
M	0.35	7	48.0	a	30.6	a	12.6	a	88.0	abcd
M	0.56	7	4.0	a	8.6	a	3.4	a	37.0	abc
M	0.75	7	12.0	a	12.0	a	5.4	a	9.4	ab
M	0	8	535.6	b	233.4	e	173.4	c	117.6	bcd
M	0.18	8	76.0	a	9.6	a	6.0	a	40.6	abc
M	0.35	8	42.0	a	17.6	a	12.6	a	20.6	ab
M	0.56	8	13.6	a	3.0	a	12.6	a	27.0	ab
M	0.75	8	24.0	a	4.6	a	8.6	a	30.0	ab

*WAP: Weeks after planting
** Means with the same letters in the same column are not significantly different

Figure 17: Effect of metribuzin, without hilling, on weed count per $0.5m^2$, 50, 70, 110, and 135 days after planting potatoes (DAP)

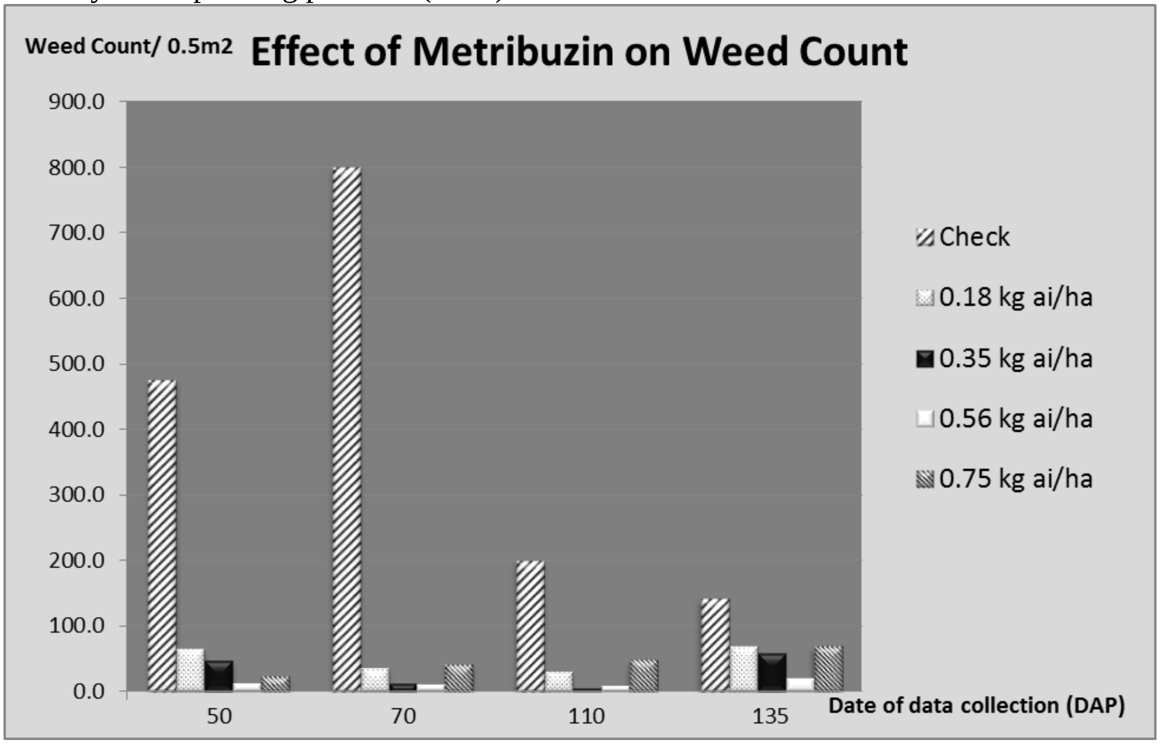
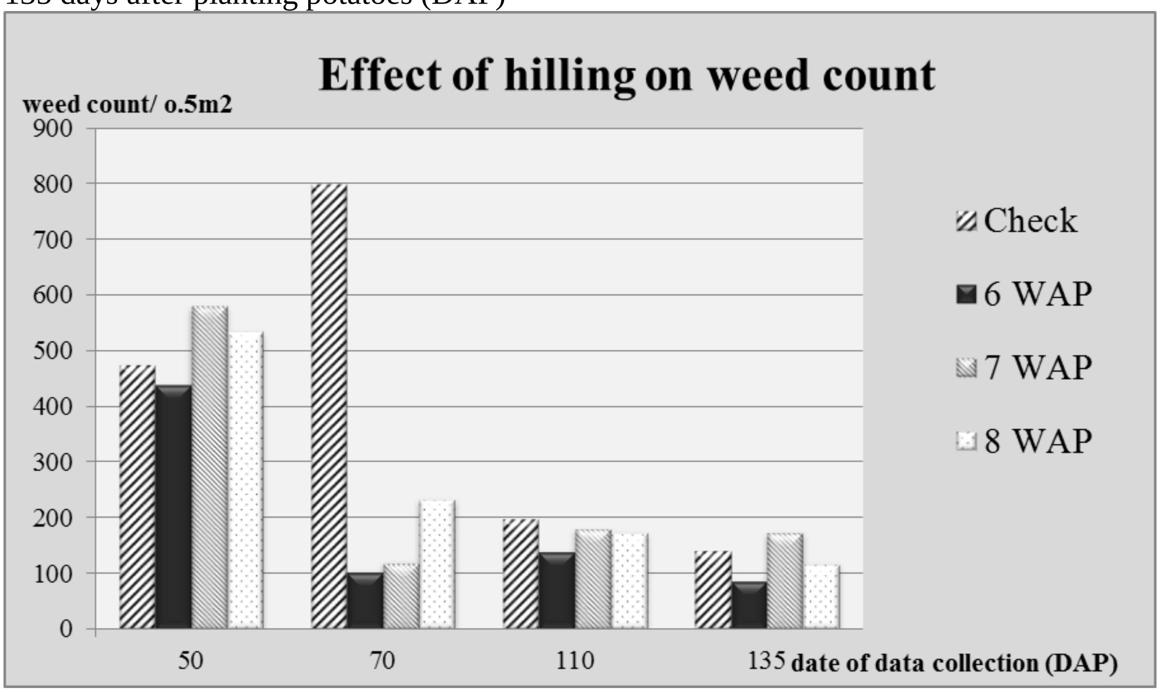


Figure 18: Effect of hilling, without metribuzin, on weed count per $0.5m^2$, 50, 70, 110, and 135 days after planting potatoes (DAP)



Same results were observed upon recording the weed count visual ratings (WCVR) on a scale from 0 (no control) to 10 (100% weed control), where all rates of metribuzin, with or without hilling, significantly reduced weed infestation after 50 and 70 DAP compared to the check. While at 110 DAP, metribuzin at 0.56 and 0.75kg ai/ha with hilling 6 and 8 WAP and metribuzin at 0.35kg ai/ha with hilling 7 WAP significantly reduced weed infestation compared to hilling alone 6 and 7 WAP (Table 9).

Another important parameter to study weed competition, along with weed count and weed count visual ratings (WCVR), is weed dry matter (Bhanumurthy and Subramanian, 1989). Dry matter is the product of the consumption of water, nutrients, and light and their utilization within the plant. Thus, weed biomass increases when weeds absorb more resources and grow faster at the expense of crops (Morgan and Smith, 1981). Interestingly, table 9 shows that all treatments, with the exception of hilling alone at 8 WAP, significantly reduced the dry weight of weeds compared to the check. Average weed dry weight, measured 135 DAP, was 48g/ 0.5m^2 in plots receiving 0.75kg ai/ ha metribuzin with no hilling, 2.2g in plots receiving the standard treatment, 6g in plots receiving 0.75kg ai/ ha metribuzin and hilled 7 WAP, and 68.6g in plots receiving the same rate of metribuzin but hilled 8 WAP, which were significantly different compared to that in the check measuring 789.4g/ 0.5m^2. While average weed dry weights in plots receiving hilling alone at 6 and 7 WAP was significantly different from the check, where it recorded 342.6g and 529.6g when plots were hilled 6 and 7 WAP, respectively; whereas it recorded 654.6g when plots were hilled 8 WAP which is the only plot showing no significant difference compared to the check. This observation was also reported by Jaiswal (1994), Suryanarayana Reddy (1993), Singh (1992), and Maliwal and Jain (1991).

Table 9: Effect of metribuzin, hilling, and their combination on weed count visual rating (WCVR), 50, 70, and 110 days after planting (DAP), and on average weed dry weight (g) per $0.5m^2$, 135 DAP

Treatment	**Rate (kg ai/ha)**	**Hilling (WAP)**	**WCVR***						**Av. weed dry wt/ $0.5m^2$ (g)**	
			50		70		110		135	
Check	0	-	3.0	c	0.0	b	2.5	acd	789.4	e
Hand Weeding	0	-	10.0	b	10.0	a	10.0	b	0.0	a
Metribuzin (M)	0.18	-	8.0	ab	8.0	a	3.8	abcd	93.0	ab
M	0.35	-	8.3	ab	8.8	a	6.0	abcd	62.6	a
M	0.56	-	9.3	ab	9.3	a	6.5	abcd	4.0	a
M	0.75	-	9.0	ab	7.8	a	5.3	abcd	48.0	a
M	0	6	1.5	c	3.5	b	1.0	cd	342.6	bc
M	0.18	6	7.4	ab	9.3	a	4.0	abcd	77.4	a
M	0.35	6	8.9	ab	9.5	a	6.8	abcd	16.6	a
M	0.56	6	9.1	ab	9.5	a	8.5	ab	38.0	a
M	0.75	6	9.8	ab	9.8	a	8.0	ab	2.2	a
M	0	7	0.8	c	3.5	b	0.5	c	529.6	cd
M	0.18	7	7.0	a	7.5	a	5.8	abcd	56.0	a
M	0.35	7	8.3	ab	8.8	a	7.8	ab	38.6	a
M	0.56	7	9.8	ab	9.0	a	5.5	abcd	12.6	a
M	0.75	7	9.4	ab	8.8	a	7.0	abd	6.0	a
M	0	8	2.0	c	3.3	b	3.0	acd	654.6	de
M	0.18	8	7.9	ab	9.3	a	5.5	abcd	24.0	a
M	0.35	8	8.5	ab	9.0	a	5.3	abcd	92.0	ab
M	0.56	8	9.5	ab	10.0	a	7.5	ab	5.4	a
M	0.75	8	9.5	ab	9.3	a	8.5	ab	68.6	a

* WCVR scale: 0-10; 0 means high weed infestation and 10 means no weeds

Hilling at the right timing is very critical in weed management. Early hilling can better control weeds than late hilling since weeds are still young and they lack their secondary roots and food reserves. Fully developed weeds will have a sturdy root system that is difficult to destroy; besides these large weeds can block the cultivators upon hilling, or they may pull potato roots relocating them and causing root injury (Felix *et al.*, 2009). But this is not always applicable since it depends on weed species and their growth habits each year. For instance *Amaranthus* spp. favors hot weather as compared to *Chenopodium album* that grows at lower temperatures early in the season (Behrens, 1966), knowing that temperature and weather conditions are variable over the years. Additionally, soil moisture should be maintained properly during hilling to avoid soil structure damage as well as to better control weeds, whereby soil should be dry for effective uprooting and desiccation of weeds while abundant moisture will favor weed re-growth after tillage. Also, rainfalls are important limitation for effective tillage since it leads to enormous unmanageable weeds germinating and delaying cultivation (Ashton and Monaco, 1991).

However, hilling fails to control weeds with perennial life cycle because of their ability to re-germinate promptly from vegetative reproductive structures such as rhizomes or tubers, especially if these structures are dispersed through the field upon cultivation in too wet soil conditions (Gianessi and Sankula, 2003). Moreover, hilling is not effective against weeds within the crop row. Weeds growing early in the season between potato plants are more threatening than those growing between rows. This is because most of them are growing beside the crop and cannot be reached by the hilling machine (Yip *et al.*, 1974). In addition, hilling can increase weeds within rows by removing soils from spaces between rows and adding them on the hills between potato plants. This will allow weed seeds buried deep in the soil layers that did not receive any herbicide to be moved to the top of the hills then germinate again in untreated zones (Rioux *et al.*, 1979) after being exposed to light and water (Lanfranconi *et al.,* 1993; VanGessel and Renner, 1990b). For example, some annual weeds like *Setaria* spp. and *Amaranthus retroflexus* are best controlled when hilling is applied at a certain period of the growing term (Nalewaja *et al.*, 1980).

And since hilling is a time consuming process and requires specific weather conditions- neither too dry, nor too wet, this encouraged farmers to find an alternative weed control strategy, which is herbicides (Rikoon *et al*., 1993). Currently, many farmers are relying on herbicides while reducing or excluding hilling practices in order to manage weeds (Schweizer *et al*., 1989). In potato fields, pre-emergence or post-emergence herbicides can be used to control weeds. Most grasses and some broadleaved weeds, such as *Xanthium strumarium*, *Capsella bursa-pastoris*, and *Sinapis arvensis* are better controlled by pre-emergence herbicides (Hutchinson, 2012).

2. Effect on potato growth and development

Hilling or metribuzin and their combinations had no negative effect on potato plants. Average shoot height (table 10), plant number, shoot number, leaf number (table 11), phytotoxicity (table 12), and average root dry weights (table 13) showed no significant differences among all treatments compared to the check, at 50, 70, and 110 DAP.

Crop injury can range from no visual symptoms, slight symptoms, chlorosis, necrosis, and can reach crop death depending on the herbicide rate, its interaction with the crop, and the environmental conditions. Crops usually metabolize herbicides into less phytotoxic compounds that are less harmful or safer to the crop and cause no or less injury (Hager, 2009). There are three phases in herbicide metabolism in plants (Hatzios, 1991; Shimabukuro, 1985), whereby oxidation, reduction, and hydrolysis of the parent complex take place in phase I to transform it to a less toxic water-soluble compound. Then the product or the metabolite is conjugated to an amino acid or to a sugar, decreasing its toxicity and making it more water soluble in the second phase. Finally, in phase III, secondary conjugates are produced from the conversion of the slightly or nonphytotoxic metabolites produced in phase II and stored in the organelles of the cells (Van Eerd *et al.*, 2003).

Table 10: Effect of metribuzin, hilling, and their combination on average potato height (cm) per 10 plants per middle row, 50, 70, and 110 days after planting (DAP)

Treatment	**Rate (kg ai/ha)**	**Hilling (WAP)**	**Average potato height (cm)/ 10 plants**					
			50		70		110	
Check	0	-	35.0	ab	59.4	a	74.6	ab
Hand Weeding	0	-	33.5	ab	65.5	a	66.0	b
Metribuzin (M)	0.18	-	31.0	ab	72.0	a	103.1	a
M	0.35	-	31.4	ab	70.6	a	90.5	ab
M	0.56	-	27.0	ab	69.7	a	102.2	a
M	0.75	-	21.5	a	67.3	a	99.4	ab
M	0	6	31.8	ab	63.5	a	93.0	ab
M	0.18	6	34.1	ab	66.5	a	79.2	ab
M	0.35	6	33.0	ab	70.7	a	102.8	a
M	0.56	6	26.2	ab	54.5	a	107.2	a
M	0.75	6	28.4	ab	68.4	a	106.7	a
M	0	7	37.8	b	59.8	a	75.1	ab
M	0.18	7	34.3	ab	72.2	a	92.2	ab
M	0.35	7	30.9	ab	72.0	a	101.2	a
M	0.56	7	29.9	ab	65.0	a	86.0	ab
M	0.75	7	29.3	ab	70.0	a	101.2	a
M	0	8	37.2	ab	62.3	a	80.3	ab
M	0.18	8	32.2	ab	69.5	a	88.3	ab
M	0.35	8	31.4	ab	69.0	a	100.0	ab
M	0.56	8	29.4	ab	65.6	a	93.8	ab
M	0.75	8	31.4	ab	68.9	a	95.0	ab

Table 11: Effect of metribuzin, hilling, and their combination on average potato plant number per plant middle row, 50 days of planting (DAP), average shoot number per plant, 50 and 70 DAP, and on average leaf number per plant, 110 DAP

Treatment	Rate (kg ai/ha)	Hilling (WAP)	Pot. #/ middle row		Average shoot #/ plant				Average leaf #/ plant	
			50		50		70		110	
Check	0	-	18.0	a	2.6	a	1.8	a	23.1	a
Hand Weeding	0	-	19.0	a	2.9	a	2.5	a	46.2	a
Metribuzin (M)	0.18	-	15.8	a	2.6	a	2.3	a	46.2	a
M	0.35	-	16.5	a	2.2	a	2.0	a	57.7	a
M	0.56	-	18.0	a	2.3	a	2.3	a	51.3	a
M	0.75	-	16.8	a	2.2	a	2.2	a	40.7	a
M	0	6	17.3	a	2.4	a	2.1	a	36.4	a
M	0.18	6	17.3	a	2.6	a	2.3	a	48.8	a
M	0.35	6	18.0	a	2.6	a	2.1	a	61.8	a
M	0.56	6	17.0	a	2.2	a	2.3	a	55.9	a
M	0.75	6	16.8	a	2.4	a	2.3	a	72.7	a
M	0	7	17.5	a	3.0	a	2.7	a	42.1	a
M	0.18	7	17.0	a	2.6	a	2.2	a	51.0	a
M	0.35	7	18.3	a	2.4	a	2.3	a	63.0	a
M	0.56	7	16.5	a	2.2	a	1.9	a	55.9	a
M	0.75	7	17.0	a	2.5	a	2.3	a	52.7	a
M	0	8	18.3	a	3.1	a	2.7	a	37.0	a
M	0.18	8	18.0	a	2.8	a	2.2	a	52.3	a
M	0.35	8	17.3	a	2.6	a	2.2	a	54.0	a
M	0.56	8	18.3	a	2.3	a	2.2	a	56.6	a
M	0.75	8	16.8	a	2.3	a	2.7	a	45.5	a

Table 12: Effect of metribuzin, hilling, and their combination on phytotoxicity visual rating (PVR), 50, 70, and 110 days after planting (DAP)

Treatment	**Rate (kg ai/ha)**	**Hilling (WAP)**	**PVR***					
			50		70		110	
Check	0	-	8.8	a	6.3	a	0.3	c
Hand Weeding	0	-	9.0	a	9.3	a	6.3	ab
Metribuzin (M)	0.18	-	9.5	a	8.3	a	3.8	abcd
M	0.35	-	9.5	a	8.5	a	6.0	abd
M	0.56	-	9.5	a	8.8	a	6.5	ab
M	0.75	-	8.8	a	8.3	a	5.3	abcd
M	0	6	9.0	a	7.5	a	1.0	bcd
M	0.18	6	9.5	a	8.8	a	4.0	abcd
M	0.35	6	10.0	a	9.8	a	6.8	a
M	0.56	6	9.8	a	9.8	a	8.5	a
M	0.75	6	9.8	a	9.5	a	8.0	a
M	0	7	10.0	a	6.8	a	0.5	cd
M	0.18	7	9.5	a	8.0	a	5.8	abcd
M	0.35	7	9.3	a	9.3	a	7.8	a
M	0.56	7	9.3	a	8.5	a	5.5	abcd
M	0.75	7	9.5	a	9.8	a	7.0	a
M	0	8	9.5	a	7.8	a	3.0	abcd
M	0.18	8	9.5	a	8.8	a	5.5	abcd
M	0.35	8	9.8	a	9.3	a	5.3	abcd
M	0.56	8	9.5	a	9.5	a	7.5	a
M	0.75	8	9.8	a	8.3	a	8.5	a

*PVR scale: 0-10; 0 means dead potato plants and 10 means healthy vigorous plants

Table 13: Effect of treatments on average potato shoot number and root dry weight (g) per two plants per plot (from the two borderlines of each plot), 70 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Hilling (WAP)	Average shoot #/ Plant	Average root dry weight (g)
Check	0	-	4.8 ab	9.3 a
Hand Weeding	0	-	6.5 ab	12.9 a
Metribuzin (M)	0.18	-	5.0 ab	12.0 a
M	0.35	-	3.3 a	9.6 a
M	0.56	-	5.8 ab	12.3 a
M	0.75	-	4.5 ab	11.1 a
M	0	6	7.8 b	14.3 a
M	0.18	6	5.5 ab	13.2 a
M	0.35	6	5.5 ab	11.7 a
M	0.56	6	5.0 ab	12.1 a
M	0.75	6	5.0 ab	13.4 a
M	0	7	4.8 ab	9.2 a
M	0.18	7	4.5 ab	11.1 a
M	0.35	7	4.0 ab	11.0 a
M	0.56	7	6.0 ab	12.9 a
M	0.75	7	4.5 ab	11.7 a
M	0	8	6.5 ab	10.8 a
M	0.18	8	5.3 ab	11.7 a
M	0.35	8	6.3 ab	13.6 a
M	0.56	8	5.0 ab	12.1 a
M	0.75	8	7.0 ab	13.1 a

Table 14 shows that except for hilling alone at 6, 7 and 8 WAP, metribuzin alone at all tested rates, with or without hilling, significantly increased marketable potato tuber weight and total tuber yield, in comparison to the check, 140 DAP. The highest marketable potato yield (38.72tons/ha) and total tuber yield (57.24tons/ha) were observed with metribuzin at 0.56kg ai/ha with hilling 8 WAP. This treatment was better than hand weeded (29.51tons/ha of marketable tubers and a total yield of 55.89tons/ha). In addition, it was observed that marketable yield in plots hilled at 6 WAP is higher than plots hilled later in the season (7 and 8 WAP), with an average of 15.45tons/ha, compared to 6.64 and

8.53tons/ha in plots hilled 7 and 8 WAP, respectively. The opposite was observed in nonmarketable weights, whereby nonmarketable tubers- including cull tubers- in plots hilled 6 WAP weighed 14.67tons/ha, while they weighed 16.25 and 16.61tons/ha in plots hilled 7 and 8 WAP, respectively.

Table 14: Effect of metribuzin, hilling, and their combination on average marketable, non-marketable, and total potato tuber weight (tons/ha), 140 days after planting (DAP)

Treatment	**Rate (kg ai/ha)**	**Hilling (WAP)**	**Average potato tuber weight (t/ha)**					
			Marketable		Non-marketable		Total	
Check	0	-	3.46	e	14.81	a	18.27	e
Hand Weeding	0	-	29.51	abcd	26.38	b	55.89	ab
Metribuzin (M)	0.18	-	29.76	abcd	17.15	ab	46.91	abcd
M	0.35	-	29.85	abc	18.80	ab	48.65	abcd
M	0.56	-	31.32	abc	16.76	ab	48.08	abcd
M	0.75	-	29.42	abcd	14.48	a	43.90	abcde
M	0	6	15.45	acde	14.67	a	30.12	acde
M	0.18	6	29.67	abcd	20.02	ab	49.68	abc
M	0.35	6	33.49	ab	17.47	ab	50.97	abc
M	0.56	6	34.37	ab	18.06	ab	52.43	ab
M	0.75	6	36.00	ab	15.43	ab	51.43	ab
M	0	7	6.64	de	16.25	ab	22.88	de
M	0.18	7	31.12	abc	17.65	ab	48.76	abcd
M	0.35	7	23.85	abcde	18.75	ab	42.60	abcde
M	0.56	7	27.09	abcd	16.46	ab	43.55	abcde
M	0.75	7	34.73	ab	20.18	ab	54.91	ab
M	0	8	8.53	cde	16.61	ab	25.14	cde
M	0.18	8	28.20	abcd	16.45	ab	44.64	abcd
M	0.35	8	30.65	abc	18.34	ab	48.98	abc
M	0.56	8	38.72	b	18.52	ab	57.24	b
M	0.75	8	30.67	abc	21.30	ab	51.97	ab

Same results were observed regarding potato tuber numbers (Table 15), measured 140 DAP. There were 58,572 marketable tubers and 152,143 nonmarketable tubers in plots hilled 6 WAP, compared to 27,143 marketable tubers and 167,857 nonmarketable tubers in plots hilled 7 WAP, and 35,000 marketable tubers and 195,714 nonmarketable tubers in plots hilled 8 WAP with no metribuzin applied, even though there is no significance between the numbers at all hilling times compared to the check, recording 13,572 marketable tubers and 172,143 nonmarketable tubers. Regarding metribuzin treatments, marketable and non-marketable tuber numbers showed no significant difference among all treatments of metribuzin, with or without hilling, but significantly different compared to the check and to plots hilled 6, 7, and 8 WAP (table 15). Weed control at the proper timing can increase potato yield by 15-50% (Eberlein *et al*., 1997; Jaiswal and Lal, 1996). Thus, hilling time should be considered as a significant factor to maintain good potato yields early in the season and to reduce the effect of weeds emerging later (Nelson and Thoreson, 1981); as well as it may aid in covering the tubers from sunlight, reducing culls, aerating soil (Bellinder *et al.*, 1996), facilitating harvesting since less soil- at least 40% less- is present in the space between potato rows where cultivators pass (Han and Qi, 2013). However, late hilling may cause pruning of potato roots and stolons, breaking soil structure, compacting soil, or causing erosion if heavy machinery were implemented or if several cultivations were applied (Nelson and Giles, 1986; Rioux *et al*., 1979).

Table 15: Effect of metribuzin, hilling, and their combination on marketable, non-marketable, and total potato tuber numbers (tubers/ha), 140 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Hilling (WAP)	Average potato tuber number (tubers/ha)					
			Marketable		Non-marketable		Total	
Check	0	-	13,572	d	172,143	a	185,714	a
Hand Weeding	0	-	98,571	ab	237,857	a	336,429	b
Metribuzin (M)	0.18	-	93,572	abc	157,857	a	251,429	ab
M	0.35	-	96,429	ab	178,571	a	275,000	ab
M	0.56	-	116,429	a	150,714	a	267,143	ab
M	0.75	-	82,857	abc	131,429	a	214,286	ab
M	0	6	58,572	abcd	152,143	a	210,714	ab
M	0.18	6	105,714	a	214,286	a	320,000	ab
M	0.35	6	104,286	a	191,429	a	295,714	ab
M	0.56	6	106,429	a	180,714	a	287,143	ab
M	0.75	6	106,429	a	147,857	a	254,286	ab
M	0	7	27,143	cd	167,857	a	195,000	ab
M	0.18	7	102,857	ab	180,714	a	283,571	ab
M	0.35	7	70,715	abcd	185,714	a	256,429	ab
M	0.56	7	89,286	abc	170,714	a	260,000	ab
M	0.75	7	108,572	a	188,571	a	297,143	ab
M	0	8	35,000	bcd	195,714	a	230,714	ab
M	0.18	8	92,857	abc	170,000	a	262,857	ab
M	0.35	8	96,429	ab	182,143	a	278,571	ab
M	0.56	8	126,428	a	157,857	a	284,286	ab
M	0.75	8	94,286	abc	170,714	a	265,000	ab

Potato yield can be reduced due to weeds competing for resources such as water, nutrients, and light (Zarzecka *et al.*, 2014). For example, broadleaf weeds have deep roots that make them good competitors for water at the expense of potato crops consequently affecting yields and tubers quality (Tscheulin *et al.*, 2009). Another causes for quality deterioration is the burns due to sunstrokes, tuber infection with some pathogens like late blight (Lacey, 1966; Svensson, 1962), or greening of the tubers due to the formation of chloroplasts from the re-differentiation of the tuber parenchyma's amyloplast (Deng and Gruissem, 1988). These can be observed in tubers developing at shallow depth when the mother seed tuber is not sowed at deep soil level. Thus, hills preparation before planting (Bohl and Love, 2005; Kouwenhoven, 1970; Svensson, 1962) and right sowing depths are important (Mosley, 1975a, 1975b; Stalham *et al.,* 2001), but a better recommended agricultural practice is to cultivate or "hill" the potato rows during the growing season after planting (Lewis and Rowberry, 1973; Moore, 1937; Stalham *et al.,* 2001). For instance, *Phytophthora infestans* are less common in tubers planted at deep soil levels (Lacey, 1966) and when post-planting hilling is applied (Svensson, 1962).

Even though potato plants have rapid growing and development characteristics during the growing season, they have slow emergence rate making them bad competitors with weeds. Vigorous potato plants with good rooting system should be maintained to compete with weeds, to resist diseases, phytotoxicity, and some side effects of pesticides, and to shade tubers in their canopy preventing greening due to sun exposure, thus produce higher yields with better quality (Lewis and Rowberry, 1973). Weeds not only reduce crop yields and cause deterioration in quality; they can be real problem during crop harvesting in addition to increasing the weed seed bank in the soil if left until seed set (Hager, 2009). Therefore, farmers should take care when managing weeds in potato fields in order not to affect potato tubers and plants total dry matter (Channappagoudar *et al.*, 2007).

B. Greenhouse Experiment

Results in table 16 show that metribuzin at all tested rates showed no significant effect on monocot weeds, 30 DAP, compared to the check. However, after 60 and 90 DAP, metribuzin at 0.56 and 0.75kg ai/ha only were effective against monocot weeds. Results regarding dicot weeds show that metribuzin at all tested rates significantly reduced weed count compared to the check, 30, 60 and 90 DAP (table 17). As for the effect of metribuzin on total weeds, results in table 18 show that metribuzin at all tested rates significantly reduced all weeds, 30 DAP, compared to the check. However, after 60, 90, and 120 DAP, only metribuzin at 0.56 and 0.75kg ai/ha were effective in reducing total weeds, in comparison to the check. Boxes treated with 0.56kg ai/ha metribuzin have the lowest number of weeds (Figures 19, 20, 21, and 22).

Table 16: Effect of metribuzin on monocot weeds count per box, 30, 60, and 90 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Monocot weeds count/box					
		30		60		90	
Check	0	82.33	a	65.00	b	93.33	b
Hand weeding	0	0.00	b	0.00	a	0.00	a
Metribuzin (M)	0.18	23.67	a	44.67	ab	62.67	ab
M	0.35	95.67	a	63.33	ab	67.00	ab
M	0.56	50.00	a	7.67	a	2.25	a
M	0.75	41.00	a	14.67	a	5.67	a

Table 17: Effect of metribuzin on dicot weeds count per box, 30, 60, and 90 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Dicot weeds count/box					
		30		60		90	
Check	0	46.00	b	41.67	b	41.00	c
Hand weeding	0	0.00	a	0.00	a	0.00	a
Metribuzin (M)	0.18	1.33	a	11.67	a	3.25	ab
M	0.35	9.50	a	25.33	ab	3.00	ab
M	0.56	0.50	a	11.00	a	2.00	a
M	0.75	3.75	a	11.00	a	15.00	b

Table 18: Effect of metribuzin on total weeds count per box, 30, 60, 90, and 120 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Total weeds count/box							
		30		60		90		120	
Check	0	128.5	c	106.6	c	141.0	b	83.3	cd
Hand weeding	0	0.00	a	0.00	a	0.00	a	0.00	a
Metribuzin (M)	0.18	25.00	ab	55.00	abc	66.33	ab	50.0	bc
M	0.35	105.1	bc	83.33	bc	69.33	ab	100	d
M	0.56	51.00	ab	16.75	ab	4.25	a	4.25	a
M	0.75	46.00	ab	22.00	ab	20.67	a	14.0	a

Figure 19: Effect of metribuzin on monocot, dicot, and total weed count per box, 30 DAP

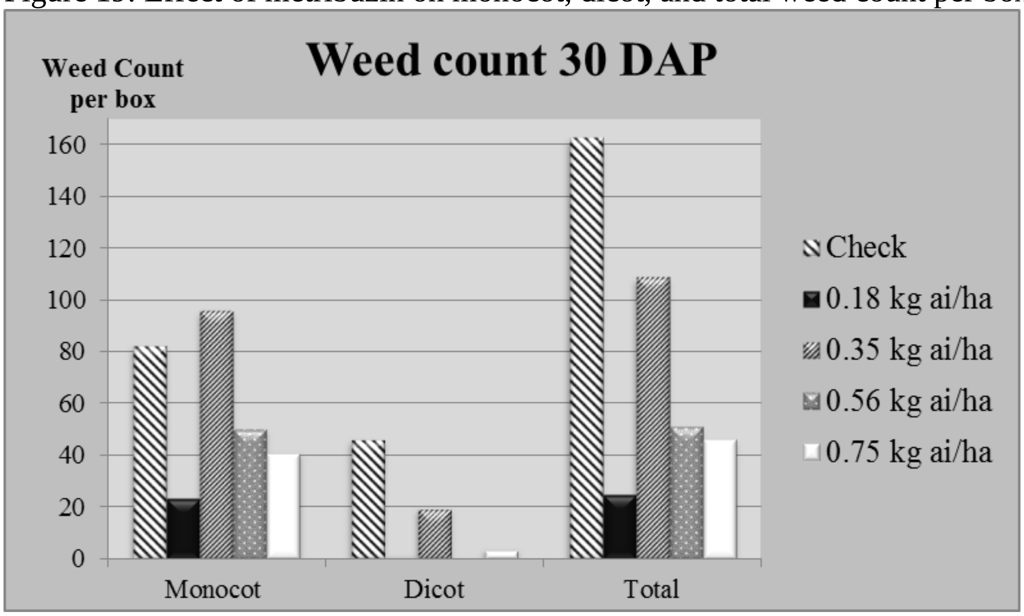


Figure 20: Effect of metribuzin on monocot, dicot, and total weed count per box, 60 DAP

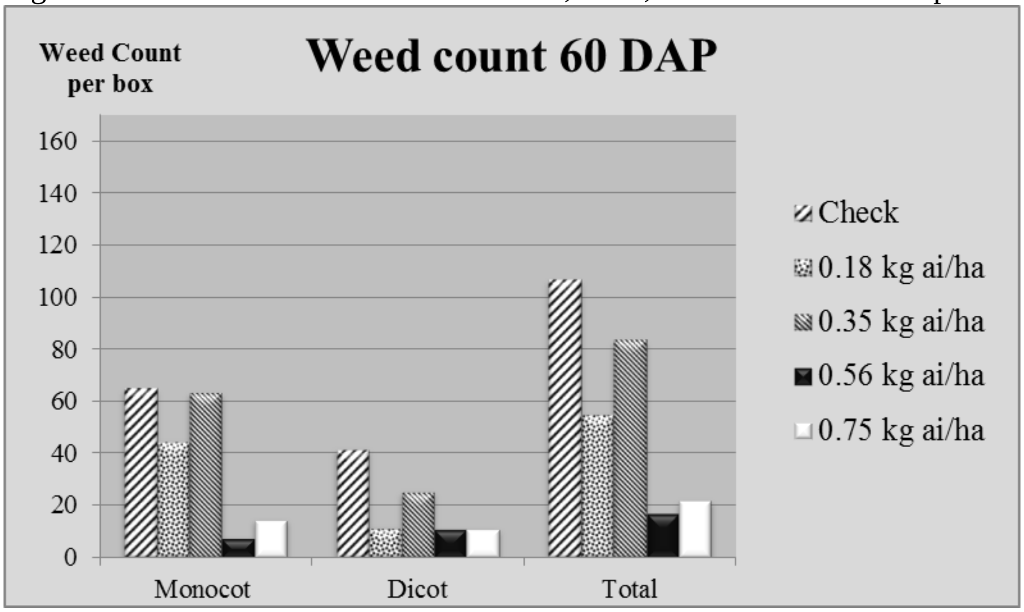


Figure 21: Effect of metribuzin on monocot, dicot, and total weed count per box, 90 DAP

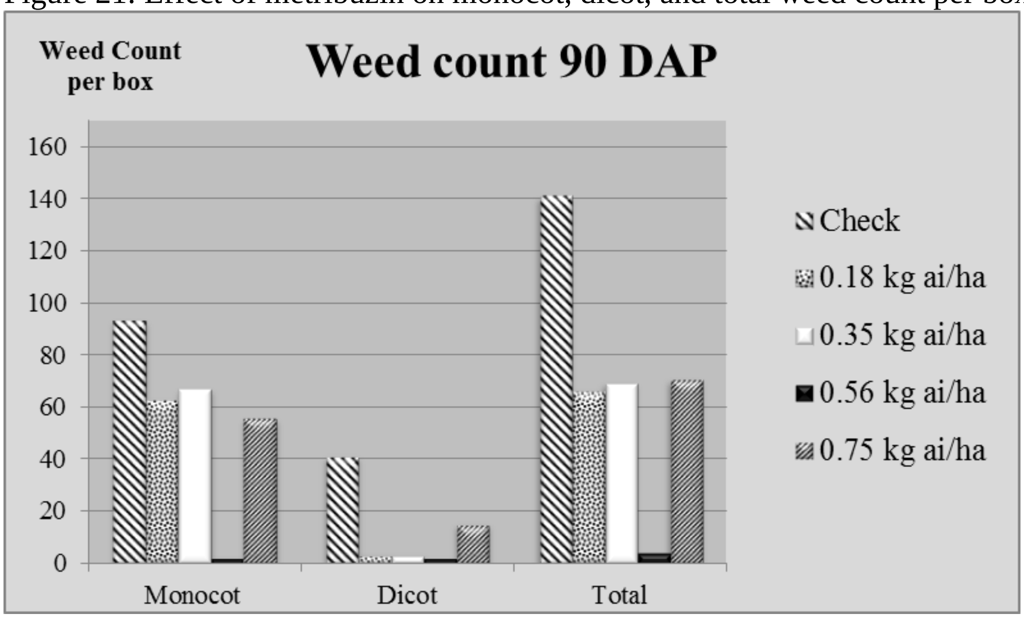
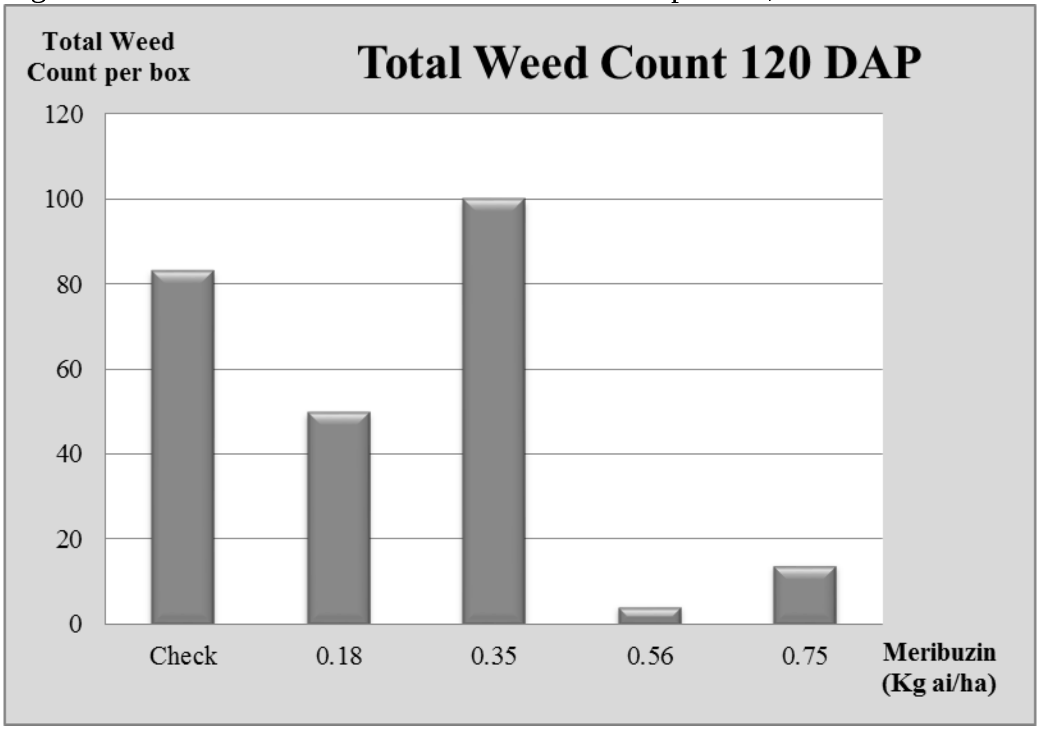


Figure 22: Effect of metribuzin on total weed count per box, 120 DAP



Regarding potato plants, table 19 shows that metribuzin at 0.35, 0.56, and 0.75kg ai/ha significantly enhanced potato shoot height per box after 30 DAP but not after 60 and 90 DAP compared to the check. As for the average potato shoot number and leaf number per box, data shows that there is no significant differences among treatments after 30, 60, 90, and 120 DAP compared to the check (tables 20 and 21). But the average leaf number in boxes treated with metribuzin at the rate of 0.56kg ai/ha was significantly different from all treatmenst, 30 DAP. Moreover, metribuzin at all tests rates were not toxic to potato plants, 60 and 90 DAP, compared to the check and hand weeded plots (Table 22). However, most of the potato plants appeared to be necrotic due to high salinity of the irrigation water in addition to the effect of white fly infestation.

Table 19: Effect of metribuzin on average potato height (cm) per box, 30, 60, and 90 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Average potato height (cm)/ box					
		30		60		90	
Check	0	11.00	a	60.00	a	80.00	a
Hand weeding	0	27.25	ab	56.83	a	83.83	a
Metribuzin (M)	0.18	24.67	ab	67.50	a	79.75	a
M	0.35	41.25	b	63.67	a	78.83	a
M	0.56	44.25	b	53.33	a	68.00	a
M	0.75	46.00	b	86.17	a	99.50	a

Table 20: Effect of metribuzin on average potato shoot number per box, 30, 60, 90, and 120 days of planting (DAP)

Treatment	Rate (kg ai/ha)	Average shoot number/ box							
		30		60		90		120	
Check	0	1.25	a	1.25	a	1.25	a	2.5	a
Hand weeding	0	1.50	a	2.75	a	2.38	a	4.8	a
Metribuzin (M)	0.18	2.00	a	2.25	a	2.00	a	3.8	a
M	0.35	1.38	a	1.63	a	1.50	a	3.0	a
M	0.56	2.38	a	2.50	a	2.38	a	4.0	a
M	0.75	1.13	a	1.88	a	2.00	a	4.3	a

Table 21: Effect of metribuzin on average potato leaf number per box, 30, 60, and 90 days of planting (DAP)

Treatment	Rate (kg ai/ha)	Average leaf number/ box					
		30		60		90	
Check	0	9.00	a	12.13	a	31.17	a
Hand weeding	0	8.50	a	15.50	a	19.88	a
Metribuzin (M)	0.18	13.00	a	15.63	a	23.88	a
M	0.35	17.67	ab	29.50	a	14.25	a
M	0.56	32.17	b	14.00	a	18.25	a
M	0.75	16.17	ab	20.00	a	24.75	a

Table 22: Effect of metribuzin on phytotoxicity visual rating (PVR), 60 and 90 days after planting (DAP)

Treatment	Rate (kg ai/ha)	PVR			
		60		90	
Check	0	9.00	a	8.50	a
Hand weeding	0	6.50	a	7.75	a
Metribuzin (M)	0.18	9.75	a	6.75	a
M	0.35	6.50	a	6.75	a
M	0.56	6.75	a	5.00	a
M	0.75	6.00	a	7.75	a

None of metribuzin rates had a negative effect on potato shoot dry weight and weed dry weight compared to the check (Table 23). However, boxes treated with 0.35 and 0.56kg ai/ha metribuzin gave the lowest potato shoot dry weight, 8.83g and 6.79g respectively. On the other hand, weed dry weight was the highest in boxes treated with 0.18 and 0.35kg ai/ha metribuzin, recording 1.45g and 1.07g respectively; even though weed dry weight was not significantly different among treatments and compared to the check, which in turn was significantly different from that of the hand weeded boxes.

Table 23: Effect of metribuzin on average potato shoot dry weight (g/box) and weed dry weight (g/box), 120 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Potato shoot dry wt (g/box)		Weed dry wt (g/box)	
Check	0	12.59	ab	2.01	b
Hand weeding	0	20.38	b	0.00	a
Metribuzin (M)	0.18	14.38	ab	1.07	ab
M	0.35	8.83	a	1.45	ab
M	0.56	6.79	a	0.13	ab
M	0.75	18.01	ab	0.37	ab

Metribuzin at all tested rates was selective in potato and had no negative effect on total potato tuber number (figure 23) and weight (figure 24) compared to the check or hand weeded plots. Yet, the total number of tubers was the highest in boxes treated with 0.56kg ai/ha metribuzin (411,765tubers/ha) while boxes treated with 0.35kg ai/ha metribuzin recorded the lowest weight (176,471tubers/ha), due to weed competition (Hager, 2009), and total weight of tubers was the highest in boxes treated with 0.18kg ai/ha metribuzin (10.05tons/ha) while hand weeded boxes recorded the lowest weight (4.63tons/ha), knowing that all the tubers are nonmarketable (table 24).

Figure 23: Effect of metribuzin on total potato number (tuber/ha), 120 DAP

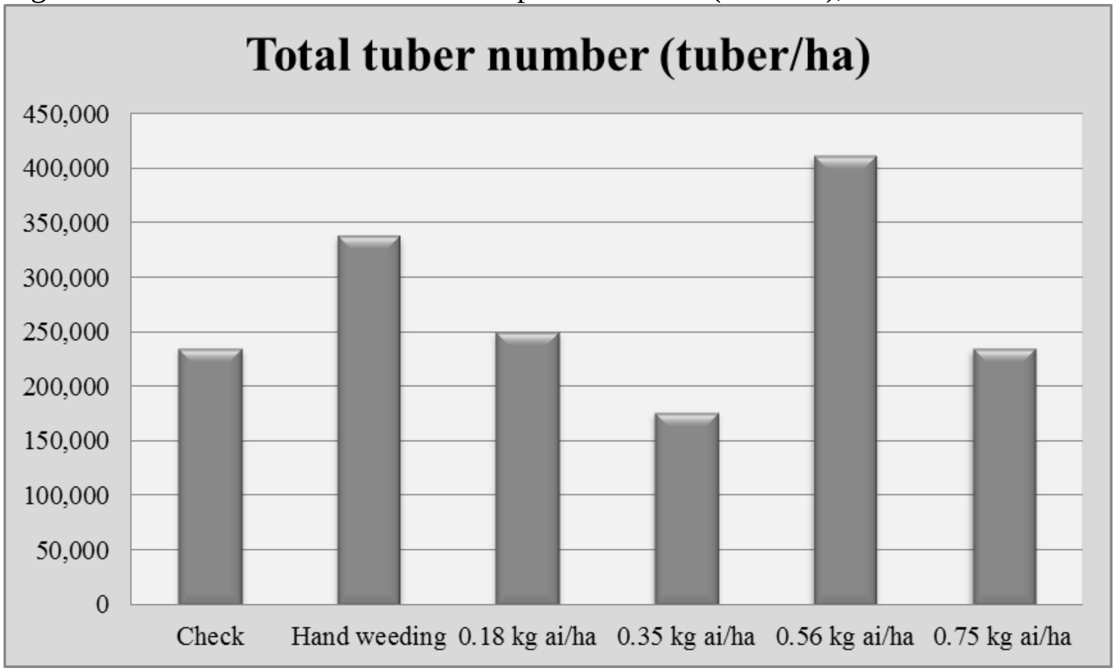


Figure 24: Effect of metribuzin on total potato weight (tons/ha), 120 DAP

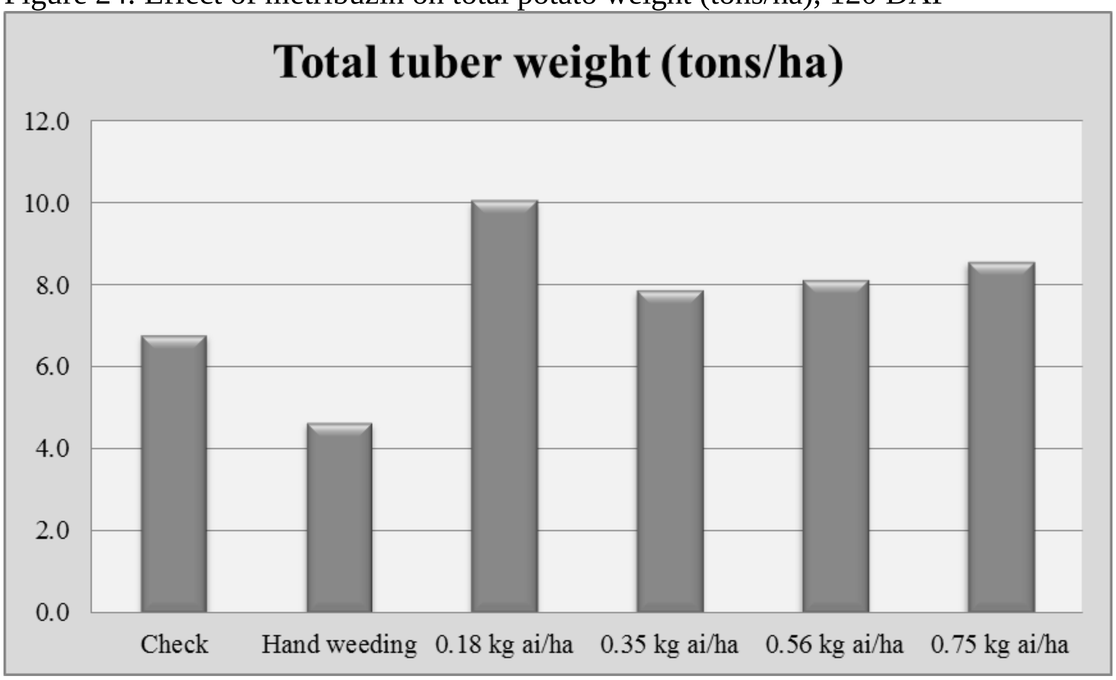


Table 24: Effect of metribuzin on total potato tuber number (tuber/ha) and weight (tons/ha), 120 days after planting (DAP)

Treatment	Rate (kg ai/ha)	Total tuber umber (tuber/ha)		Total tuber weight (tons/ha)	
Check	0	235,294	a	6.78	a
Hand weeding	0	338,235	a	4.63	a
Metribuzin (M)	0.18	250,000	a	10.05	a
M	0.35	176,471	a	7.87	a
M	0.56	411,765	a	8.13	a
M	0.75	235,294	a	8.57	a

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. Summary

Weeds are a major problem in potato production in Lebanon. They can reduce potato yield through competition for light, water, and nutrients. The competition with weeds during the early season is most detrimental to potato growth and yield. Thus, weeds should be controlled during this period. One effective way of managing weeds early in the season however, is hilling (Connell *et al*., 1999). Weed management involving the time of hilling and low rates of metribuzin applications were compared. Results showed that all tested rates of metribuzin (0.18, 0.35, 0.56, and 0.75kg ai/ha), irrespective of the time of hilling, significantly reduced weeds compared to the check and plots hilled 6, 7, and 8 WAP. Hilling alone was not effective against weeds. Pre-emergence application of metribuzin at 0.35 and 0.56kg ai/ha alone or with hilling at 6, 7, and 8 WAP, respectively, provided excellent long season weed control. Metribuzin alone at all tested rates or combined with hilling had no negative effect on potato yield.

B. Conclusions

It can be concluded from this study that:

- All tested rates of metribuzin (0.18, 0.35, 0.56, and 0.75kg ai/ha) were effective for weed management in potato.
- Hilling alone 6, 7, and 8 WAP was not efficient to manage weeds.

- Any rate of metribuzin (0.18, 0.35, 0.65, or 0.75kg ai/ha), combined with any hilling time (6, 7, or 8 WAP), was effective for weed management in potato plantation besides the standard management practice, which uses metribuzin at 0.75kg ai/ha with hilling 6 WAP.
- Combination of metribuzin and hilling can greatly enhance long season weed control during that season.
- All treatments had no negative effect on potato plants or tuber yields.
- The research provides innovative and sustainable information for weed management in potato.

C. Recommendations

After conducting this research, it is recommended that:

- Weed management strategies should be shifted from the standard application of 0.75kg ai/ha metribuzin with hilling 6 WAP, to lower rates of metribuzin combined with different hilling times.
- Surveying on the use of metribuzin in the Beq'aa plain in potato should be conducted.
- Further studies should be done on:
    a. The effect on metribuzin on ground and surface water and its residues in the soil.
    b. Environmental and health impact of metribuzin.
    c. Metribuzin resistant weeds.

- Additional research is recommended under different locations in Lebanon before a final recommendation to potato growers for the use of low rates of metribuzin can be made.
- Farmers should plan a total weed control program that integrates chemical, mechanical, and cultural methods to manage weeds and enhance potato yield.

CHAPTER VI

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