The effect of natural mulches on crop performance, weed suppression, and herb quality in organic field production of catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos')

by

Lisa Marie Duppong

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Crop Production and Physiology

Program of Study Committee:
Kathleen Delate (Major Professor)
Matt Liebman
Robert Horton

Iowa State University

Ames, Iowa

2002

Graduate College
Iowa State University

This is to certify that the master's thesis of

Lisa Marie Duppong

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

TABLE OF CONTENTS

CHAPTER 1. General Introduction and Literature Review

Organic Agriculture

Organic agriculture is defined by the National Organic Standards Board (NOSB) as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity" (NOSB, 1995). The organic industry is a consumer driven market that has been growing at least 20% every year for the past 10 years, with projected retail sales of $20 billion in the U.S. by 2005 (OTA, 2002). This market has not only increased in the U.S., but also in Europe, Asia, Australia, and New Zealand. In response to the increased demand for organic products, Iowa farmers increased their acres of organic production from 13,000 in 1995 to 120,000 in 1998 (IDALS, 1999a).

The Iowa Department of Agriculture and Land Stewardship (IDALS) Organic Agriculture Program through the Iowa Organic Certification Standards (Iowa Code, Chapter 190C, 1999) works with private certification agencies to assure that rules governing the certification of organic farms are enforced. Certification is a seal of assurance for use in trade and marketing. Producers, processors, and handlers earning over $5,000 from organic products must be certified (IDALS, 1999b). Farmers who transition some or all of their fields to organic production must follow the same regulations as certified organic production. Farmers must also submit a written plan for growing and handling their crops and livestock. Because crop rotations are critical for maintaining soil quality, and interrupting insect, disease, and weed cycles, no two annual crops of the same species can be grown on the same field in consecutive years.

One of the most basic requirements of certification prohibits the application of synthetic chemicals for three years prior to certification. Organic fields bordering conventional fields must have a 30-foot border to separate the fields. Any synthetic materials, including fungicides, insecticides, and herbicides, are disallowed in organic production, as are genetically modified organisms (GMOs) and irradiation treatment (IDALS, 1999b).

Soil health is the backbone of organic farming. Soils in organic farming systems have been shown to contain greater levels of microbial biomass, necessary for nutrient cycling, compared with conventional systems (Scow et al., 1994). An adequate supply of nutrients may also be achieved by applying compost, manure, and naturally-based soil amendments accepted within certification regulations (Kelly, 1990). Leguminous crops, such as vetch, alfalfa, or clover, can be an important source of nitrogen (Stute and Posner, 1995), and therefore are required in organic crop rotations in annual cropping systems.

The use of cover crops in rotations further provides nutrients and organic matter to the soil, while offering many other benefits to farmers. They can slow erosion by anchoring soil throughout the winter and spring, protecting the soil from wind, increasing water infiltration rates, and reducing rapid runoff (SAN, 1998; Teasdale, 1996). Implementing them as part of a cropping system increases biodiversity of the agroecosystem, as they can provide an overwintering habitat for beneficial insects on ground that might otherwise lay bare (SAN, 1998). Often organic farmers will also include them in their crop rotations as part of their weed management practices.

Organic production is management intensive because it relies on a systems approach in production rather than a blanket chemical approach (Swezey et al., 2000). In addition to basic crop production knowledge, a thorough knowledge is needed in pest management and biological controls, including knowledge of the life cycles of insects and plant pathogens in order to recognize, prevent, and control pests. Managing diseases, insects, and weeds are some of the more challenging issues in organic production. Effective control is achieved through an integrated approach that implements biological control, cultural, and mechanical practices. The goal of producers is not to eradicate particular pests, but to regulate their populations at tolerable levels or levels below the economic threshold.

Organic Weed Management

Weeds are commonly viewed as undesirable competitors of water, nutrients, and light (Cavigelli et al., 2000). Different types of weeds require different management approaches by producers, including tillage practices and planting and harvesting dates (Dyer, 1995). Seed dormancy, and therefore, seed germination, is influenced by light, soil fertility, soil moisture content, and temperatures (Dyer, 1995). Weed seed size can also be a factor (Mohler and Teasdale, 1993). Small-seeded and light-sensitive weeds such as redroot pigweed (*Amaranthus retroflexus*) and common lambsquarters (*Chenopodium album* L.) are less likely to germinate in hairy vetch residue than velvetleaf (*Abutilon theophrasti* Medicus), a large-seeded, light-insensitive weed (Mohler and Teasdale, 1993).

Out of 32 research topics listed, weed management was the number one concern of organic farmers across the nation in a recent survey published by the Organic Farming Research Foundation (Walz, 1999). However, weed control is not only problematic in organic crop production. Between 20-25% of the annual energy cost in a conventional system (corn-soybean-winter wheat rotation) is associated with weed control practices (Clements et al., 1995). This percentage does not include the substantial labor and material costs involved in managing weeds (Feldman et al., 2000), nor does it consider negative environmental and human health effects, which may be the most detrimental of all costs.

Degraded herbicide compounds were three of the top four most frequently detected substances in Iowa municipal wells during the summer of 1995 (Kolpin, 1997), and herbicides have been detected in surface and ground waters at amounts exceeding maximum contamination levels established by the EPA (Goolsby et al., 1991).

Producers are continually looking for ways to decrease herbicide usage as part of an integrated pest management approach. Furthermore, these chemicals are disallowed in organic production, and some crops have no, or only a few, herbicides labeled for use in them. Manual labor and cultivation are weed management options in these situations, but may not always be effective, feasible, or affordable. Economically and environmentally sustainable weed control alternatives, such as mulches, can provide many benefits for herb producers.

Mulches

Mulches influence heat, moisture, and radiation in and at the surface of the soil, and therefore affect plant growth, yield, and seed germination (Bristow, 1988). Mulches can be classified as living or dead, and natural or synthetic. Living mulches are cover crops that have been planted in between crop rows, broadcast across a field at the end of a growing season, or planted beneath a perennial row crop such as in a vineyard or orchard. Living mulches increase competition for water, nutrients, and light, displacing weedy populations (Teasdale, 1996). A secondary function of a living mulch may be to attract certain beneficial insects by providing habitat, nectar, and pollen. An example a living mulch system is a mixture of grasses, legumes, and wildflowers planted in the rows between trees in an orchard.

Dead mulches are crop residues left in place during or after the growing season and sometimes throughout the subsequent one. These mulches can conserve moisture and soil by decreasing surface evaporation and increasing water infiltration (Hoyt and Hargrove, 1986), and by stabilizing the soil and decreasing exposure to erosive agents (SAN, 1998). Weed suppression and delayed weed seed emergence are the result of decreased light levels at the soil surface, decreased diurnal temperature amplitude, and increased activity by predatory insects and small mammals that can live in the mulch (Mohler and Teasdale, 1993). It is important that they are managed properly, however, because these same mulches can slow crop seedling growth by contributing to cool, moist conditions in the spring (Bristow, 1988). Additional organic matter and nutrients are also provided over time as dead mulches slowly decompose. Soil quality is improved with the consequential increase in soil porosity, water holding capacity, microbial populations and activity, and cation exchange capacity (Cavigelli et al., 1998; Feldman et al., 2000).

Synthetic mulches such as polyethylene film (plastic) and polypropylene landscape fabric are durable and can contribute to positive yield responses (Brown et al., 1986; Taber, 1983; Himelrick, 1982), but they must be removed from organically certified fields at the end of each growing season (USDA/AMS, 2002). These materials restrict soil, air, and water movement above and below the artificial barrier. Furthermore, runoff volume is increased by the use of plastic mulches compared to living mulches, with associated increases in soil erosion and pesticides off-loading to other sites (Rice et al., 2001). Additional post-harvest disposal and landfill concerns are inherent in the use of these products because of their lack of biodegradability.

Natural mulches that are produced on the farm from plant waste products or crop residues offer producers alternatives to herbicides and encourage the recycling of nutrients on the farm (Feldman et al., 2000). Moreover, organic mulches are more permeable to air and water than synthetic mulches. Fewer problems are associated with the disposal of these mulches because they are biodegradable and can be used in compost or tilled into the soil. Other natural mulches include wood chips, shredded newspaper, and natural fibers from plants or animals.

Straw mulch can be found on or near many farms. This mulch has been reported to slow down the spread of disease in cultivation, such as *Colletotrichum acutatum* in strawberry production (Gleason et al., 2001). Nevertheless, an increase in disease incidence and severity of Phytophthora root rot has also been associated with its use in red raspberry cultivation (Wilcox et al., 1999), most likely due to high soil moisture retained by its use.

A flax straw mat is an example of a plant-based residue mulch that has been used in demonstration horticulture trials in the Midwest. Manufactured by FlaxTech LLC in Rock Lake, ND, it suppressed all weed growth and was durable throughout the growing season at two North Dakota State Univ. demonstration sites (R. Smith, 2001, personal communication).

A nonwoven wool mat made for mulching purposes is currently produced by Hobbs Bonded Fibers in Waco, TX. Several field experiments have compared wool and other weed management treatments in strawberry, tomato, and apple production in Minnesota, with reports of increased crop yields, biomass, and weed suppression equal or greater than hand-weeded treatments (Hoover et al., 2000; Poppe et al., 2001; Forcella et al., 2003). As a natural protein fiber, wool is flexible, absorbant, and biodegradable, making it ideal material for a mulch. Unlike impermeable synthetic materials, water and air can pass through wool, allowing it to retain moisture in the soil beneath and act as an insulator (ERS, 1996).

Medicinal Herbs

Plants were the main, and often only, source of healing and health improvement for thousands of years. Garlic, juniper, and other herbs of medicinal use have been found on Egyptian papyri dating from 1700 B.C. (Ody, 1993), while a written Chinese herbal dated from approximately 5000 years ago has also been discovered (Bonar, 1985). Dioscorides, a Greek physician in Emperor Nero's army in the first century A.D., composed the text *De Materia Medica.* This book described 400 plants of healing value and was used as a reference for 1500 years in European medicine (Bonar, 1985). Many Anglo-Saxon herbs made their way into North America with the settlement of pilgrims, who combined this medicine with that of native plant remedies of indigenous peoples. Medicinal herbs declined in popularity in Western medicine at the turn of the twentieth century with the advent of antibiotics and the chemical pharmaceutical industry, though they have remained the steadfast central therapy in traditional Eastern medicine (Ody, 1993).

Interest in natural herbal remedies has rebounded in the West as more people have become dissatisfied with synthetic drugs and chemical formulas (Bonar, 1985) and concerned about increasing accounts of antibiotic resistance. The herb industry was worth $1.4 billion in 1994 (Brevoort, 1996), and by 1996, an estimated 60 million Americans spent $3.24 billion on herbal products (Blumenthal, 1998). With the steady growth in the organic and medicinal herb industries, many consumers have increased their use of organic herbs. An excellent opportunity exists for organic farmers in the Midwest to plant crops to meet the demands of these high-value niche markets. As depressed prices for surplus commodity crops continue, organic premiums may provide extra incentive for farmers to consider these alternative organic crops. An estimated 17,041 acres of culinary and medicinal herbs were produced in the U.S. in 2001, and 33.3% of these acres were grown organically (ERS, 2002).

Reports from conventional medicinal herb literature indicate environmental effects such as temperature, radiation, and moisture (Hay and Waterman, 1993), and field management systems (Pank, 1992; Omidbaigi and Hornok, 1992) greatly influenced herb growth, development, and yield. There is considerable pressure for growers to upgrade agricultural methods and improve management techniques to increase herb crop yields and quality (Weiss, 1997). Information on cultural methods, particularly those of organic production systems, and their effects on the growth, yield, and chemical composition of botanical crops is very limited (Li, 1998). Researchers throughout the country have demonstrated the importance of management practices on herb quality (Simon et al., 1984, 1987; Janick and Simon, 1993), but little information is available for organic growers.

St. John's Wort

St. John's wort (*Hypericum perforatum* L. 'Helos') has a long history of human use. The common name of the plant is derived from the day this herb traditionally blooms and is harvested, on or near June 24, the feast day of St. John the Baptist (Schooley, 2001; Foster, 1998). 'Wort' is a middle English term for 'plant.' Native to the Mediterranean, it is a herbaceous perennial widely distributed throughout Europe, North and South America, South Africa and Australia (Foster, 1998). It is a member of Hypericaceae, a family which includes 10 genera and over 400 species (WSNWCB, 2001).

Historically, St. John's wort was recommended by Dioscorides as a wound-healer (Foster, 1998), and because of its bright yellow flowers, it was associated with curing jaundice and hysteria (Ody, 1993). This herb has been used to treat chest congestion, menstrual cramps, diarrhea, fever, and infections since the Middle Ages (Porter et al., 1998; Ody 1993). Today it is included in the German Commission E Monographs for its role in treating depression and anxiety (Blumenthal, 1998). In Germany, St. John's wort is the most commonly prescribed antidepression medication, operating with the effectiveness of conventional therapies (80%), but with significantly fewer side effects than conventional therapies (2.5%) (Tyler, 1999). Antiinflammatory and antiviral properties are also reported, and so it is commonly topically applied to skin injuries, burns, contusions, and sore muscles (Blumenthal, 1998; Porter et al., 1998; Ody, 1993).

St. John's wort contains a number of biologically active constituents, including chlorogenic acid, flavonoids, naphthodianthrones, phloroglucinols, essential oils and xanthones (Porter et al., 1998; Mauri and Pietta, 2000). Hyperforin is a phloroglucinol that is currently considered the most important antidepressant compound (Mazza, 2001), with important antibacterial properties as well (Schempp et al., 1999). Two naphthodianthrones, hypericin and pseudohypericin, are also of primary interest because of their photodynamic and related antimicrobial properties (Blumenthal, 1998; Prince et al., 2000). The photosensitivity of hypericin is well-documented (Diwu, 1995; Duran and Song, 1986) and is linked to virus inactivation (Cohen et al., 1996), even in retroviruses such as HIV (Prince et al., 2000), and offers anticancer properties as well (Diwu, 1995). Photosensitivity in people can be a negative side effect from photodynamic reactions of hypericin, and fair-skinned patients using St. John's wort are warned to keep sun exposure to a minimum (Ody, 1993; Blumenthal, 1998).

On the leaf surface and within the yellow flower petals of St. John's wort are translucent and dark glandular 'dots' that occur in all members of the subfamily Hypericoideae (Curtis and Lersten, 1989). These 'dots' are glandular epithelial cells, with the translucent oil-containing cells scattered across the leaf surface, and the dark glands of anthraquinones occurring mainly along the leaf and petal margins (Fornasiero et al., 1998). Hypericin and pseudohypericin are the two main compounds in these glands, and their red-purple pigments have been used to make dye for wool, silk, and cosmetics (Porter et al., 1998).

Though it is not understood what affects the concentrations of the aforementioned compounds at the cellular level, it is clear that there is significant variation in St. John's wort extracts based on different genotype and environmental factors (Buter et al., 1998). Heightened plant stress may increase anthranoid production. In a soil fertility experiment, hypericin and pseudohypericin levels were increased 2.3 to 2.5 times in plants that were grown with little nutrient supply compared to plants supplemented with nitrogen (Briskin et al., 2000). The concentration of hypericin is more prevalent in some parts of the plant, with lower leaves < top leaves < flowers and buds, as reported by Southwell and Campbell (1991). Developmental stage also affects the amount of hypericin present, with the highest amounts found during the budding stage, followed by mid-flowering (Kireeva et al., 1999). Production guidelines include harvesting the upper half of the plant during bloom and before seed formation by mowing or manual cutting (Porter et al., 1998). One Midwest commercial organic producer of St. John's wort manually harvests the upper 10 to 15 cm of budding and flowering shoots (B. Tornow, 2001, personal communication). The recommended drying temperature range is 30 to 40°C for 3-5 days in shaded conditions (Porter et al., 1998; Buter et al., 1998; R. Soberg, 2001, personal communication).

Characterized as an aggressive, invasive plant, St. John's wort is commonly called Klamath weed by ranchers, weed scientists, and biological control specialists worldwide. It appears on the noxious weed list in several western states and provinces in North America (Porter et al., 1998; WSNWCB, 2001). At one time, St. John's wort was considered the leading cause of economic loss to California, due to its infestation of millions of acres of rangeland and related toxicity to livestock (WSNWCB, 2001). Outlawed in commercial production in Montana and seven other western states (Adam, 2001), it can be poisonous to horses, sheep, goats, and cattle of light skin (Porter et al., 1998). Adverse side effects such as blistering and even death in instances of high consumption in bright sunlight have been reported (Griese, 1980). Herbicide campaigns in both South Africa and British Columbia proved unsuccessful in eradicating the weed (Gordon and Kluge, 1991).

St. John's wort is under satisfactory control now in many regions of the world because of various biological control efforts. The first importation of four insect species occurred in Australia in 1930 (Briese, 1989), and subsequent releases of the beetle, *Chrysolina quadrigemina,* were made in California in 1945 (McCoy, 1999). This release was the first successful biocontrol weed program in North America (Mitich, 1994). Today several natural enemies continue in controlling St. John's wort as a weed, including the predominant Klamathweed beetle (*C. quadrigemina*), and a host-specific, highly virulent fungal pathogen, *Colletotrichum gloeosporioides* f. sp. *hypericum.* Several species of *Colletotrichum* have been used as mycoherbicides, and this particular species is an anthracnose that has been known to control the weed in all growth stages (Hildebrand and Jensen, 1991). The beetle causes more damage to the host in hot, dry weather, while the anthracnose reportedly increases in severity as conditions become increasingly moist (Hildebrand and Jensen, 1991). Conidia transmittal by the beetle was shown in field experiments in Nova Scotia, where the mortality in non-cultivated plants ranged from 36 to 96% (Morrison et al., 1998). Biological control agents have reduced St. John's wort stands to nearly 1% of their former levels in the western U.S. (Mitich, 1994).

Commercial production of St. John's wort in the U.S. has also been greatly impacted by the dissemination of its natural enemies, particularly *C. gloeosporioides*. Fortunately for producers, hypericin content in infected plant material does not appear to be reduced, according to Jensen et al. (1995). An herb company in Washington state reported research on disease resistance to anthracnose is imperative to producers (Aboca USA Inc., 2002). A commercial grower in the Midwestern U.S. reported total crop destruction due to this disease in 2001 (B. Tornow, 2001, personal communication). The disease has also been reported to spread more quickly in cultivation of St. John's wort using plastic mulch (Schooley, 2001). Research is necessary to ascertain what cultural practices, if any, can mitigate or slow disease incidence for farmers.

Catnip

Catnip (*Nepeta cataria* L.) is indigenous to Eurasia, and is also known as catmint, cat's wort, and catnep, this plant is indigenous to Eurasia. The genus name refers to the ancient city of Nepete (in present day Italy) where one species was found to grow profusely (FNP, 2000). A member of the mint family (Lamiaceae), its leaves were used by the Romans in salads (Kowalchik and Hylton, 1987), and was a familiar culinary herb in English gardens by the mid-1200's (FNP, 2000). Used to flavor meats and stews (FNP, 2000), catnip made a soothing, relaxing tea (FNP, 2000; Bakker and Schooley, 2002), and was served as a remedy for colds, chest congestion, and sore throats (Kowalchik and Hylton, 1987; Bonar, 1985). First introduced to North America in Newfoundland in1620 (FNP, 2000), catnip was carried overseas by many English settlers and cultivated in the New World, and has since spread across temperate regions of the entire continent (Kowalchik and Hylton, 1987; Simon et al., 1984). Today catnip is perhaps most widely known for its attracting and intoxicating effects on cats.

Like other mint species, essential oils can be obtained from the plant by steam distillation of leaves, flowers, and stems (Waller and Johnson, 1984). The constituents are readily analyzed with a gas chromatograph (Handjieva and Popov, 1996; Chalchat and Lamy, 1997). Catnip essential oils are comprised of aromatic and volatile substances including citral, nerol, geraniol, and geranial (Ibrahim and El Din, 1999; Chalchat and Lamy, 1997), and yields can range from 0.2 to 0.4% of fresh plant matter (Waller and Johnson, 1984; Domokos et al., 1994; FNP, 2000). Nepetalactone, a bicyclic monoterpenoid, is the main organic constituent of the oil and is found as two isomers (Sakan et al., 1963). These isomers are produced by trichomes that appear on the surface of the plant and are readily released by physical disturbances caused by wind, insects, and animals (Black, 1995). Reports vary widely on nepetalactone percent composition within the oil, with a range of 20 to 90% (Ibrahim and El Din, 1999; Malizia et al., 1996; Pappas, 2001). This variation most likely can be attributed to genotype and environment interactions and should be further investigated.

The nepetalactone isomers are the feline attractants of catnip (Waller and Johnson, 1984; Black, 1995). Some research indicates nepetalactone may possess antimicrobial properties, with reports of fungistatic activity on phytopathogens (including *Botrytis* and *Sclerotinia*) and human pathogens (*Candida* and *Aspergillus*) (Bourrel et al., 1993). Not many catnip crop diseases have been reported in the literature, and this may be attributed to the inhibiting effects of this substance on microbes in general. In wet conditions, a few fungal and bacterial leafspots have been reported, and catnip is susceptible to *Fusarium* wilt.

No insect pests have been reported in catnip crop monographs. On the contrary, entomologists know of insect repellency associated with nepetalactone (Eisner, 1964), and have isolated the compound from the defense secretions of some insects. Research has indicated that mosquitoes are similarly repelled by nepetalactone at one-tenth the concentration of the most common chemical mosquito repellent, N,N-diethyl-meta-toluamide (DEET) (J. R. Coats, 2002, personal communication). Similar repellency effects have been demonstrated in an experiment with cockroaches (Peterson et al., 2002). This is of interest because catnip essential oil has no toxic substances compared to DEET and other synthetic chemicals, and therefore could be used as a safe, natural product for household and personal use.

Lactone content is lower in the vegetative stage than during the flowering period (Bourrel et al.,1993), with highest essential oil yield and quality found during full bloom (Chalchat and Lamy, 1997; Ibrahim and El Din, 1999). Catnip producers either manually or mechanically harvest the upper 15 to 20 cm of the crop at the 20 and 50% blooming stage (FNP, 2000; R. Soberg, 2001, personal communication). The harvested material should be dried at 29 to 35°C for three days in shaded conditions (FNP, 2000; R. Soberg, 2001, personal communication). The dried leaves and flowers are usually separated from bulkier stems before the product can be marketed (R. Soberg, 2001, personal communication). According to the quality assurance laboratory of a Midwest organic herb cooperative, harvested catnip product should include >20% flowers and <5% stems, and an essential oil concentration of at least 0.3% (FNP, 2000). Grown as a perennial crop, catnip yields are usually highest in the second season (Domokos et al., 1994), with expected fresh yields of 3360 to 4480 kg ha^{-1} (FNP, 2000). Plants should be replaced plants every three years, after which time weeds have been noted to become a serious problem (Ferguson et al., 1990). To satisfy crop needs, soils can be amended with: 90-112 kg N ha^{-1}, 112 kg P ha^{-1}, and 448 kg potash ha^{-1} (FNP, 2000).

Thesis Organization

This thesis has four chapters. The first chapter gives general information about organic production, organic weed management, medicinal herbs, and organic herb production. Chapter 2 is a manuscript to be submitted to *Crop Science* reporting a field experiment that examined crop performance and weed suppression using organic mulches as weed management treatments in catnip and St. John's wort production. Chapter 3 is a manuscript to be submitted to *HortTechnology* that describes target biochemical constituents in each herb species as affected by weed management treatments. Chapter 4 is a brief discussion of my general conclusions based upon the aforementioned field and laboratory research.

Literature Cited

Aboca USA, Inc. 2002. St. John's wort / *Hypericum perforatum* L. Seattle, WA. <http://www.aboca.us/organic_farming/cultivation/iperico.asp>

Adam, K. 2001. St. Johnswort as an Alternative Crop. Appropriate Technology Transfer for Rural Areas (ATTRA). Fayetteville, AR.

Bakker, C., and J. Schooley. 2002. Catnip. Ontario Ministry of Agriculture, Food, and Rural Affairs. <http://www.gov.on.ca:80/OMAFRA/english/crops/hort/herbs/catnip.htm>

Black, J.W. 1995. Nepetalactone: scores purrfect with cats! Univ. of Waterloo. Waterloo, ON.

Blumenthal, M. 1998. The Complete German Commission E Monograph. American Botanical Council. Austin, TX.

Bonar, A. 1985. Herbs Past and Present. p. 12. *In* The Macmillan Treasury of Herbs. Macmillan Publishing Company, New York.

Bourrel, C., F. Perineau, G. Michel, and J.M. Bessiere. 1993. Catnip (*Nepeta cataria* L.) essential oil: Analysis of chemical constituents, bacteriostatic, and fungistatic properties. J. Essent. Oil Res. 5:159-167.

Briese, D.T. 1989. Host-Specificity and virus-vector potential of *Aphis chloris* (Hemiptera: Aphididae), a biological control agent for St. John's wort in Australia. Entomophaga 34:247-264.

Briskin, D.P., A. Leroy, and M. Gawienowski. 2000. Influence of nitrogen on the production of hypericins by St. John's wort. Plant Physiol. Biochem. 38(5):413-420.

Brevoort, P. 1996. The U.S. Botanical Market—An Overview. Herbalgram 36:49-57.

Bristow, K.L. 1988. The role of mulch and its architecture in modifying soil temperature. Aust. J. Soil Res. 26:269-280.

Brown, J.E., C.A. Lewis, J.T. Eason, M.E. Ruf, D.W. Porch, and M.E. Marvel. 1986. Effect of black plastic mulch and drip irrigation on bell pepper performance. Proc. Natl. Agr. Plastics Congr. 19:256-262.

Buter, B., C. Orlacchio, A. Soldati, and K. Berger. 1998. Significance of genetic and environmental aspects in the field cultivation of *Hypericum perforatum*. Planta Med. 64:431-437.

Cavigelli, M.A., S.R. Deming, L.K. Probyn, and R.R. Harwood (eds.). 1998. Michigan Field Crop Ecology: Managing biological processes for productivity and environmental quality. Michigan State Univ. Extension Bulletin E-2646. 92 pp.

Cavigelli, M.A., S.R. Deming, L.K. Probyn, and D.R. Mutch (eds.). 2000. Michigan Field Crop Pest Ecology and Management. Michigan State Univ. Extension Bulletin E-2704. 108 pp.

Chalchat, J.C., and J. Lamy. 1997. Chemical composition of the essential oil isolated from wild catnip *Nepeta cataria* L. cv. *citriodora* from the Drôme region of France. J. Essent. Oil Res. 9:527-532.

Clements, D.R., S.F. Weise, R. Brown, D.P. Stonehouse, D.J. Hume, and C.J. Swanton. 1995. Energy analysis of tillage and herbicide inputs in alternative weed management systems. Agric. Ecosystems Environ. 52:119-128.

Coats, J.R. 2002. Personal communication. Iowa State Univ. Dep. of Entomology. Ames, IA.

Cohen, P.A., J.B. Hudson, and G.H.N. Towers. 1996. Antiviral activities of anthraquinones, bianthrones, and hypericin derivatives from lichens. Experientia 52:180-183.

Curtis, J.D., and N.R. Lersten. 1989. Internal secretory structures in *Hypericum* (Clusiaceae): *H. perforatum* L. and *H. balearicum* L. New Phytol. 114:571-580.

Diwu, Z. 1995. Novel therapeutic and diagnostic applications of hypocrellins and hypericins. Photochem. Photobiol. 61(6):529-539.

Domokos, J., J. Peredi, and K. Halasz-Zelnik. 1994. Characterization of seed oils of dragonhead (*Dracocephalum moldavic* L.) and catnip (*Nepeta cataria* var. *citriodora* Balb.) Ind. Crops Prod. 3:91-94.

Duran, N., and P.S. Song. 1986. Hypericin and its photodynamic action. Photochem. Photobiol. 43:677-680.

Dyer, W.E. 1995. Exploiting weed seed dormancy and germination requirements through agronomic practices. Weed Sci. 43:498-503.

Economic Research Service (ERS). 1996. Wool Gaining Favor Outside of Apparel Industry. USDA-ERS. Industrial Uses. p. 27-29. ERS, Washington, DC.

Economic Research Service (ERS). 2002. Organic Production Data. USDA-ERS. <http://www.ers.usda.gov/data/organic/>

Eisner, T. 1964. Catnip: Its raison d'etre. Science 146:1318-1320.

Feldman, R.S., C.E. Holmes, and T.A. Blomgren. 2000. Use of fabric and compost mulches for vegetable production in a low tillage, permanent bed system: Effects on crop yield and labor. Amer. J. Alt. Agric. 15(4):146-153.

Ferguson, J.M., W.W. Weeks, and W.T. Fike. 1990. Production of catnip in North Carolina. p. 527-528. *In*: J. Janick and J.E. Simon (eds.) Advances in new crops. Timber Press. Portland, OR.

Forcella, F., S. Poppe, N. Hansen, E. Hoover, W. Head, F. Propsom, and J. McKensie. 2003. Biological mulches for managing weeds in transplanted strawberry. Weed Technol. In review.

Fornasiero, R.B., A. Bianchi, and A. Pinetti. 1998. Anatomical and ultrastructural observations in *Hypericum perforatum* L. leaves. Journal of Herbs, Spices & Medicinal Plants 5(4):21-33.

Foster, S. 1998. 101 Medicinal Herbs: An Illustrated Guide. Interweave Press Inc., Loveland, CO.

Frontier Natural Products (FNP). 2000. Catnip Grower's Crop Monograph. Norway, IA.

Gleason, M., S. Wegulo, and G. Nonnecke. 2001. Efficacy of straw mulch for suppression of anthracnose on day-neutral strawberries. ISU Ext., FG-601:48. Iowa State Univ., Ames, IA.

Goolsby, D.A., E.M. Thurman, and D.W. Koplin. 1991. Geographic and temporal distribution of herbicides in surface waters of the upper Midwestern United States, 1989-90. p. 183-188. *In* G.E. Mallard and D.A. Aronson (eds.) U.S. Geological Survey Toxic Substances Hydrology Program. Proc. Technical Meeting, Monterey, CA. 11-15 Mar. 1991. U.S. Geological Survey Water-Resources Investigations Report 91-4034.

Gordon, A.J., and R.L. Kluge. 1991. Biological control of St. John' Wort *Hypericum perforatum* (Clusiaceae), in South Africa. Agric. Ecosyst. Environ. 37: 77-90.

Griese, A.C. 1980. Hypericism. Photochem. Photobiol. Rev. 5:229-255.

Handjieva, N.V., and S.S. Popov. 1996. Constituents of essential oils from *Nepeta cataria* L., *N. grandiflora* M.B. and *N. nuda* L. J. Essent. Oil Res. 8:639-643.

Hay, R., and P. Waterman (eds.). 1993. Volatile Oil Crops: Their Biology, Biochemistry and Production. Longman, Essex, England.

Hildebrand, P.D., and K.I.N. Jensen. 1991. Potential for the biological control of St. John's-wort (*Hypericum perforatum*) with an endemic strain of *Colletotrichum gloeosporioides*. Can. J. Plant Pathol. 13:60-70.

Himelrick, D.G. 1982. Effect of polyethylene mulch color on soil temperatures and strawberry plant response. Adv. Strawberry Prod. 1:15-16.

Hoover, E., F. Propsom, S. Poppe, F. Forcella, N. Hansen, B. Head, and B. Jacobson. 2000. Bio-based weed control in strawberries using sheep wool mulch, canola mulch, and canola green manure. *In* Greenbook 2000. Energy and Sustainable Agriculture Program. Minnesota Dep. of Agriculture, St. Paul, MN.

Hoyt, G.D., and W.L. Hargrove. 1986. Legume cover crops for improving crop and soil management in the southern United States. HortScience 23(3):397-402.

Ibrahim, M.E., and A.A.E. El Din. 1999. Cultivation of *Nepeta cataria* L. in Egypt: its growth, yield, and essential oil content as influenced by some agronomic practices. Egypt. J. Hortic. 26(3):281-302.

Iowa Dep. of Agriculture and Land Stewardship (IDALS). 1999a. Iowa Organic Certification and Organic Standards. Des Moines, IA.

Iowa Dep. of Agriculture and Land Stewardship (IDALS). 1999b. Annual Survey on Organic Production. Des Moines, IA.

Janick, J., and J.E. Simon. 1993. Progress in New Crops. John Wiley & Sons, New York.

Jensen, K.I.N., S.O. Gaul, E.G. Specht, and D.J. Doohan. 1995. Hypericin content of Nova Scotia biotypes of *Hypericum perforatum* L. Can. J. Plant Sci. 75:923-926.

Kelly, W.C. 1990. Minimal use of synthetic fertilizers in vegetable production. HortScience 25:168-169.

Kireeva, T.B. U.L. Sharanov, and W. Letchamo. 1999. Biochemical and eco-physiological studies on *Hypericum* spp. p. 467-468. *In* J. Janick (ed.) Perspectives on New Crops and New Uses. ASHS Press, Alexandria, VA.

Kolpin, D.W., S.J. Kalkhoff, D.A. Goolsby, D.A.Sneck-Fahrer, and E.M. Thurman. 1997. Occurrence of selected herbicides and herbicide degradation products in Iowa's ground water. 1995. Ground Water 35(4):679-688.

Kowalchik, C., and W.H. Hylton (eds.). 1987. Rodale's Illustrated Encyclopedia of Herbs. p. 71-74. Rodale Press, Emmaus, PA.

Li, T. 1998. *Echinacea*: Cultivation and medicinal value. HortTechnology 8:122-129.

Malizia, R.A., J.S. Molli, D.A. Cardell, and J.A. Retamar. 1996. Volatile constituents of the essential oil of *Nepeta cataria* L. grown in Cordoba Province (Argentina). J. Essent. Oil Res. 8:565-567.

Mauri, P., and P. Pietta. 2000. High performance liquid chromatography/electrospray mass spectrometry of *Hypericum perforatum* extracts. Rapid Commun. Mass Spectrom. 14:95-99.

Mazza, G. 2001. Canadian Crops Rich in Bioactives with Health Benefits. Proc.Workshop Conference on Growing Global Organic and New Crop Opportunities, Edmonton, AB. 5-7 Mar. Food Research Program, Edmonton, Canada.

McCoy, J.A.H. and C.S. Gorsuch. 1999. Klamathweed Beetle: Friend or Foe? *In* Entomology Insect Information Series. Clemson Univ. Coop. Ext. Serv., Clemson, SC.

Mitich, L.W. 1994. Common St. Johnswort. Weed Technol. 8:658-661.

Mohler, C.L., and J.R. Teasdale. 1993. Response of weed emergence to rate of hairy vetch and rye residue. Weed Res. 33:487-499.

Morrison, K.D., E.G.Reekie, and K.I.N. Jensen. 1998. Biocontrol of common St. Johnswort (*Hypericum perforatum*) with *Chrysolina hyperici* and a host-specific *Colletotrichum gloeosporioides*. Weed Technol. 12:426-435.

National Organic Standards Board (NOSB). 1995. NOSB Annual Meeting, Apr. 1995. USDA, Washington, DC.

Ody, P. 1993. The Complete Medicinal Herbal. DK Publishing, Inc., New York.

Omidbaigi, R. and L. Hornok. 1992. Effect of N-fertilization on the production of fennel (*Foeniculum vulgare* Mill.). Acta Hortic. 306:249-252.

Organic Trade Association (OTA). 2002. OTA Newsletter. Greenfield, MA.

Pank, F. 1992. The influence of chemical weed control on quality characters of medicinal and aromatic plants. Acta Hortic. 306:145-154.

Pappas, R.S. 2001. Certificate of Analysis—Pure Catnip Essential Oil. Essential Oil Univ., New Albany, IN.

Peterson, C.J., L.T. Nemetz, L.M. Jones, and J.R. Coats. 2002. Behavioral activity of catnip *Nepeta cataria* (Lamiaceae), to the German cockroach, *Blattella germanica* (Blattodea: Blattellidae). J. Econ. Entomol. 95:377-380.

Poppe, S. R. Becker, N. Hansen, M. Solemsaas, V. Fritz, F. Forcella, S. Wagner, B. Head, B. Padula, T. Nennich, and J. Stordahl. 2001. Wool mulching systems for specialty crops. *In* Greenbook 2003. Sustaining People, Land and Communities. Energy and

Sustainable Agriculture Program. Minnesota Dep. of Agriculture, St. Paul, MN. In review.

Porter, B. R. McVicar, and L. Bader. 1998. St. John's Wort in Saskatchewan. Saskatchewan Agriculture, Food, and Rural Revitalization. <http://www.agr.gov.sk.ca/docs/crops/special_crops/production_information/johnswort00.asp>

Prince, A.M., D. Pascual, D. Meruelo, L. Liebes, Y. Mazur, E. Dubovi, M. Mandel, and G. Lavie. 2000. Strategies for evaluation of enveloped virus inactivation in red cell concentrates using hypericin. Photochem. Photobiol. 71(2):188-195.

Rice, P.J., L.L McConnell, L. P. Heighton, A.J. Sadeghi, A.R. Isensee, J.R. Teasdale, A.A. Abdul-Baki, J.A. Harman-Fetcho, and C.J. Hapeman. 2001. Runoff loss of pesticides and soil: A comparison between vegetative mulch and plastic mulch in vegetable production systems. J. Environ. Qual. 30:1808-1821.

Sakan, T., A. Fugino, F. Murai, A. Suzui, and Y. Butsugan. 1963. Terpenoids. *Cis-trans-* and *trans-cis-nepetalactones*. Bull. Chemical Society. Experientia XIX 11:564-565.

Schempp, C.M., K. Pelz, A. Wittmer, E. Schöpf, and J.C. Simon. 1999. Antibacterial activity of hyperforin from St. John's wort, against multiresistant *Staphylococcus aureus* and gram-positive bacteria. Lancet 353:2129.

Schooley, J. 2001. St. John's Wort and Chrysolina Beetles. Ontario Ministry of Agriculture, Food, and Rural Affairs. <http://www.gov.on.ca/OMAFRA/english/crops/facts/info_sjwbeetles.htm>

Scow, K.M., O. Somasco, N. Gunapala, S. Lau, R. Venette, H. Ferris, R. Miller, C. Shennan. 1994. Transition from conventional to low-input agriculture changes soil fertility and biology. Calif. Agr. 48(5):20-26.

Simon, J.E., A.F. Chadwick, and L.E. Craker. 1984. Herbs, An Indexed bibliography, 1971-1980. The Scientific Literature on Selected Herbs, and Aromatic and Medicinal Plants of the Temperate Zone. Archon Books, Hamden, CT.

Simon, J.E., A. Mathe, and L.E. Craker (eds). 1987. Sixth International Symposium on Medicinal and Aromatic Plants. Technical Communication of the International Society for Horticultural Science. Acta Hortic. 208:1-279.

Smith, R. 2001. Personal communication. North Dakota State Univ. Dep. of Plant Sciences. Fargo, ND.

Soberg, R. 2001. Personal communication. Organic Herb Producer Cooperative. Lakeville, MN.

Southwell, I.A., and M.H. Campbell. 1991. Hypericin content variation in *Hypericum perforatum* in Australia. Phytochem. 30(2):475-478.

Stute, J.K., and J.L. Posner. 1995. Legume cover crops as a nitrogen source for corn in an oat-corn rotation. J. Prod. Agric. 8:385-390.

Sustainable Agriculture Network (SAN). 1998. Managing cover crops profitably. 2nd ed. Sustainable Agriculture Network, National Agricultural Library. Beltsville, MD.

Swezey, S.L., P. Vossen, J. Caprile, and W. Bentley. 2000. Organic Apple Production Manual. Univ. of California. Publication 3403. Santa Cruz, CA.

Taber, H.G. 1983. Effects of plastic soil and plant covers on Iowa tomato and muskmelon production. Proc. Natl. Agr. Plastics Congr. 17:37-45.

Teasdale, J.R. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. J. Prod. Agric. 9:475-479.

Tornow, B. 2001. Personal communication. Tornow Herb Farms. Commercial Producer. Wausau, WI.

Tyler, V.E. 1999. Herbs affecting the central nervous system. p. 442-449. *In* J. Janick (ed.) Perspectives on New Crops and New Uses. ASHS Press, Alexandria, VA.

USDA Agriculture Marketing Service (USDA/AMS). 2002. National Organic Program. Final rule: 7 CFR Part 205. <http://www.ams.usda.gov/nop>

Waller, G.R., and R.D. Johnson. 1984. Metabolism of nepetalactone and related compounds in *Nepeta cataria* L. and components of its bound essential oil. Proc. Okla. Acad. Sci. 64:49-56.

Walz, E. 1999. Final Results of the Third Biennial National Organic Farming Survey. Organic Farming Research Foundation, Santa Cruz, CA.

Washington State Noxious Weed Control Board (WSNWCB). 2001. Saint Johnswort (*Hypericum perforatum* L.). Washington State Dep. of Agriculture, Olympia, WA.

Weiss, E.A. 1997. Essential Oil Crops. CAB International, New York.

Wilcox, W.F., M.P Pritts, and M.J. Kelly. 1999. Integrated control of phytophthora root rot of red raspberry. Plant Dis. 83(12):1149-1154.

CHAPTER 2: The effect of natural mulches on crop performance and weed suppression in organic field production of catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos').

A paper to be submitted to *Crop Science*

L. M. Duppong[1], K. Delate[2], M. Liebman[3], and R. Horton[3]

ABSTRACT

Due to expanding markets, an excellent opportunity exists for organic farmers in the Midwest to plant high-value niche crops, such as medicinal herbs. An experiment was conducted in 2001 and 2002 near Gilbert, Iowa, to study crop performance, weed suppression, and environmental conditions associated with the use of several organic mulches in two herbs, catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos'). Treatments were arranged in a completely randomized design and included a positive (hand-weeded) control, a negative (non-weeded) control, oat straw, a flax straw mat, and a nonwoven wool mat. Catnip plant height was significantly greater in the oat straw than the other treatments at 4 wk through 6 wk in 2001; at 4 to 8 wk in 2002, catnip plant height and width was significantly lower in the negative control compared with the other treatments. Catnip yield was significantly higher in the flax straw mat than all other treatments in 2001. In 2002, St. John's wort yields were not statistically different in any treatments. All weed management treatments had significantly fewer weeds than the non-weeded rows in 2002. Total weed density comparisons in each crop from two years showed fewer weeds were

---

Dep. of Agronomy, Iowa State University, Ames, IA 50011
[1]Graduate student, primary researcher and author
[2]Assistant professor, corresponding author
[3]Coauthor

present in the flax straw and wool mat treatments compared to positive control plots, even through a consecutive season of mulch use. Because of positive yield responses and effective weed suppression over two years, these natural mulches may be well suited for high-value perennial row crop production.

INTRODUCTION

The organic industry is a consumer driven market that has been growing at least 20% every year for the past 10 years, with projected retail sales of $20 billion in the U.S. by 2005 (OTA, 2002). Due to expanding markets, an excellent opportunity exists for organic farmers in the Midwest to plant crops for high-value niche markets. Organic premiums may provide extra incentive for these producers to consider such alternative crops, though additional research is needed to ascertain the influence of specific production practices on herb productivity.

There is considerable pressure for growers to upgrade agricultural methods and improve management techniques to increase herb crop yields and quality (Weiss, 1997). Information on cultural methods, particularly those used in organic production systems, and their effects on the growth, yield, and chemical composition of botanical crops is very limited (Li, 1998). Factors that may affect medicinal herb production include temperature, radiation, and moisture (Hay and Waterman, 1993). Field management systems (Pank, 1992; Omidbaigi and Hornok, 1992) also greatly influence herb growth, development, and yield. Researchers in the U.S. have demonstrated the importance of management practices on conventionally produced herbs (Simon et al., 1984, 1987; Janick and Simon, 1993), but little information is available for organic growers.

Out of 32 research topics listed, weed management was the number one concern of organic farmers across the nation in a recent survey published by the Organic Farming Research Foundation (Walz, 1999). Weed management is not only problematic in organic crop production. Between 20-25% of the annual energy cost in a conventional system (corn-soybean-winter wheat rotation) is associated with weed control practices (Clements et al., 1995). This percentage does not include the substantial labor and materials costs involved in managing weeds (Feldman et al., 2000), nor does it consider negative environmental and human health effects. Degraded herbicide compounds were three of the top four most frequently detected substances in Iowa municipal wells during the summer of 1995 (Kolpin, 1997), and herbicides have been detected in surface and ground waters at amounts exceeding maximum contamination levels established by the EPA (Goolsby et al., 1991).

Economically and environmentally sustainable weed control alternatives, such as mulches, can provide many benefits for herb producers. Synthetic mulches such as polyethylene film (plastic) and polypropylene landscape fabric are durable and can contribute to positive yield responses (Brown et al., 1986; Taber, 1983; Himelrick, 1982), but they must be removed from organically certified fields at the end of each growing season (USDA/AMS, 2002). These materials restrict soil, air, and water movement above and below the artificial barrier. Furthermore, runoff volume is increased by the use of plastic mulches compared to living mulches, with associated increases in soil erosion and pesticide off-loading to other sites (Rice et al., 2001). Additional post-harvest disposal and landfill concerns are inherent in the use of these products because of their lack of biodegradability.

Natural mulches that are produced on the farm from plant waste products or crop residues offer producers alternatives to herbicides and encourage the recycling of nutrients on the farm (Feldman et al., 2000). Additional organic matter and nutrients are provided over time as these mulches slowly decompose. Soil quality is improved with the consequential increase in soil porosity, water holding capacity, microbial populations, and cation exchange capacity activity (Cavigelli et al., 1998; Feldman et al., 2000). Moreover, natural mulches are more permeable to air and water than synthetic mulches, and fewer problems are associated with their disposal because they are biodegradable and can be used in compost or tilled into the soil. These mulches can also reduce soil erosion, mitigate water loss, and suppress weed populations (Abdul-Baki and Teasdale, 1993).

Straw mulch can be found on or near many farms. Other natural mulches include wood chips, shredded newspaper, and natural fibers from plants or animals. A flax straw mat is one example of a plant-based residue mulch. Based on observations made during the 2000 growing season in North Dakota, this mulch remained durable throughout the season and provided adequate weed control in vegetable demonstration gardens at two locations (R. Smith, 2001, personal communication). As a natural protein fiber, wool is flexible, absorbant, and biodegradable, making it ideal mulch material. Several field experiments have compared wool and other weed management treatments in strawberry, tomato, and apple production in Minnesota, with reports of increased crop yields, biomass, and weed suppression equal or greater than hand-weeded treatments (Hoover et al., 2000; Poppe et al., 2001).

Interest in catnip and St. John's wort for medicinal, antimicrobial, and insecticidal uses has been demonstrated throughout the U.S. (Simon et al., 1984; Peterson and Coats, 2001; Bourrel et al., 1993; Diwu, 1995; Cohen et al., 1996; Prince et al., 2000). A member of the mint family (Lamiaceae), catnip is often sold in feline products in pet stores. In

Germany, St. John's wort is the most commonly prescribed antidepression medication (Tyler, 1999).

The objective of our field experiment was to compare the effects of different weed management treatments (oat straw; wool mat; flax straw mat; hand-weeded, positive control; non-weeded, negative control) on crop performance and weed suppression in perennial herb row crop production. Additional environmental effects, including soil temperature and moisture, were evaluated under the mulched and non-mulched treatments. Our hypothesis was that the mulched treatments would enhance crop performance and increase weed suppression compared to the negative control treatment.

MATERIALS AND METHODS

Field Site

A field experiment was conducted in 2001 and 2002 on uniformly sloped Nicollet fine sandy loam soil at the Iowa State University Horticulture Research Station, in Gilbert, Iowa (USDA hardiness zone 5a; 42°3′ N lat). The experimental site was previously in an alfalfa-grass fallow for >5 yr, and though left uncertified, was managed according to organic certification standards (IDALS, 2001). Field dimensions were 36 by 29 m. Forty plots containing a total of 2176 plants were arranged in a completely randomized design in weed management-herb species combinations. Five weed management treatments were imposed on two medicinal herb species, catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos'). Treatments were replicated four times and consisted of the following: a nonwoven wool mat (0.6 cm thickness) (Hobbs Bonded Fibers, Waco, TX), a flax straw mat (1.2 cm thickness) (FlaxTech LLC, Rock Lake, ND), organic oat straw (from oat fields at the certified organic Iowa State University Neely-Kinyon Research Farm in

Greenfield, IA), a hand-weeded (positive) control, and a non-weeded (negative) control. Each experimental unit consisted of three rows of plants, 0.9 m apart, with the two outer rows serving as buffers. There were 17 plants per row, spaced 46 cm apart.

Herb Culture

Catnip and St. John's wort 'Helos' seeds (Johnny's Selected Seeds, Albion, ME) were sown in plastic trays using a commercial organic germination mix (Beautiful Land Products, West Branch, IA) on 10 March 2001. Soil was moistened and catnip seed trays were placed in the Iowa State Univ. Horticulture Dep. greenhouse and maintained at 18°C. The St. John's wort trays were moistened and kept in the dark in 4°C refrigeration for 5 d, after which time they were moved to the greenhouse with natural light and ambient temperature (18°C). Every 4 wk the plants were fertilized at a rate of 4 mL L^{-1} with commercial fish emulsion containing nitrogen, phosphate, and potash (2-4-0.5) (Bonide Products, Inc., Yorkville, NY). Four-week-old plants were transplanted into 4 by 4-cm cells containing commercial organic potting mix (Beautiful Land Products, West Branch, IA), and three weeks later into 6 by 6-cm Fertil Pots® (Carlin Horticulture Supplies, Milwaukee, WI).

Catnip and St. John's wort plants that were 7 to 9 cm in height were transplanted into the Gilbert field on 13 June 2001 using a one-row mechanical transplanter. All plots were manually mulched with their respective treatments on 14 June, and a knife was used to cut holes into the mats for placement of the herbs. Both flax straw and wool mats were tacked down with 15-cm landscape staples. The oat straw mulch was layered to a 10-cm depth. All three mulch treatments were centered over the planted rows to provide a 46-cm weed management zone, 23 cm on each side of the herb plants.

Each row of the positive control plots was hand-weeded within the same dimensions of the weed management zone (46 cm by the entire 7.8 m row length) every 2 weeks during the growing season. Mechanical cultivation between the mulched areas of the rows (46 cm between each mulch treatment) occurred two weeks and eight weeks after transplanting in 2001, and mid-May in 2002. Irrigation from overhead risers was applied immediately after transplanting and as needed during the first two months of establishment. The flax straw mat and wool mat remained in place throughout the two years of the experiment, while an additional amount of oat straw was added 10 May 2002 to maintain a 10-cm depth for the 2002 growing season.

Data Collection

All plant and soil data were collected from the 46-cm weed management zone of the middle row of each experimental unit. Four randomly selected plants in each experimental unit were assessed for plant height and width. Measurements were taken on 10 July, 24 July, 8 Aug., and 28 Aug. 2001, and 17 May and 14 June 2002. On 14 Sept. 2001 (in the 50% bloom stage) four catnip plants in each plot were manually harvested by cutting the upper 15 to 16 cm of each shoot on the plant, according to protocols established by the herb industry (FNP, 2000; R. Soberg, 2001, personal communication). The plants were placed in individual nylon mesh bags and fresh weights were obtained immediately. The bags were dried at 30 to 32°C for 72 h, and dry weights were recorded (FNP, 2000; R. Soberg, 2001, personal communication). A second catnip harvest occurred on 28 June 2002 (in the 25% bloom stage) by cutting and drying eight plants per experimental unit in the aforementioned manner. The St. John's wort plants were manually harvested 17 June 2002 by cutting the upper 15 cm of each budding and flowering shoot (collectively known as 'flowering tops') on the plant. The harvested plant material was processed using the same methods as the catnip, though it was dried at 37 to 38°C for 5 d (Porter et al. 1998; Buter et al., 1998). The dried plant matter was stored in the dark at room temperature (24°C) until subsequent chemical analysis.

Weeds were counted in 2001 at 3, 8, and 12 wk after the initiation of the experiment, and again in 2002 at 6, 11, and 16 wk after the herbs were 9 cm in height. A 0.9-m^2 quadrat was placed within the 46-cm weed management zone in three random locations along the row, and counted weeds were classified as either grass, broadleaf, or oats. In addition, at the end of each growing season, weed biomass was harvested from the 46-cm weed management zone across the entire row and a dry weight was determined for each experimental unit (Teasdale and Daughtry, 1993).

Tissue and roots samples from plants that displayed disease symptoms were submitted to the Iowa State Univ. Plant Disease Diagnostic Laboratory (Ames, IA) for analysis. On 7 June 2002, disease occurrence and severity were assessed for each plant in the middle row of each experimental unit. Numbers of diseased vs. healthy plants were recorded, along with the number of diseased vs. healthy shoots in each infected plant. On 17 June 2002 (the St. John's wort harvest) the diseased shoots from each harvested plant were cut and bagged separately from healthy plant material.

In order to compare soil temperatures between the mulched and bare soil treatments, copper-constantan fixed thermocouple wires were placed 5 cm beneath the soil surface in each plot (except for the non-weeded, negative control treatments) (Teasdale and Daughtry, 1993) from 25 June to 23 Aug. 2001, and from 24 May to 26 Aug. 2002. Each wire was placed in the middle of two herb plants in the center of the weed management zone within each middle row. The temperature data were collected with a Campbell 21X Micrologger (Campbell Scientific, Inc., Logan, UT). Hourly average, daily average, and daily maximum/minimum temperatures were calculated.

Moisture readings of the top 5 cm of the soil surface were taken using a Theta Probe (meter type HH1, sensor type ML1; Delta-T Devices Ltd., Cambridge, UK). Readings were taken at both 24- and 48-h intervals after a moisture event three times each year. The probe was randomly placed near the center of the row in each treatment for each sampling. Three readings were taken during the first collection of the first year, and five readings were taken on all subsequent collections each year.

Data Analysis

All field data were analyzed using analysis of variance (SAS Inst., 2001). The biomass measurements were subjected to a repeated measures analysis. Within each year and species combinations, treatment means of herb yield, weed density, weed biomass, and soil temperature were statistically separated using Fisher's PLSD at $P \leq 0.05$. Within each year, species, and hour combinations, treatment means of soil moisture were statistically separated using Fisher's PLSD at $P \leq 0.05$.

RESULTS AND DISCUSSION

Plant Productivity

Catnip plant height was significantly greater in the oat straw treatment than the other treatments at 4 to 6 wk in the first growing season (Fig. 1). By 10 wk of growth, plant height of each herb crop was statistically equivalent among all weed management treatments. On average, catnip plants were 33% wider in the wool mat treatment than in the weeded, positive control, and St. John's wort plants were 24% wider in the flax straw mat than the nonweeded, negative control, though no statistical differences in plant width among treatments were observed at 10 wk. At both 4 and 8 wk of the second growing season, however, catnip plant height and width was significantly lower in the non-weeded, negative control treatment than the other treatments (Fig. 2).

This treatment effect was less apparent in the St. John's wort plots. Catnip plant height was significantly greater in the weeded, positive control treatment than the oat straw and non-weeded treatments by 8 wk of growth. Plants were significantly wider in the weeded, positive control compared to the flax and oat straw mulches by this same time. St. John's wort plant height was significantly greater in the flax straw mat and oat straw in 2002 than the wool mat treatment at 8 wk. St. John's wort plant width was significantly greater in the flax straw mat than either non-mulched control treatments.

In summary biomass comparisons between the treatments were variable, but general trends suggested that the oat straw initially increased plant growth more rapidly, and the mulches supported equivalent or greater aboveground biomass than the weeded, positive control treatment. No significant treatment by date interactions were shown in the repeated measures analysis.

Yields

Catnip yield was significantly greater in the flax straw mat than all other treatments in the first growing season (Table 1), yielding three times more dry matter than the non-weeded control treatment (920 kg ha^{-1} vs. 278 kg ha^{-1}). The weeded, positive control treatment yield was equivalent to catnip yields in the oat straw and wool mat treatments. In 2002, the highest catnip yield was from the weeded control treatment (4138 kg ha^{-1}), though this yield did not differ statistically from the flax or wool mat treatments (3647 kg ha^{-1} and 3578 kg

ha^{-1}, respectively). The weeded, positive control treatment mean yields were 116% and 62% greater than the nonweeded, negative control treatment in 2001 and 2002, respectively. Overall, the average yield in the second growing season was approximately six times greater than the yield in the first year (3415 kg ha^{-1} vs. 595 kg ha^{-1}). When grown as a perennial crop, catnip yields are normally expected to be significantly greater in the second season. All 2002 yields compared well above the typical second season commercial yield of 1680 kg ha^{-1} (FNP, 2000).

There was no significant treatment effect in St. John's wort yields, which ranged from 1650 kg ha^{-1} in the negative control plots to 2299 kg ha^{-1} in the wool mat treatment. The mean yield of the positive control treatment was 15% higher than the negative control. In a similar study, fruit yield, dry matter, and plant height of tomatoes, catnip, and St. John's wort grown in wool mat mulch were also equivalent to hand-weeded plots (Poppe et al., 2001).

Weed Management

Weed densities in both catnip and St. John's wort were significantly greater in the non-weeded control and oat straw mulch treatments compared to the other treatments in the first growing season (Table 2). The least amount of total weeds in 2001 in either herb crop were observed in the flax straw and wool mat treatments, though these mulches were not statistically different than the weeded control treatment. In the second year, all weed management treatments had significantly fewer weeds than the non-weeded rows, with the least number of total weeds found in the oat straw mulch in St. John's wort (6 weeds m^{-2}) and in the flax straw mat in catnip (7 weeds m^{-2}). Total weed density comparisons in each crop from two growing seasons showed fewer weeds in the flax straw mat and wool mat treatments compared to the weeded control plots, even through a consecutive season of mulch use. This decrease in weed density may be positively correlated with the increased crop performance in the second growing season in these mulch treatments. Some nutrients may also have been released into the soil from the mulch fibers as they slowly decomposed.

Volunteer oats, germinated in the oat straw, were included in total weed density and dry weight analyses, but were not counted as a grass species in the analysis of grass vs. broadleaf weedy species (Table 2). Though these oats were the main contributing factor in the high weed density in the oat straw mulch in 2001, their effect on end-of-season weed biomass was negligible compared to the biomass of other weeds in the non-weeded control treatment. There was a significant treatment effect on total weed dry weight due to weed management treatments in both years: 2001 and 2002 end-of-season weed biomass in both herb species averaged 95% less in each respective year in the mulched treatments than in the non-weeded control treatment. Giant foxtail (*Setaria faberi* Herrm.) produced the greatest biomass and was the most dominant weed species each year. Other major weedy grasses included yellow foxtail (*S. glauca* L.), green foxtail (*S. viridis* L.), large crabgrass (*Digitaria sanguinalis* L. Scop.), witchgrass (*Panicum capillare* L.), and barnyardgrass (*Echinochloa crus-galli* L.). Broadleaf species were predominately Virginia pepperweed (*Lepidium virginicum* L.), common purslane (*Portulaca oleracea* L.), smooth groundcherry (*Physalis subglabrata* Mack. and Bush.), and horsenettle (*Solanum carolinense* L.).

In this particular field, fewer broadleaf weeds were found compared to grass species in both years of the experiment. Broadleaf weed densities were not significantly different among treatments in either year in catnip, or in St. John's wort in the first growing season. By 2002, however, broadleaf weed densities were significantly lower in all mulched treatments in St. John's wort than in either control treatment. Broadleaf density averages were similar among herb species, though the number of grass weeds found in catnip was higher than St. John's wort each growing season.

Disease Management

In April 2002, alfalfa mosaic virus was detected in several catnip plants, and all plants displaying infected symptoms (approximately 20 plants) were removed from the experiment. Two other catnip diseases, detected one month later, were bacterial leaf spot (*Pseudomonas tabaci*) and *Fusarium* wilt, though no control measures were warranted in this field. The former disease may be important to producers who market catnip leaves for teas or culinary purposes, while *Fusarium* affects whole plants and can substantially reduce crop yields. Despite variability in disease development, there were no significant treatment effects on numbers of diseased catnip plants and disease severity (Table 3).

In May 2002, symptoms of St. John's wort anthracnose, *Colletotrichum gloeosporioides* f. sp. *hypericum*, were observed on several St. John's wort plants. One commercial grower in the Midwestern U.S. reported total crop destruction due to this disease in 2001 (B. Tornow, 2001, personal communication). A study in eastern Canada attributed a mortality rate of 36 to 96% to this virulent fungus in non-cultivated habitats of St. John's wort (Morrison et al., 1998). In at least one instance, anthracnose was reported to have spread more quickly in St. John's wort plants growing in plastic mulch (Schooley, 2001). Therefore, disease development was closely monitored in the mulched and non-mulched treatments. Prior to harvest, disease severity was significantly lower in the oat straw than the wool mat treatment (Table 3). Straw mulches have been reported to slow down the spread of disease in cultivation, such as *Colletotrichum acutatum* in strawberry production (Gleason et al., 2001), though the cause of inhibition is not clearly understood.

Environmental Effects

Soil moisture levels among mulch treatments were variable across seasons and herb crops. Soil moisture levels in the top 5 cm of the soil surface were significantly higher under the flax straw mat compared to the wool mat both 24 and 48 h in catnip rows in 2001 (Table 4). The oat straw mulch retained significantly higher soil moisture values after 48 h in St. John's wort than either the flax straw or wool mats in 2001. Among mulch treatments, there were no significant differences in any soil moisture comparisons of either herb crop in 2002.

Comparing between herb species, average soil moisture levels of all treatments were 1% lower in St. John's wort than in catnip. This difference may be attributed to root architecture and water requirements of each species. Though higher soil moisture levels were retained under all mulches compared to non-mulched treatments 48 h after precipitation events, disease manifestation was not significantly greater in the mulched treatments. There was a trend towards greater soil moisture loss in the non-weeded versus weeded control treatments in all factor comparisons, though levels were not statistically different. This difference may be due to greater competition for resources among higher densities and greater biomass of weeds.

Daily average and daily maximum soil temperatures were significantly reduced under the oat straw and flax straw mat treatments compared to the hand-weeded treatment in both species each year (Table 5). The wool mat also significantly reduced daily average and daily maximum soil temperatures compared to the positive control treatment in the catnip plots in 2001 and 2002. Overall, soil temperatures beneath the mulches increased in the following order: oat straw < flax straw mat < wool mat. The warmer daily average and daily maximum soil temperatures under the wool mat may be related to the dark mottled black/gray color of the fabric, which may help retain more heat. During the 2001 growing season, significantly warmer daily minimum soil temperatures were detected beneath the flax straw mat than the other mulch treatments in St. John's wort plots. However, no statistical differences were found in daily minimum soil temperatures in any other treatment comparisons between growing seasons or crops. It cannot be ascertained from this data if either the wool mat or the flax straw mat is a better insulator.

Comparing diurnal fluctuation patterns underneath the mulched and bare soils on 8 Aug. 2001, the soil temperature was 5 to 7°C lower in the mulch treatments during the warmest hour of the day (Fig. 3). The smallest soil temperature amplitude was found underneath the oat straw mulch, whereas the largest amplitude was recorded under the weeded control treatment. A phase shift was also apparent for the soil temperatures under the flax straw and wool mats, with soil temperatures reaching maximum levels an hour later in the day than the non-mulched and oat straw treatments. Because of lower daily average and daily maximum temperatures in the soil beneath them, these mulches may reduce the germination of weed seeds that have a diurnal temperature fluctuation requirement. This requirement was demonstrated by Taylorson (1987), who showed that some weed seeds will not germinate without a 10°C diurnal change. These findings offer one explanation for the lower weed densities reported in the mulch treatments.

All three mulch treatments evaluated in this experiment offered viable weed management and were associated with optimum herb plant productivity under Midwest growing conditions. After a consecutive season of use, the natural fiber mulches effectively suppressed weed populations to levels below the hand-weeded plots. The flax straw and wool mats augmented crop growth and yield through two growing seasons of two unrelated perennial herb crops, attaining yields significantly greater or comparable to those from hand-weeded plots. Similar fruit yield responses and weed suppression were noted in wool mulched plots compared to hand-weeded plots in a strawberry field production experiment (Forcella et al., 2003). Though initial purchasing and implementation costs may be higher, these mulches offer organic farmers an environmentally sustainable alternative to costly hand-weeding labor, synthetic mulches, and chemical inputs. Their use also encourages innovation and consideration of local or on-farm inputs, thus contributing to a more sustainable farming system. Further research is needed to examine how soil microbial populations and soil nutrient status is affected by the decomposition of these and other natural mulches. This information can be used in recommendations for managing mulches during and after the field season. Additional research is needed on the role that such mulches play in suppressing or exacerbating diseases in crop cultivation.

LITERATURE CITED

Abdul-Baki, A.A., and J.R. Teasdale. 1993. A no-tillage tomato production system using hairy vetch and subterranean clover mulches. HortScience 28:106-108.

Bourrel, C., C. Perineau, G. Michel, and J.M. Bessiere. 1993. Catnip (*Nepeta cataria* L.) essential oil: Analysis of chemical constituents, bacteriostatic and fungistatic properties. J. Essent. Oil Res. 5:159-167.

Brown, J.E., C.A. Lewis, J.T. Eason, M.E. Ruf, D.W. Porch, and M.E. Marvel. 1986. Effect of black plastic mulch and drip irrigation on bell pepper performance. Proc. Natl. Agr. Plastics Congr. 19:256-262.

Buter, B., C. Orlacchio, A. Soldati, and K. Berger. 1998. Significance of genetic and environmental aspects in the field cultivation of *Hypericum perforatum*. Planta Med. 64:431-437.

Cavigelli, M.A., S.R. Deming, L.K. Probyn, and R.R. Harwood (eds.). 1998. Michigan Field Crop Ecology: Managing biological processes for productivity and environmental quality. Michigan State Univ. Extension Bulletin E-2646. 92 pp.

Clements, D.R., S.F. Weise, R. Brown, D.P. Stonehouse. D.J. Hume, and C.J. Swanton. 1995. Energy analysis of tillage and herbicide inputs in alternative weed management systems. Agric. Ecosystems Environ. 52:119-128.

Cohen, P.A., J.B. Hudson, and G.H.N. Towers. 1996. Antiviral activities of anthraquinones, bianthrones, and hypericin derivatives from lichens. Experientia 52:180-183.

Diwu, Z. 1995. Novel therapeutic and diagnostic applications of hypocrellins and hypericins. Photochem. Photobiol. 61:529-539.

Feldman, R. S., C. E. Holmes, and T. A. Blomgren. 2000. Use of fabric and compost mulches for vegetable production in a low tillage, permanent bed system: Effects on crop yield and labor. Am. J. Altern. Agric. 15(4):146-153.

Forcella, F., S. Poppe, N. Hansen, E. Hoover, W. Head, F. Propsom, and J. McKensie. 2003. Biological mulches for managing weeds in transplanted strawberry. Weed Technol. In review.

Frontier Natural Products (FNP). 2000. Catnip Grower's Crop Monograph. Norway, IA.

Gleason, M., S. Wegulo, and G. Nonnecke. 2001. Efficacy of straw mulch for suppression of anthracnose on day-neutral strawberries. ISU Ext., FG-601:48. Iowa State Univ., Ames, IA.

Goolsby, D.A., E.M. Thurman, and D.W. Koplin. 1991. Geographic and temporal distribution of herbicides in surface waters of the upper Midwestern United States, 1989-90. p. 183-188. *In* G.E. Mallard and D.A. Aronson (eds.) U.S. Geological Survey Toxic Substances Hydrology Program. Proc. Technical Meeting, Monterey, CA. 11-15 Mar. 1991. U.S. Geological Survey Water-Resources Investigations Report 91-4034.

Hay, R., and P. Waterman (eds.). 1993. Volatile Oil Crops: Their Biology, Biochemistry and Production. Longman, Essex, England.

Himelrick, D.G. 1982. Effect of polyethylene mulch color on soil temperatures and strawberry plant response. Adv. Strawberry Prod. 1:15-16.

Hoover, E., F. Propsom, S. Poppe, F. Forcella, N. Hansen, B. Head, and B. Jacobson. 2000. Bio-based weed control in strawberries using sheep wool mulch, canola mulch, and canola green manure. *In* Greenbook 2000. Energy and Sustainable Agriculture Program. Minnesota Dep. of Agriculture, St. Paul, MN.

Iowa Dep. of Agriculture and Land Stewardship (IDALS). 1999. Iowa Organic Certification and Organic Standards. Des Moines, IA.

Janick, J. and J.E. Simon (eds.). 1993. Progress in New Crops. John Wiley & Sons, New York.

Kolpin, D.W., S.J. Kalkhoff, D.A. Goolsby, D.A.Sneck-Fahrer, and E.M. Thurman. 1997. Occurrence of selected herbicides and herbicide degradation products in Iowa's ground water, 1995. Ground Water 35(4):679-688.

Li, T. 1998. *Echinacea*: Cultivation and medicinal value. HortTechnology 8:122-129.

Morrison, K.D., E.G.Reekie, and K.I.N. Jensen. 1998. Biocontrol of common St. Johnswort (Hypericum perforatum) with Chrysolina hyperici and a host-specific Colletotrichum gloeosporioides. Weed Technol. 12:426-435.

Omidbaigi, R. and L. Hornok. 1992. Effect of N-fertilization on the production of fennel (*Foeniculum vulgare* Mill.) Acta Hortic. 306:249-252.

Organic Trade Association (OTA). 2002. OTA Newsletter. Greenfield, MA.

Pank, F. 1992. The influence of chemical weed control on quality characters of medicinal and aromatic plants. Acta Hortic. 306:145-154.

Peterson, C., and J. Coats. 2001. Insect Repellents—Past, Present, and Future. Pesticide Outlook 12(4):154-158.

Poppe, S. R. Becker, N. Hansen, M. Solemsaas, V. Fritz, F. Forcella, S. Wagner, B. Head, B. Padula. T. Nennich, and J. Stordahl. 2001. Wool mulching systems for specialty crops. *In* Greenbook 2003. Sustaining People, Land and Communities. Energy and Sustainable Agriculture Program. Minnesota Dep. of Agriculture, St. Paul, MN. In review.

Porter, B., R. McVicar, and L. Bader. 1998. St. John's wort in Saskatchewan. Saskatchewan Agriculture, Food, and Rural Revitalization. <http://www.agr.gov.sk.ca/docs/crops/special_crops/production_information/johnswort00.asp>

Prince, A.M., D. Pascual, D. Meruelo, L. Liebes, Y. Mazur, E. Dubovi, M. Mandel, and G. Lavie. 2000. Strategies for evaluation of enveloped virus inactivation in red cell concentrates using hypericin. Photochem. Photobiol. 71(2):188-195.

Rice, P.J., L.L McConnell, L. P. Heighton, A.J. Sadeghi, A.R. Isensee, J.R. Teasdale, A.A. Abdul-Baki, J.A. Harman-Fetcho, and C.J. Hapeman. 2001. Runoff loss of pesticides and soil: A comparison between vegetative mulch and plastic mulch in vegetable production systems. J. Environ. Qual. 30:1808-1821.

SAS Institute. 2001. SAS User's Guide: Statistics. Version 8.2 ed. Statistical Analysis Service Institute Inc. Cary, NC.

Schooley, J. 2001. St. John's Wort and Chrysolina Beetles. Ontario Ministry of Agriculture, Food, and Rural Affairs. <http://www.gov.on.ca/OMAFRA/english/crops/facts/info_sjwbeetles.htm>

Simon, J.E., A.F. Chadwick, and L.E. Craker. 1984. Herbs, An Indexed Bibliography, 1971-1980. The Scientific Literature on Selected Herbs, and Aromatic and Medicinal Plants of the Temperate Zone. Archon Books, Hamden, CT.

Simon, J.E., A. Mathe, and L.E. Craker (eds.). 1987. Sixth International Symposium on Medicinal and Aromatic Plants. Technical Communication of the International Society for Horticultural Science. Acta Hortic. 208:1-279.

Smith, R.C. 2001. Personal communication. North Dakota State Univ. Dep. of Plant Sciences. Fargo, ND.

Soberg, R. 2001. Personal communication. Organic Herb Producer Cooperative. Lakeville, MN.

Taber, H.G. 1983. Effects of plastic soil and plant covers on Iowa tomato and muskmelon production. Proc. Natl. Agr. Plastics Congr. 17:37-45.

Taylorson, R.B. 1987. Environmental and chemical manipulation of weed seed dormancy. Rev. Weed Sci. 3:135-154.

Teasdale, J.R., and C.S.T. Daughtry. 1993. Weed suppression by live and desiccated hairy vetch (*Vicia villosa*). Weed Sci. 41:207-212.

Teasdale, J.R. and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673-680.

Tornow, B. 2001. Personal communication. Tornow Herb Farms. Commercial Producer. Wausau, WI.

Tyler, V.E. 1999. Herbs affecting the central nervous system. p. 442-449. *In* J. Janick (ed.) Perspectives on New Crops and New Uses. ASHS Press, Alexandria, VA.

USDA Agriculture Marketing Service (USDA/AMS). 2002. National Organic Program. Final rule: 7 CFR Part 205. <http://www.ams.usda.gov/nop>

Walz, E. 1999. Final Results of the Third Biennial National Organic Farming Survey. Organic Farming Research Foundation, Santa Cruz, CA.

Weiss, E.A. 1997. Essential Oil Crops. CAB International, New York.

Table 1. Yields (dry matter) from catnip (CAT) and St. John's wort (SJW) harvests, 2001 and 2002.

	CAT		SJW
	2001	2002	2002
Treatment	------------------kg ha^{-1}-------------------		
Control+	600b†	4138c	1903
Control-	278a	2558a	1650
Flax straw mat	920c	3647bc	2236
Oat straw	632b	3154ab	2167
Wool mat	546ab	3578bc	2299
LSD (0.05)	282	728	NS

†Within a year, means followed by the same letter are not significantly different at $P = 0.05$.

Table 2. Weed density and biomass response to different weed management treatments in St. John's wort (SJW) and catnip (CAT), 2001 and 2002.

	Total density		Grass density		Broadleaf density		Total dry wt	
	2001	2002	2001	2002	2001	2002	2001	2002
Treatment	---------------------------- m^{-2} ----------------------------						---------g m^{-2}------	
SJW								
Control+	8b†	26b	6b	19b	1.7	7a	11b	30b
Control-	19b	232a	18a	225a	1.8	7a	6218a	4194a
Flax straw mat	2b	22b	2bc	22b	0	0b	117b	394b
Oat straw	59a	6b	1c	1b	0.3	1b	235b	95b
Wool mat	2b	12b	2bc	11b	0.5	1b	618b	376b
LSD (0.05)	27	57	4.6	56	NS	4.9	1593	498
CAT								
Control+	9bc	25b	6b	22b	2	3	42b	28b
Control-	31b	376a	30a	372a	1	5	7922a	2618a
Flax straw mat	2c	7b	1b	4b	1	3	70b	84b
Oat straw	71a	18b	2b	2b	0	4	998b	142b
Wool mat	4c	16b	4b	15b	0	1	256b	211b
LSD (0.05)	23	85	5.7	84	NS	NS	1026	572

†Within a column, means of each species followed by the same letter are not significantly different at $P = 0.05$.

Table 3. Disease occurrence and severity in catnip (CAT) and St. John's wort (SJW) in weed management treatments during the second growing season, 7 June 2002.

	Diseased plants		Disease severity	
	CAT	SJW	CAT	SJW
Treatment	----------------------	%	----------------------	
Control+	41	45	28	32ab†
Control-	31	36	21	26ab
Flax straw mat	29	10	25	29ab
Oat straw	17	12	25	11a
Wool mat	59	39	31	46b
LSD (0.05)	NS	NS	NS	35

†Within a column, means followed by the same letter are not significantly different at $P = 0.05$.

Table 4. Soil moisture content 0 to 5 cm below the soil surface, separated by growing season and interval after a moisture event in St. John's wort (SJW) and catnip (CAT).

	2001		2002	
	24 h	48 h	24 h	48 h
Treatment	---------------------%-------------------			
SJW				
Control+	25.3b[†]	22.3c	30.3	23.7b
Control-	23.6b	20.6c	29.3	22.6b
Flax straw mat	28.9a	26.7b	29.8	27.1a
Oat straw	30.0a	29.5a	30.3	26.3a
Wool mat	27.9a	25.6b	30.6	27.4a
LSD (0.05)	2.3	1.9	NS	1.6
CAT				
Control+	26.5c	23.9c	30.9	25.4b
Control-	25.4c	22.9c	30.4	23.7c
Flax straw mat	30.4a	28.4a	31.0	27.9a
Oat straw	29.5ab	27.8ab	29.8	27.3a
Wool mat	27.7bc	26.1b	31.1	27.1a
LSD (0.05)	2.4	2.1	NS	1.5

[†]Within a column, means of each species followed by the same letter are not significantly different at $P = 0.05$.

Table 5. Mean soil temperatures 5 cm below the soil surface of several weed management treatments in St. John's wort (SJW) and catnip (CAT), taken by fixed thermocouples in 2001 and 2002.

	Daily average		Daily maximum		Daily minimum	
	2001	2002	2001	2002	2001	2002
Treatment	-----------------	-----------------	----------------- °C	-----------------	-----------------	-----------------
SJW						
Control+	26.6a[†]	24.0a	34.8a	29.1a	20.7c	20.5a
Flax straw mat	24.9bc	23.2b	28.3c	27.7b	21.7b	20.1a
Oat straw	24.3c	22.4c	28.3c	25.1c	21.3a	20.3a
Wool mat	25.1b	24.4a	30.0b	29.5a	21.3a	20.7a
CAT						
Control+	25.9a	23.6a	32.4a	29.3a	21.0a	19.8a
Flax straw mat	25.2b	23.0b	29.4b	26.9b	21.6a	20.1a
Oat straw	23.5c	22.6b	26.5c	25.5c	21.2a	20.3a
Wool mat	25.2b	23.0b	30.1b	26.9b	21.3a	20.1a

[†]Within a column, means of each species followed by the same letter are not significantly different at $P = 0.05$.

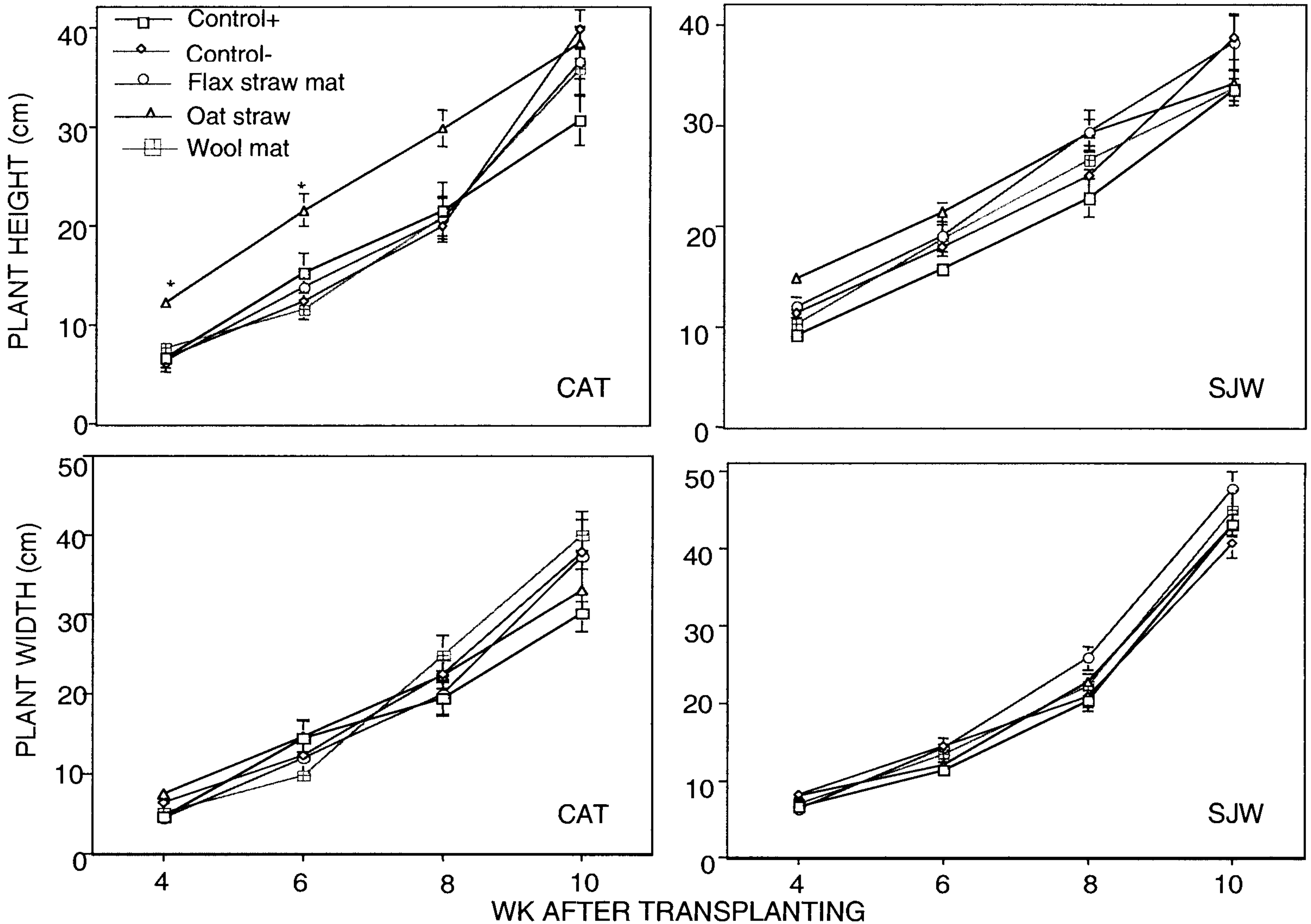

Fig. 1. Catnip (CAT) and St. John's Wort (SJW) biomass measurements during first growing season, 2001. Significant differences between treatments within each sampling date are indicated using *.

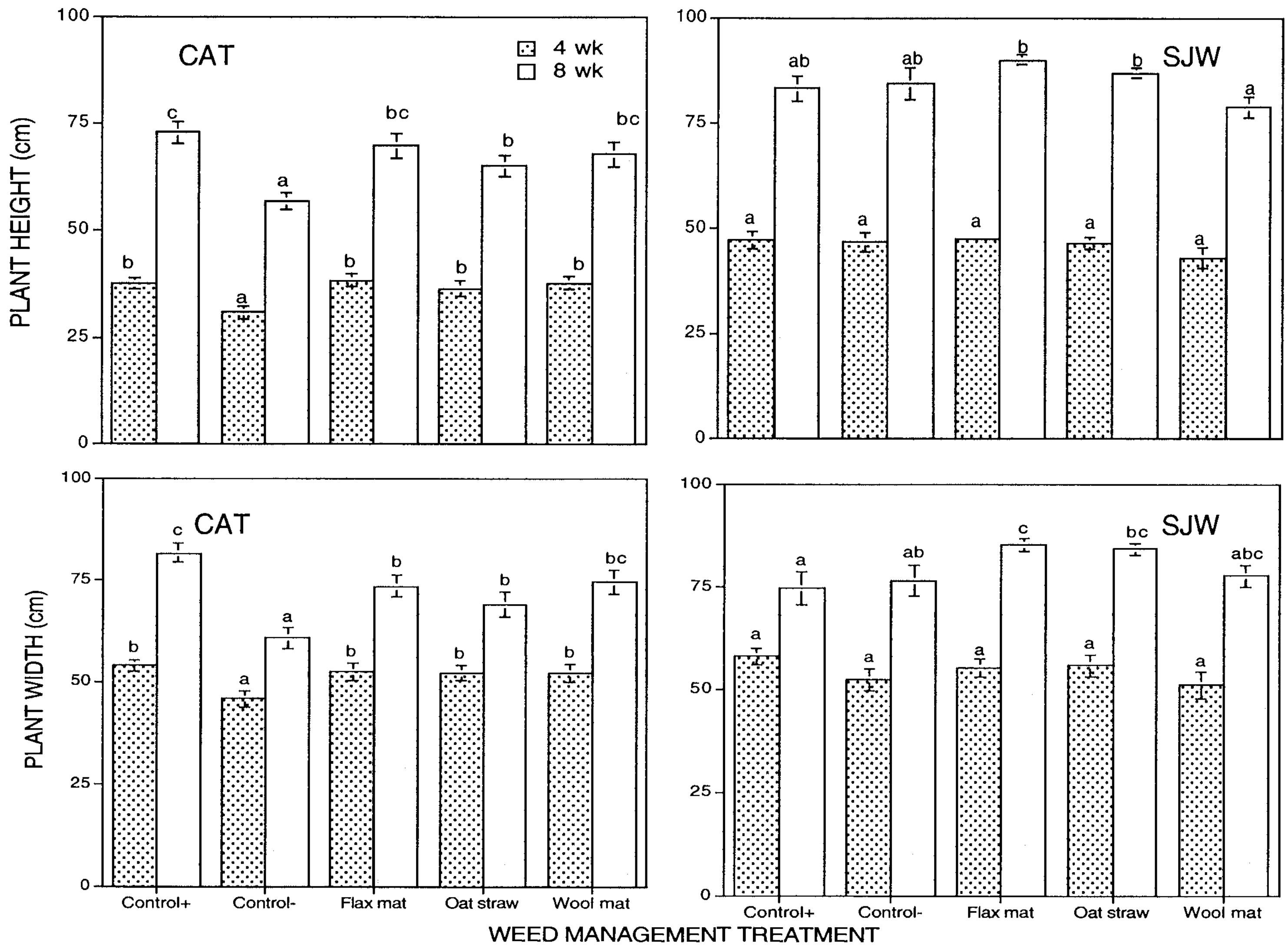

Fig. 2. Catnip (CAT) and St. John's Wort (SJW) biomass during second growing season, 2002. Bars within the same sampling period and with the same letter above them are not significantly different at the $P = 0.05$ level.

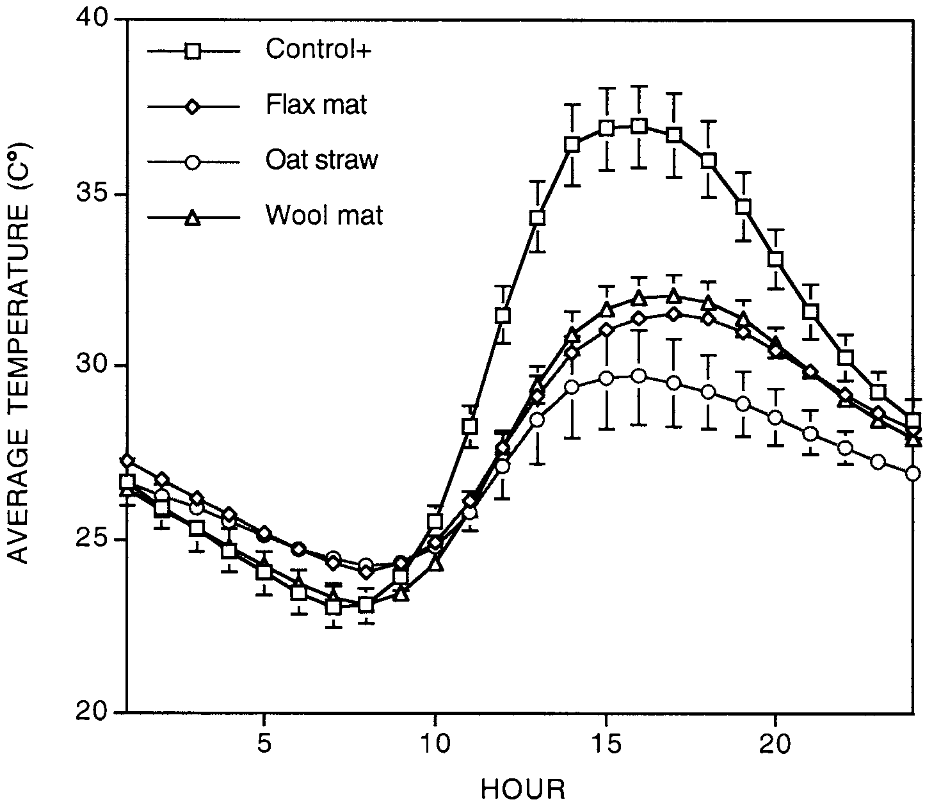

Fig. 3. Soil temperature diurnal fluctuation 5 cm below the soil surface in each weed management treatment of catnip and St. John's wort herbs, 8 Aug. 2001. Thermocouples were placed midrow and centered between plants.

CHAPTER 3. The effect of natural mulches on herb quality in organic field production of catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos')

A paper to be submitted to *HortTechnology*

L. M. Duppong[1], K. Delate[2], M. Liebman[3], and R. Horton[3]

ABSTRACT

Due to expanding markets, an excellent opportunity exists for organic farmers in the Midwest to plant high-value niche crops, such as medicinal herbs. Organic premiums may provide extra incentive for producers to consider these alternative crops, though additional research is needed to ascertain the influence of specific production practices on herb quality. An experiment was conducted in 2001 and 2002 near Gilbert, Iowa, to study how target biochemical constituents of two herbs, catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos') are influenced by the use of several natural mulches. Five treatments were applied in a weed management zone around each herb species: a nonwoven wool mat, a flax straw mat, organic oat straw, a hand-weeded, positive control, and a non-weeded, negative control. Catnip plant material was analyzed for nepetalactone content using gas chromatography (GC), while hypericin levels in the extracted St. John's wort samples were determined by high performance liquid chromatography (HPLC). There was no significant weed management treatment effect on the concentration of the target compounds, nepetalactone and hypericin. These findings, along with the production aspects of enhanced crop performance and effective weed suppression shown in previous research,

Dep. of Agronomy, Iowa State University, Ames, IA 50011
[1]Graduate student, primary researcher and author
[2]Assistant professor, corresponding author
[3]Coauthor

support the use of natural mulches, particularly flax straw and wool mats, as weed management alternatives to manual labor and herbicide usage.

INTRODUCTION

The organic industry is a consumer driven market that has been growing at least 20% annually for the past 10 years, with projected retail sales of $20 billion in the U.S. by 2005 (OTA, 2002). Due to these expanding markets, an excellent opportunity exists for organic farmers in the Midwest to plant crops for high-value niche markets. Organic premiums may provide extra incentive for these producers to consider such alternative crops, though additional research is needed to ascertain the influence of specific production practices on herb quality.

An important quality requirement for herb buyers is a specific essential oil content or target compound concentration in the chemical extracts of a particular herbal crop (FNP, 2000). A farmer's crop that does not meet specific quality assurance guidelines faces rejection by herb buyers. One of the marker constituents of St. John's wort is hypericin,a naphthodianthrone which reportedly possesses antidepressive properties (Thiede and Walper, 1994; Butterweck et al., 2002). Nepetalactone is a monoterpenoid found in the essential oil of catnip that has been shown to be more effective than N,N-diethyl-meta-toluamide (DEET) in repelling mosquitoes (J. R. Coats, 2002, personal communication) and cockroaches (Peterson et al., 2002). Furthermore, antimicrobial activity has been associated with both nepetalactone (Bourrel et al., 1993) and hypericin (Diwu, 1995; Cohen et al., 1996; Prince et al., 2000).

Reports from conventional medicinal herb literature indicated that environmental effects, such as temperature, radiation, and moisture (Hay and Waterman, 1993), and field management systems (Pank, 1992; Omidbaigi and Hornok, 1992) greatly influenced herb growth, development and yield. There is considerable pressure for growers to upgrade agricultural methods and improve management techniques to increase herb crop yields and quality (Weiss, 1997). Information on cultural methods and their effects on the growth, yield, and chemical composition of botanical crops is very limited (Li, 1998). Researchers throughout the country have demonstrated the importance of management practices on herb quality (Simon et al., 1984, 1987; Janick and Simon, 1993), but little information is available for organic growers.

The objective of this experiment was to compare the effect of several organic weed management treatments on the concentration of target biochemicals of two unrelated medicinal herb species, catnip and St. John's wort. The hypothesis was that there would be no significant weed management treatment effect on these biochemical compounds.

MATERIALS AND METHODS

Herb Culture and Harvest

A field experiment was conducted in 2001 and 2002 at the Iowa State University Horticulture Research Station, in Gilbert, Iowa, involving the cultivation of two medicinal herb species, catnip and St. John's wort 'Helos' (Duppong et al., 2002). Five treatments were applied in a weed management zone around each herb plant: a nonwoven wool mat (Hobbs Bonded Fibers, Waco, TX), a flax straw mat (FlaxTech LLC, Rock Lake, ND), organic oat straw (from oat fields at the certified organic Iowa State University Neely-Kinyon Research Farm, Greenfield, IA), a hand-weeded, positive control, and a non-weeded, negative control. Treatments were arranged in a completely randomized design of weed management-herb species combinations and replicated four times. Forty plots were established and the herbs were transplanted to the field on 13 June 2001.

On 14 Sept. 2001, four catnip plants in each plot were manually harvested (near the seed formation stage) by cutting the upper 15 to 16 cm of each shoot on the plant (FNP, 2000; R. Soberg, 2001, personal communication). The plants were placed in individual nylon mesh bags and fresh weights were immediately obtained. The plants were dried at 30°C for 72 h (FNP, 2000; R. Soberg, 2001, personal communication), after which dry weights were recorded. A second catnip harvest occurred 28 June 2002 (in the 20% bloom stage) by cutting and drying eight plants per unit in the aforementioned manner. The St. John's wort was harvested 17 June 2002 using the same methods as the catnip, and the plant material was dried at 37 to 38°C for 5 d (Porter et al., 1998; Buter et al., 1998; R. Soberg, 2001, personal communication). The dried plant matter was stored in the dark at room temperature (24°C) until subsequent chemical analysis.

Catnip Chemical Analysis

A homogeneous 10-g sample of dried catnip leaves and flowers from each experimental unit was collected into separate 250-mL French square jars. For the second harvest of catnip, two 10-g homogeneous samples were collected and treated as replications throughout the extraction and chemical analysis. The plant material in each jar was completely submerged in acetone (approximately 210 mL) for the extraction and kept at room temperature (24°C) for 2 d. Following this period, the contents were mechanically shaken for 2 minutes and then gravity-filtered with Whatman #1 15 cm filter paper. The final volume was recorded and the filtrate was stored in the dark at 3°C until subsequent chemical analysis.

Nepetalactone levels in the catnip plant material were determined by a Varian 3700 GC (Walnut Creek, CA), equipped with a flame ionization detector and employing a 15 m DB5 phase capillary column (Supelco, Bellefonte, PA). The injection volume of each sample was 1 μL. The temperature program started at 100°C, ramped at 15°C min^{-1} until 220°C, and was held there for 8 minutes. The extraction and analysis of the first harvest occurred on 18 Jan. and 28 Feb. 2002, respectively. The extraction and analysis of the second harvest occurred on 15 July and 17 Sept. 2002, respectively.

St. John's Wort Chemical Analysis

The upper 5 cm of the dried flowering tops from the St. John's wort were ground and sifted through a US #40 mesh screen, and two homogeneous 10-g samples were collected to replicate each treatment. A representative 1-g subsample from each sample was placed in a 250-mL round bottom flask, and 20 mL of acetone and 2 mL of 0.1 N NaOH were added to each flask. These flasks were individually wrapped with flame retardant material to protect the St. John's wort extract from light, and refluxed for 30 min. The flask contents were gravity filtered using GF-A 70-mm glass fiber filter paper and rinsed twice with 5 mL of acetone. The filter paper and extractant were returned to the boiling flask, and the extraction, filtration, and rinses were repeated. Four milliliters of 0.1 N HCl was added to the filtrate in each flask, and a final volume of 50 mL was obtained by adding acetone. Each solution was placed in a separate vial and immediately analyzed by HPLC. All reagents met or exceeded ACS grade.

Hypericin levels of the extracted samples were determined with a Hitachi L-7000 series HPLC (Hitachi Analytical Instruments, San Jose, CA) fitted with an L-7200 autosampler, L-7100 pump, and L-7420 UV-Visible detector set to 510 nm. The HPLC was controlled using a D-7000 chromatography data station interface. The analytical column was a 150 mm by 4.6 mm Prodigy (Phenomenex, Torrance, CA) coupled to a SecurityGuard (Phenomenex) C_{18} guard column. The hypericin standard was obtained from Calbiochem (La Jolla, CA).

The HPLC mobile phase was set for an isocratic elution of 10 mM ammonium phosphate (pH 2.8)/acetonitrile (15:85) at 1.5 mL min^{-1}. The detector was set to 510 nm. A calibration curve of hypericin containing 0.20 μg – 0.60 μg was created. From each of the prepared samples, 20 μL was injected and analyzed against the standard curve. The extraction and chemical analysis of the St. John's wort occurred on 25 and 26 Sept. 2002, respectively.

Data Analysis

All laboratory data was analyzed using analysis of variance with StatView software (SAS Inst.,1999). Means were statistically separated using Fisher's PLSD at $P \leq 0.05$.

RESULTS AND DISCUSSION

There was no significant treatment effect on the concentration of the target compounds, nepetalactone (NEP) and hypericin (HYP), examined in this study (Table 1). The greatest quantity of nepetalactone was detected in the herbs harvested in the second growing season. The trend that year showed that the highest concentration of each target compound was found in the flax straw mat (NEP = 11.8 mg g^{-1}, and HYP = 0.69 mg g^{-1}) compared to the averages of all other treatments (NEP = 9.4 mg g^{-1}, and HYP = 0.52 mg g^{-1}). Because of reported variation in nepetalactone concentration in essential oil analysis of catnip (Ibrahim and El Din, 1999; Malizia et al., 1996; Pappas, 2001), oil contents in each treatment could not be accurately calculated based only on the detected nepetalactone concentrations in this experiment. The quality assurance specification of a Midwest herb cooperative is a 0.3% oil content in leaves and flowers (FNP, 2000). The St. John's wort hypericin content of each weed management treatment (0.48 to 0.69 mg g^{-1}) fell within other reported ranges of hypericin analysis of whole plants with flowers (0.36 to 2.0 mg g^{-1} and 0.12 to 0.80 mg g^{-1}), respectively reported by Benigni et al. (1971), and by Jensen et al. (1995). This range is also above the minimum St. John's wort quality specification concentration of 0.25 mg g^{-1} of hypericin in herbal extracts for a Midwest herb cooperative (B. Letchworth, 2002, personal communication).

Nepetalactone levels in the catnip were approximately four times higher in 2002 than in 2001. This result may be correlated with the later chemical extraction of the dried catnip leaves and flowers after the first growing season compared with the second season (four months as opposed to one month, respectively). Moreover, the catnip plants were harvested at a late developmental stage in 2001 (seed formation), rather than at the early to mid-bloom stage (20%) established in herb industry protocols (FNP, 2000). Highest lactone and essential oil yield and quality have been reported in catnip harvested at full bloom (Bourrel et al.,1993; Chalchat and Lamy, 1997; Ibrahim and El Din, 1999). Essential oils are comprised of volatile, aromatic compounds, and will be less concentrated over time in plant matter.

As there were no significant treatment effects on key metabolite concentrations in harvested St. John's wort and catnip, the natural mulches used in this experiment did not appear to interfere with normal metabolic processes. These results, along with the production aspects of reported enhanced crop performance and effective weed suppression (Duppong et al., 2002), support the use of natural mulches as a weed management alternative to manual labor and herbicide usage.

LITERATURE CITED

Benigni, R., C. Capra, and P.E. Cattorini. 1971. *Hypericum*. Plante Medicinali: Chimica, Farmacologia e Terapia. Inverni & Della Beffa. Milano, Italy.

Bourrel, C., C. Perineau, G. Michel, and J.M. Bessiere. 1993. Catnip (*Nepeta cataria* L.) essential oil: Analysis of chemical constituents, bacteriostatic and fungistatic properties. J. Essent. Oil Res. 5:159-167.

Buter, B., C. Orlacchio, A. Soldati, and K. Berger. 1998. Significance of genetic and environmental aspects in the field cultivation of *Hypericum perforatum*. Planta Med. 64:431-437.

Butterweck, V., T. Böckers, B. Korte, W. Wittkowski, and H. Winterhoff. 2002. Long-term effects of St. John's wort and hypericin on monoamine levels in rat hypothalamus and hippocampus. Brain Res. 930(1-2):21-29.

Chalchat, J.C., and J. Lamy. 1997. Chemical composition of the essential oil isolated from wild catnip *Nepeta cataria* L. cv. *Citriodora* from the Drôme region of France. J. Essent. Oil Res. 9:527-532.

Coats, J.R. 2002. Personal communication. Iowa State Univ. Dep. of Entomology. Ames, IA.

Cohen, P.A., J.B. Hudson, and G.H.N. Towers. 1996. Antiviral activities of anthraquinones, bianthrones, and hypericin derivatives from lichens. Experientia 52:180-183.

Diwu, Z. 1995. Novel therapeutic and diagnostic applications of hypocrellins and hypercins. Photochem. Photobiol. 61(6):529-539.

Duppong, L.M., K. Delate, M. Liebman, and R. Horton. 2002. The effect of natural mulches on crop performance and weed suppression in organic field production of catnip (*Nepeta cataria* L.) and St. John's wort (*Hypericum perforatum* L. 'Helos'). Agron. M.S. Thesis. Iowa State Univ., Ames, IA.

Frontier Natural Products (FNP). 2000. Catnip Grower's Crop Monograph. Norway, IA.

Hay, R., and P. Waterman (eds.). 1993. Volatile Oil Crops: Their Biology, Biochemistry and Production. Longman, Essex, England.

Ibrahim, M.E., and A.A.E. El Din. 1999. Cultivation of *Nepeta cataria* L. in Egypt: its growth, yield, and essential oil content as influenced by some agronomic practices. Egypt. J. Hortic. 26(3):281-302.

Janick, J., and J.E. Simon. 1993. Progress in New Crops. John Wiley & Sons. New York.

Jensen, K.I.N., S.O. Gaul, E.G. Specht, and D.J. Doohan. 1995. Hypericin content of Nova Scotia biotypes of *Hypericum perforatum* L. Can. J. Plant Sci. 75:923-926.

Letchworth, B. 2002. Personal communication. Commodity Manager. Frontier. Norway, IA.

Li, T. 1998. *Echinacea*: Cultivation and medicinal value. HortTechnology 8:122-129.

Malizia, R.A., J.S. Molli, D.A. Cardell, and J.A. Retamar. 1996. Volatile constituents of the essential oil of *Nepeta cataria* L. grown in Cordoba Province (Argentina). J. Essent. Oil Res. 8:565-567.

Omidbaigi, R., and L. Hornok. 1992. Effect of N-fertilization on the production of fennel (*Foeniculum vulgare* Mill.). Acta Hortic. 306: 249-252.

Organic Trade Association (OTA). 2002. OTA Newsletter. Greenfield, MA.

Pank, F. 1992. The influence of chemical weed control on quality characters of medicinal and aromatic plants. Acta Hortic. 306:145-154.

Pappas, R.S. 2001. Certificate of Analysis—Pure Catnip Essential Oil. Essential Oil Univ. New Albany, IN.

Peterson, C.J., L.T. Nemetz, L.M. Jones, and J.R. Coats. 2002. Behavioral activity of catnip *Nepeta cataria* (Lamiaceae), to the German cockroach, *Blattella germanica* (Blattodea: Blattellidae). J. Econ. Entomol. 95:377-380.

Porter, B. R. McVicar, and L. Bader. 1998. St. John's wort in Saskatchewan. Saskatchewan Agriculture, Food, and Rural Revitalization. <http://www.agr.gov.sk.ca/docs/crops/special_crops/production_information/johnswort00.asp>

Prince, A.M., D. Pascual, D. Meruelo, L. Liebes, Y. Mazur, E. Dubovi, M. Mandel, and G. Lavie. 2000. Strategies for evaluation of enveloped virus inactivation in red cell concentrates using hypericin. Photochem. Photobiol. 71(2):188-195.

SAS Institute. 1999. StatView. Third ed. Statistical Analysis Service Institute. Cary, NC.

Simon, J.E., A.F. Chadwick, and L.E. Craker. 1984. Herbs, An Indexed Bibliography, 1971-1980. The Scientific Literature on Selected Herbs, and Aromatic and Medicinal Plants of the Temperate Zone. Archon Books, Hamden, CT.

Simon, J.E., A. Mathe, and L.E. Craker (eds). 1987. Sixth International Symposium on Medicinal and Aromatic Plants. Technical Communication of the International Society for Horticultural Science. Acta Hortic. 208:1-279.

Soberg, R. 2001. Personal communication. Organic Herb Producer Cooperative. Lakeville, MN.

Thiede, H.M., and A. Walper. 1994. Inhibition of MAO and COMT by *Hypericum* extracts and hypericin. J. Geriatr. Psychiatry Neurology 1:54-56.

Weiss, E.A. 1997. Essential Oil Crops. CAB International, New York.

Table 1. Concentrations of selected secondary metabolites from dried plant material of catnip (nepetalactone) and St. John's wort (hypericin) harvests, 2001 and 2002.

	Nepetalactone		Hypericin
	2001	2002	2002
Treatment	$mg\ g^{-1}$		
Control+	2.3	9.1	0.48
Control-	2.5	9.6	0.59
Flax straw mat	2.5	11.8	0.69
Oat straw	2.4	9.2	0.48
Wool mat	2.4	9.8	0.53
LSD	NS	NS	NS

CHAPTER 4. General Conclusions

In recent years, the beneficial effects of organic management practices have been documented for soil (Scow et al., 1994; Reganold et al., 2001), plant health (Delate and Lawson, 1999, 2000), yield (Delate and Cambardella, 1999, 2000) and food quality (Woese et al., 1997; Friedrich et al., 2003). The amount of information available for organic producers of agronomic and key horticultural crops continues to grow, but gaps remain in organic herb production. Specifically, little information exists on integrated pest management practices in herbal crops and their influence on herb quality.

This research was done in an attempt to find effective weed management practices for organic producers, since this was identified as their number one production concern (Walz, 1999). Alternatives to herbicides and synthetic mulches need to be explored for truly sustainable agroecosystems. The biodegradable mulches used in this experiment were specifically chosen because they come from on-farm resources and have the potential to be used in successive growing seasons. Effects on crop performance, weed suppression, and herb quality were assessed.

The oat straw, flax straw mat, and wool mat treatments had equivalent or significantly greater yields compared to hand-weeded, positive control plots in both years of the experiment. During each growing season, weeds were effectively suppressed to levels equivalent to or significantly less than the hand-weeded, positive control treatment. This result in particular demonstrates the durability of both natural fiber mulches through a consecutive growing season in a perennial row crop system. Furthermore, the mulch treatments did not appear to interfere with normal metabolic processes of each herb species, because no significant treatment effects on key metabolite concentrations were found in harvested plant materials.

One major obstacle for producers in utilizing the wool and flax straw mats is the high initial cost to install these mulches. The cost of each fiber mat at the time of this research project was \$0.02 m^{-2} and \$0.05 m^{-2}, respectively, while polypropylene mulch was priced at \$0.01 m^{-2}. In organic perennial crop production systems, however, the fiber mulches have a time/labor cost advantage because they do not need to be removed and installed each year as is the case with synthetic mulches. Moreover, there should be no waste disposal problems in using biodegradable mulches in production systems, whereas plastic mulches are estimated to contribute between 18-64 million kg of annual waste to landfills, the most of any agricultural plastic product (Garthe and Kowal, 2001).

Organic production improves soil quality and nutrient cycling with soil-building crop rotations and cover crops (Scow et al., 1994), supports biodiversity (Brummer, 1998), and has a less destructive impact on natural resources (Youngberg et al., 1984). Organic agriculture also encourages support for small-scale farmers, since many organic foods come from "small farms." In the era of corporate farming and large grain or livestock confinement operations, organic farming offers an avenue of farming that may allow for the survival of the small farm.

With the growing demand for organic foods, organic farmers require efficient and productive farming methods to meet these demands. Continued research is needed in the area of organic practices and production methods. Ecologically and economically sustainable pest management should be further examined in order to develop more innovative products that utilize on-farm resources such as flax straw and wool mats.

Literature Cited

Brummer, E.C. 1998. Diversity, stability, and sustainable American agriculture. Agron. J. 90:1-2.

Delate, K.M., and C. Cambardella. 1999. Comparison of organic and conventional rotations at the Neely-Kinyon Long-Term Agroecological Research (LTAR) site-First year results. Iowa State Univ. Armstrong Research and Demonstration Farm Progress Report, College of Agriculture, Iowa State Univ., Ames, IA.

Delate, K.M., and C. Cambardella. 2000. Comparison of organic and conventional rotations at the Neely-Kinyon Long-Term Agroecological Research (LTAR) site. Iowa State Univ. Armstrong Research and Demonstration Farm Progress Report, College of Agriculture, Iowa State Univ., Ames, IA.

Delate, K.M., and V. Lawson. 1998. Evaluation of organic soil amendments for certified organic pepper production. Annual Fruit and Vegetable Progress Report, 1997. Coop. Ext. Serv., Iowa State Univ., Ames, IA.

Delate, K.M., and V. Lawson. 2000. Evaluation of organic soil amendments and cover crops for certified organic pepper production. Annual Fruit and Vegetable Progress Report, 1999. Coop. Ext. Serv., Iowa State Univ., Ames, IA. Bull. Pm-601.

Friedrich, H.J, K. Delate, P. Domoto, G. Nonnecke, and L. Wilson. 2003. Effect of organic pest management practices on apple productivity and apple food safety. Biological Ag. & Hort. In press.

Garthe, J.W. and P.D. Kowal. 2001. Recycling Used Agricultural Plastics. Agriculture and Biological Engineering. PennState Coop. Ext. Factsheet, C-8, College Station, PA.

Reganold, J.P., J.D. Glover, P.K. Andrews, and H.R. Hinman. 2001. Sustainability of three apple production systems. Nature 410:926-929.

Scow, K.M., O. Somasco, N. Gunapala, S. Lau, R. Venette, H. Ferris, R. Miller, and C. Shennan. 1994. Transition from conventional to low-input agriculture changes soil fertility and biology. Calif. Agr. 48(5):20-26.

Walz, E. 1999. Final Results of the Third Biennial National Organic Farming Survey. Organic Farming Research Foundation, Santa Cruz, CA.

Woese, K., D. Lange, C. Boess, and K.W. Bogl. 1997. A comparison of organically and conventionally grown foods - Results of a review of the relevant literature. J. Sci. Food Agric. 74:281-293.

Youngberg, I.G., J.F. Parr, and R.I. Papendick. 1984. Potential benefits of organic farming practices for wildlife and natural resources. Trans. N. Amer. Wildlife and Natural Resources Conference 49:141-153.

ACKNOWLEDGEMENTS

I have much to be thankful for in my past 2.5 years of work with the organic agriculture program at Iowa State University. First and foremost, I extend deep appreciation to Dr. Kathleen Delate, who has devoted much time and energy in advising and encouraging me in my research and higher education. I have been introduced to many good people in the university system and in production agriculture in Iowa through her, and she has provided me with diverse extension work experiences that I have thoroughly enjoyed. The practical skills that I have gained under her supervision in research and extension are a big asset to my life-long goals.

I owe special thanks to Heather Friedrich and Noreen Wantate in the Organic Agriculture Lab for their continued encouragement and assistance through the thick-and-thin times of my research project. Lab assistants who were of great help in field and with labwork included Molly Wilson, Andrea McKern, Jenny Peterson, Karen Joslin, Katie Schroeder, Nate Lindsay, Ryann Ankerstjerne, and Jorge Alvaro.

Dr. Matt Liebman and Dr. Bob Horton have also put time and ideas into this project, and I have appreciated their consultation. I have learned much in seeing their commitment to education and research, and am grateful that they chose to help guide me as POS committee members. The following other people have also assisted in this project in various ways: Dr. Bill Graves (soil moisture Theta probe), Tyson Ochsner (thermocouples), Dr. Tom Kaspar and Ben Knutson (installing thermocouple wires and downloading data), Dr. Joel Coats and Jason Belden (catnip biochemical analysis and equipment), and Bruce Lyon and Dr. George Kraus (St. John's wort biochemical analysis and calculations). Reid Landes in the A&E Statistical Consulting Lab provided extra spirit and assistance in the statistical analysis whenever I called upon him. Frontier Cooperative graciously allowed us the use of their HPLC equipment for the St. John's wort analysis. Renne Soberg, president of the Organic Herb Producers Cooperative, was of great help at harvest time, in addition to providing advice on various aspects of herb cultivation. Ron Hendrickson of FlaxTech LLC obtained the flax straw mat mulch for this project, while Steve Poppe at the University of Minnesota West Central Research and Outreach Center provided the wool mulch and information on its use in other studies. I also am very grateful for the funding and support I received from the Leopold Center for Sustainable Agriculture.

My family has been very supportive and interested in my well-being and work as I have attended Iowa State, and I thank them all—Mom, Dad, Jeff, Lisa, Sara, Michelle, Renae, and Kalene—for their love and attention across the miles! I am at a loss for words in describing my appreciation to my boyfriend, Ed Vizenor, who has been the best example of steadfast love and support I have ever known, especially under trying and long-distance circumstances. His gentle and heartening reminders of my desire to bring life and love to all activities I pursue have helped me through difficult circumstances in all my academic pursuits thus far. I have also received much support and love from the Vizenor family, especially Linda.

Lastly I give thanks to God, the Father of all life, for my life and the blessings He has sent me in Iowa. He has guided me through the dialogue, mentoring, and interaction of the aforementioned people and many others, and it is my hope to that all my small undertakings will glorify Him. I dedicate this thesis and all of my research to Our Lady of Victory, for she has lovingly has sustained me since the beginning.