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Utilization of Sunn Hemp for Cover Crops and Weed Control in Temperate Climates

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1. Introduction

The use of smother crops or cover crop residue to suppress weed growth in agriculture is not a recent innovation; yet, only recently have smother, or cover crops, received considerable attention. The need to develop increasingly integrated pest management and sustainable food production systems has encouraged a greater interest to thoroughly evaluate effective utilization of cover crops in agricultural systems. In addition to providing a measure of weed control through physical obstruction and/or biochemical suppression, cover crops provide numerous environmental benefits that can promote long-term viability of farm lands (Jordan et al. 1999; Phatak et al. 2002; Yenish et al. 1996). Implementation of cover crops can reduce soil erosion, reduce runoff and improve water availability, improve soil structure, enhance soil organic matter, and increase diversity of soil biota (Bugg and Dutcher 1989; Reeves 1994; Wang et al. 2002a). These soil improvements, along with weed suppression capabilities, have made cover crops ideally suited for use in current and future sustainable agronomic systems.

Autumn-seeded cover crops include cereal grains, such as oat (*Avena sativa* L.) or rye (*Secale cereale* L.), Brassicas, like mustard (*Brassica* spp.) and radish (*Raphanus sativus* L.), or legumes, like clover (*Trifolium* spp.) or vetch (*Vicia* spp.) (SARE 2007). Each type of cover provides ecological benefits; however, leguminous cover crops are capable of providing biologically fixed nitrogen (N) which is available for uptake by the succeeding cash crop (Balkcom and Reeves 2005; Cherr et al. 2006; Karlen and Doran 1991; Wang et al. 2005). This source of nitrogen can greatly reduce N fertilizer applications necessary for the subsequent crop, and is of particular interest in low-input agriculture systems (Deberkow and Reichelderfer 1988). The drawback when utilizing legume cover crops, in comparison to grain covers, is acceleration of residue decomposition (Cherr et al. 2006; Somda et al. 1991). For weed control purposes, cover crops with plant portions containing relatively high C:N and high residue levels, such as cereal grains or sunn hemp (*Crotalaria juncea* L.), offer increased weed suppression for a relatively lengthier period of time during the growing season compared to cover crops with low C:N ratios (Cherr et al. 2006; Vigil and Kissel 1995). Legume cover crops have low C:N ratios, thus generally decompose more rapidly than cereal grains and require substantial biomass for extended ground cover. To resolve this issue, research has examined the use of tropical legume cover crops in temperate regions to facilitate N fixation while achieving suitable levels of biomass (Balkcom et al. 2011; Gallaher et al. 2001; Marshall et al. 2002; Mosjidis and Wehtje 2011).

Sunn hemp, a tropical legume that most likely originated from the Indo-Pakistani sub-continent, has been identified as a potential alternative to traditional legume cover crops employed in the southern portion of the United States (Cook and White 1996; Mansoer et al. 1997; Montgomery 1954; Mosjidis and Wetje 2011). As a tropical legume, sunn hemp can produce larger quantities of biomass in a shorter time period than winter legumes from temperate zones, while still providing an agronomically important amount of fixed N (Mansoer et al. 1997; Reeves et al. 1996; Wang et al. 2002b). The increased biomass production from sunn hemp would improve and extend weed control compared to other legume covers. Research continues worldwide to evaluate this species to determine its potential for widespread use in sustainable agricultural production, as well as to identify any limitations with the use of sunn hemp.

This chapter briefly explores the biological features of sunn hemp that make it a suitable cover crop and reviews previous research concerning weed suppression by sunn hemp. It also outlines current research projects targeting constraints on extensive adoption which include plant breeding studies and herbicide evaluations to improve sunn hemp production for seed availability. In order to improve weed managment options, it is necessary to continue investigating alternative methods to achieve effective, yet sustainable, weed control.

2. Cover crops

As stated previously, cover crops provide numerous environmental and weed suppression benefits. Implementation of cover crops into a production system is often in response to the need to reduce soil erosion and water runoff (Hartwig and Ammon 2002). However, with current advances toward sustainable growing practices as well as a need to reduce input costs, growers have begun to integrate cover crops for their weed control capabilities. The use of cover crops is typically found in conservation agriculture settings; cover crop residue left on the soil surface at planting provides a measure of weed control through shading of the soil and/or through allelopathy, chemical inhibition of plant germination, and as physical barrier for weed growth (Creamer et al. 1996; Price et al. 2007; Teasdale 1996).

To maximize weed suppression, high-residue cover crop systems that provide at least 4,500 kg ha^{-1} of biomass for ground cover are generally utilized (Balkcom et al. 2007). In these instances, winter cereal grain crops such as rye or oat are employed to attain the greatest amounts of residue prior to cash crop planting to maintain ground cover for an extended period into the growing season (Duiker and Curran 2005; Price et al. 2006, 2007; Ruffo and Bollero 2003). Although cereal crops can be established with relatively low costs and offer maximum biomass production for weed suppression, some systems would benefit more from the use of fall or winter legume cover crops.

3. Legume cover crops

Leguminous cover crops provide many benefits also achieved with other cover crop species including erosion control, improved water filtration, and improved soil organic matter.

However, a major constraint to the use of winter legumes covers is the lack of ample growing time between cash crops (Mansoer et al. 1997). Traditional planting windows for cover crops do not allow for maximum growth of cover crop species prior to the onset of cold temperatures; earlier planting of legumes would require a harvest of summer crops before maturity. In addition, planting cash crops often interferes with maturation of cover crops. Current limitations with legume biomass production have warranted research to resolve these issues in order to make use of the nitrogen fixation properties offered by legumes.

3.1 Nitrogen fixation in legumes

With the majority of atmospheric nitrogen present in a form unavailable for plant use (N_2), biological fixation of N_2 to NH_3 by bacteria is a critical process for contributing nitrogen to the soil environment (Meyer et al. 1978; Novoa and Loomis 1981). With legumes, bacteria fix atmospheric nitrogen within root nodules while the plant provides needed carbohydrates to facilitate the process (Figure 1). This symbiotic relationship allows many leguminous crops to be grown without the addition of synthetic fertilizers (Lindemann and Glover 2003; Phillips 1980).

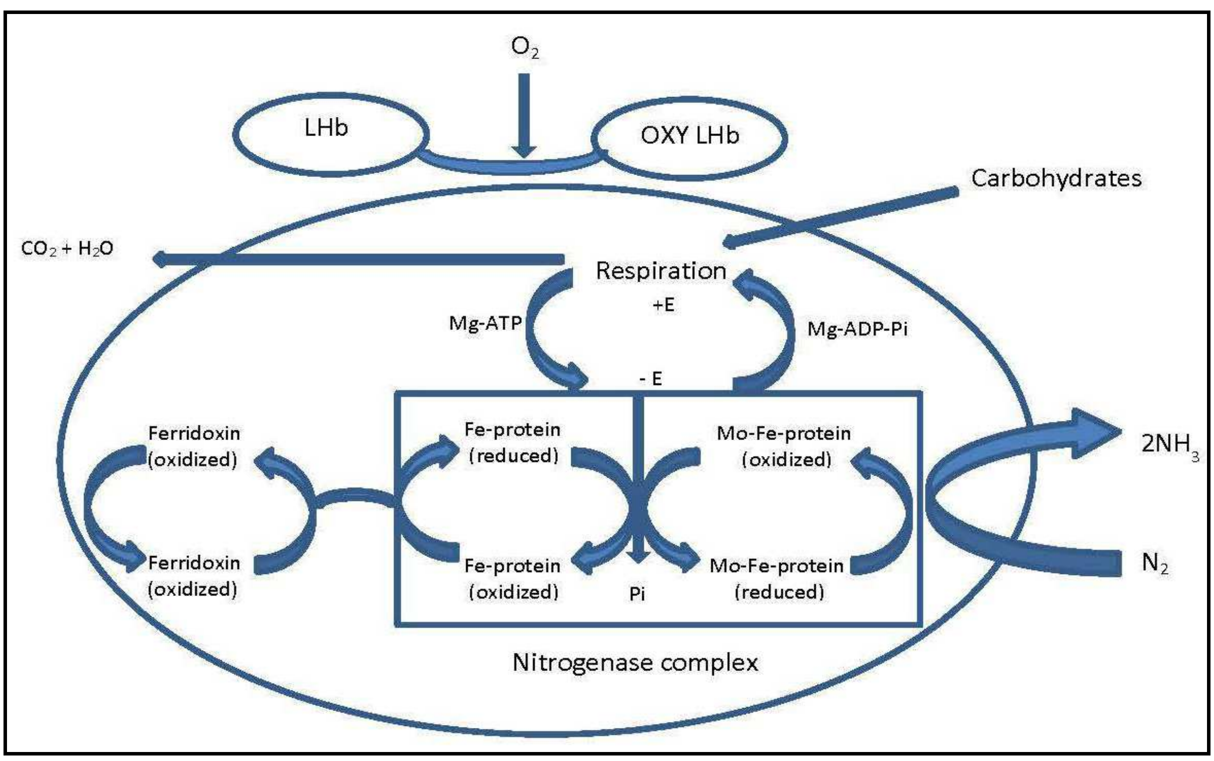

Fig. 1. Nitrogen fixation by bacteria, such as *Rhizobium*, occurs in root nodules of legumes.

As cover crops, legumes release nitrogen accumulations through vegetative decomposition, making NH_3 available for succeeding crops (Lindemann and Glover 2003). The rising cost of synthetic fertilizer, and the desire for viable alternatives to traditional high-input production practices, has boosted interest in the use of a number of legumes for cover crops.

The amount of N biologically fixed by a legume is dependent on a number of environmental conditions and management practices that affect biomass production (Holderbaum et al.

1990; Reeves 1994; Wagger 1989). Traditional fall-seeded legume cover crops have limited biomass production prior to cold temperatures, which can limit N accumulation and availability to subsequent crops. Utilization of tropical legumes, such as sunn hemp, may allow for greater biomass production and N accumulation during the available growing season between fall harvest and onset of winter in temperate climates (Mansoer et al. 1997).

3.2 Weed control with legume cover crops

Weed control obtained through legume cover crops has been well researched for a variety of cash crops (Caamal-Maldonado et al. 2001; DeGregoria and Ashley 1986; Teasdale 1988). Common legume covers have been shown to suppress growth of many species like pigweed (*Amaranthus* spp.), foxtail (*Setaria* spp.), and morningglory (*Ipomoeae* spp.) (Collins et al. 2007; Teasdale 1988; White et al. 1989). Either as a ground cover or through allelopathy, as noted in subterranean clover (*Trifolium subterraneum* L.), weed control achieved through legume cover crops has the potential to reduce early-season herbicide use in agricultural systems (Hartwig and Ammon 2002; Leather 1983; Mosjidis and Wehtje 2011). However, in most climates, the inability to produce high biomass with winter legumes, coupled with rapid decomposition, weed suppression is largely obtained during active cover growth and just after cover crop termination (Reddy 2001; Teasdale 1996). The use of sunn hemp immediately behind an early harvest summer cash crop like corn (*Zea mays* L.) may allow for extended post-harvest weed control through increased biomass production as well as slower decomposition rates in comparison to some other legume choices (Cherr et al. 2006; Cobo et al. 2002; Mansoer et al. 1997).

4. Sunn hemp

Sunn hemp, or Indian hemp, has become an important crop in regions such as India and Brazil that have climates well suited to the tropical, herbaceous annual (Bhardwaj et al. 2005; Duke 1981) (Figure 2). Typically utilized as a green manure due to its nitrogen accumulation, sunn hemp is also grown as a fiber crop; it can also be grown for forage since this *Crotalaria* species is nontoxic to animals (Rotar and Joy 1983). As a vigorously growing, relatively drought tolerant plant species, sunn hemp has been shown to thrive in a variety of soil types and with variable rainfall, but it is still most successful in tropical or subtropical environments (Wang et al. 2002b).

The utilization of this species in cooler, temperate climates, such as those found in the continental United States (US), began in the early 1930's in response to sunn hemp's potential as a green manure and for suppression of root-knot nematodes (Cook and White 1996; Cook et al. 1998; Dempsey 1975). At the onset of World War II, increased demands for rope fiber drew more attention to sunn hemp as an alternative for imported cordage material (Cook and White 1996; Wilson et al. 1965). During the 1950's and 1960's, US research placed particular emphasis on sunn hemp production as a quickly-renewed source of fiber for paper materials (Nelson et al. 1961). Although most attention for nonwood fiber sources has been concentrated on kenaf (*Hibiscus cannabinus* L.), some research continues to identify sunn hemp as a potential source that can be produced in the US, particularly in Hawaii, southern Texas, and south Florida (Cook and Scott 1998; Webber and Bledsoe 1993). In temperate regions of the US, however, more recent research has evaluated the cover crop potential of sunn hemp as a frost-terminated, late-summer alternative to winter legume covers such as clover and vetch or between crop harvest and cereal cover crop planting (Balkcom and Reeves 2005; Mansoer et al. 1997).

4.1 Sunn hemp cover crops

Sunn hemp is readily used as a rotational crop in tropical regions with cash crops such as rice, cotton, and corn (Purseglove 1974). Its value as a cover crop is due to its biomass production, N accumulation, reduced pests and pathogen infestation, and weed suppression achieved when planted (Wang et al. 2002b). While sunn hemp is not winter hardy, its adaptability to various soil types and precipitation amounts has allowed sunn hemp to be grown in temperate regions as a green manure (Dempsey 1975). In the US, sunn hemp was used in this manner during the 1930's until reduced seed availability caused interest in the crop to diminish (Cook and White 1996). Recently, sunn hemp has again received attention as a potential alternative to winter annual legume cover crops in these temperate climates (Balkcom and Reeves 2005; Mansoer et al. 1997). Sunn hemp's vigorous growth and nitrogen production can provide needed ground cover to control erosion and an N source to succeeding cash crops. To fully utilize sunn hemp nitrogen release, investigations have also been conducted to determine the suitability of sunn hemp grown as a late summer cover crop between harvest and winter planting of cash crop or cereal cover crop (Balkcom et al. 2011; Creamer and Baldwin 2000; Schomberg et al. 2007).

The rapid growth of sunn hemp in a relatively short period of time allows for a relatively high amount of biomass production prior to the onset of cool temperatures in mild climates across the southeastern US. Previous research has reported sunn hemp biomass to average between 1 and 9 Mg ha^{-1} in 45 to 90 days after planting, respectively (Mansoer et al. 1997; Morris et al. 1986; Schomberg et al. 2007; Reeves et al. 1996; Yadvinder et al. 1992). Although environmental conditions affect potential biomass production, substantial amounts of biomass can be achieved under typical late-summer and autumn conditions to aid in erosion control, nematode and weed suppression, and N accumulation before frost occurs.

As a legume cover crop, sunn hemp can fix atmospheric nitrogen that is available over time to succeeding crops as it decomposes. With high fertilizer prices and sustainability concerns with synthetic soil amendments, the potential use of sunn hemp to provide nitrogen to crops such as cotton, corn, and rice has prompted research to determine N availability from a sunn hemp cover crop (Balkcom and Reeves 2005; Chung et al. 2000; Sangakkara et al. 2004; Schomberg et al. 2007). Nitrogen production with sunn hemp varies depending on many factors; however, reported N values in sunn hemp range between 110 and 160 kg ha^{-1} (Balkcom and Reeves 2005; Mansoer et al. 1997; Marshall et al. 2001). In most investigations, sunn hemp nitrogen content equals or exceeds N content of traditional winter legume cover crops (Reeves 1994).

With nitrogen release during winter months reported at approximately 75 kg ha^{-1}, remaining N may still be utilized by spring planted crops (Reeves et al. 1996). Due to winter nitrogen loss from leaching and utilization, however, an alternative scenario mentioned previously for sunn hemp use is to employ the crop as a late summer cover prior to grain cover crop or winter cash crop planting in the fall (Balkcom et al. 2011; Schomberg et al. 2007). Released nitrogen from sunn hemp residue would be available to the subsequent crop while minimizing N losses during winter months.

Fig. 2. The vigorous growth of sunn hemp cultivars developed at Auburn University, Alabama, can be seen here, 70 days after planting (Photo by J.A. Mosjidis).

4.2 Weed suppression by sunn hemp

It has been noted by many researchers that *C. juncea* can suppress populations of pests such as nematodes and vigorous weed species (Collins et al. 2007; Fassuliotis and Skucas 1969; McSorley et al. 1994; Taylor 1985; Wang et al. 2001). Much of the pest control potential of sunn hemp has focused primarily on nematode control of such species as *Meloidogyne* spp., *Rotylenchulus reniformis*, *Radopholus similis,* and *Heterodera glycines* (Birchfield and Bristline 1956; Desaeger and Rao 2000; Good et al. 1965; Marla et al. 2008; Robinson et al. 1998; Wang et al. 2004). Although some questions remain concerning suppression by sunn hemp for specific nematode species, extensive research has provided considerable knowledge as to how *C. juncea* reduces certain nematode populations (Halbrendt 1996; Kloepper et al. 1991; LaMondia 1996; Rodriguez-Kabana 1994; Wang et al. 2002b).

In contrast, weed suppression specifically by sunn hemp cover crops has been minimally investigated and only recently has it received more attention. General comments concerning the potential of sunn hemp to suppress weed species have been reported in several studies (Reeves et al. 1996; SARE 2007). Weed control by sunn hemp has been mostly attributed to vigorous plant growth and rapid shading of the ground (Duke 1981). In fact, Mosjidis and Wehtje (2011) demonstrated that there was a progressive reduction in weed biomass as a sunn hemp stand increased up to 100 plants/m^2. Furthermore, recent research has suggested allelopathic compounds released from sunn hemp also cause weed suppression (Adler and Chase 2007; Collins et al. 2007; Leather and Forrence 1990; Price et al. 2008). More research is necessary to determine the extent of allelochemical functions in sunn hemp.

Significant weed control can be achieved under moderate to high levels of sunn hemp (Mosjidis and Wehtje 2011; SARE 2007; Severino and Christoffoleti 2004). However, several weed species, such as nutsedge (*Cyperus* spp.), morningglory (*Ipomoea* spp.), and bermudagrass (*Cynodon dactylon*), are capable of thriving in a sunn hemp stand (Chaudhury et al. 2007; Collins et al. 2007; McKee et al. 1946). It is expected that, as sunn hemp utilization for cover crops and weed control grows, research efforts to fully understand weed suppression by *C. juncea* will continue.

4.3 Weed control in sunn hemp production

Little research has been conducted to determine weed control strategies in sunn hemp production. *C. juncea* grown as a green manure or cover crop typically does not require extensive weed management but production of sunn hemp for seed production may benefit from additional weed control practices. Due to sunn hemp's rapid growth and possible allelopathic effects, it can be easily established and can out-compete neighboring weed species. In fact, areas that rely on hand removal of weed species in agricultural productions generally do not employ this practice in sunn hemp grown for fiber, since weed competition is minimal (Chaudhury et al. 2007). However, in regions that utilize herbicides for weed control, early season weed suppression with herbicide applications may increase seed production in sunn hemp stands.

At present, no herbicides are labelled for use in sunn hemp production, but research by Mosjidis and Wehtje (2011) identified a preemergent herbicide, pendimethalin, as a potential treatment that would provide effective weed control during establishment. This research also found that sunn hemp could also tolerate 2,4-DB as a postemergent application (Mosjidis and Wehtje 2011). Imazethapyr was also determined to be safe for use in sunn hemp and effective against yellow nutsedge (*Cyperus esculentus* L.), which is not well suppressed by sunn hemp (Collins et al. 2007; Mosjidis and Wehtje 2011). With advancements in sunn hemp breeding and increased utilization of this species in a broader geographical range, continued research efforts to determine additional herbicide programs will be critical for successful production in the future.

4.4 Breeding and seed availability

As a native tropical species, sunn hemp use in temperate regions faces some challenges. Although sunn hemp experiences rapid vegetative growth in a short time frame, viable seed production typically requires a longer season than can be achieved before winter conditions in temperate regions (Li et al. 2009)(sunn hemp seed pictured in Figure 3). The lack of seed production outside of tropical and subtropical climates severely limits seed availability to producers in cooler climates. Moreover, with seed costs ranging from $90 to $130 (US) per hectare, implementation of *C. juncea* as a cover crop can be an expensive task for growers (Li et al. 2009; Petcher 2009).

Fig. 3. Sunn hemp seed production can yield 450 to 1000 kg of seed per hectare (Photo by J.A. Mosjidis).

A good deal of breeding research has been conducted in countries throughout the world that grow sunn hemp for fiber production (Kundu 1964; Ram and Singh 2011). In India, particularly, cultivars are developed for high fiber yield and resistance to wilt diseases (Chaudhury et al. 2007). Most commonly used in this region is 'Kharif sunn' or 'K-12' which produce high yield of good quality fiber (Chaudhury et al. 2007). Other important cultivars in India include 'SS-11' and 'T-6' which is a day-neutral variety, while most varieties are short day plants (Chaudhury et al. 2007). In other regions of sunn hemp production, varieties such as 'Somerset' in South Africa and 'KRC-1' in Brazil are commonly used.

Due to elevated seed costs and limited seed production in the US, sunn hemp breeding research has focused on developing a *C. juncea* cultivar that can produce seeds in climatic conditions prevalent in the southeastern US. For successful seed production in traditional sunn hemp regions, characteristics of seed production locations should typically be below 24° N latitude, not fall below 10° C, have ample sunlight and not receive rainfall during fruit set (Chaudhury et al. 2007). In cooler climates above this latitude, temperatures below optimal usually occur before sunn hemp seed can mature. The recent development of cultivar, 'AU Golden' and 'AU Durbin' has been shown to produce viable seed in these temperate regions; research is on-going to determine best management practices for implementing these sunn hemp cultivars (Balkcom et al. 2011; Mosjidis 2007, 2010).

5. Conclusions

The progression of agricultural systems towards more sustainable, yet high yielding production has required researchers to identify numerous alternative weed management practices that can be employed along with traditional weed control tactics. The use of sunn hemp as a cover crop, either as a substitute for winter annual legumes or as a late summer cover between harvest and winter crops, delivers effective weed control while providing ground cover and a nitrogen source for subsequent crops. Continued research with sunn hemp and crops similar to this species may provide even more benefits to weed control efforts in the future.

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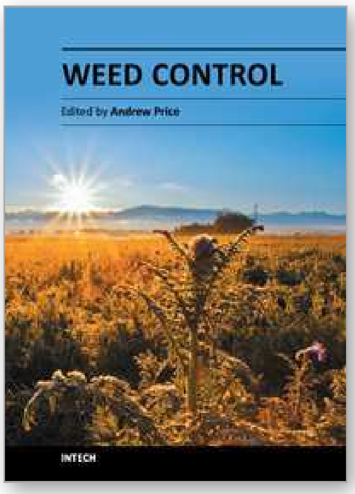

Weed Control

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Crop loss due to weeds has challenged agricultural managers since man began to develop the first farming systems. In the past century, however, much progress has been made to reduce weed interference in crop settings through effective yet mostly non-sustainable weed control strategies. With the commercial introduction of herbicides during the mid-1900's, advancements in chemical weed control tactics have provided efficient suppression of a broad range of weed species for most agricultural practices. Currently, with the necessity to design effective sustainable weed management systems, research has been pushing new frontiers on investigating integrated weed management options including chemical, mechanical as well as cultural practices. Author contributions to Weed Science present significant topics of research that examine a number of options that can be utilized to develop successful and sustainable weed management systems for many areas of crop production

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