# Plant Residues and Newspaper Mulch Effects on Weed Emergence And Collard Performance

THESIS

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By


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## Abstract

Small-scale urban agriculture production has become increasingly prevalent in the United States, due to an increased availability of abandoned property and demand for locally grown products. As with most agriculture production, weed suppression is a major concern for urban growers. Mulch is ideal for managing weeds because it is inexpensive and readily available. A variety of mulches have been found successful in conserving soil moisture, moderating soil temperature, suppressing weeds, and improving crop performance. These include continuous mulches such as black plastic, and particulate mulches, such as residues from cover crops. Disadvantages of black plastic, the industry standard, include impermeability and difficulty of removal and disposal. Alternatively, newspaper end-rolls (the unprinted remains of the newspaper printing process) may be a good alternative to black plastic in that they are permeable and biodegradable. However, newspaper has a high C:N ratio which can reduce soil fertility and crop growth. The primary disadvantage of plant residue is the large quantity necessary for adequate weed suppression, but combining newspaper and plant residues may provide adequate weed suppression with reduced mulch material and a lower C:N ratio. The objective of this research was to compare two continuous (sheet) mulches, newspaper and black plastic, with and without an underlying particulate mulch of killed cover crop. Field studies were conducted in 2011 and 2012 to determine the effects of mulches on soil moisture, soil temperature, weed growth, weed removal cost, and collard (*Brassica oleracea* L.) performance in a low input production system.

Mulch treatments were newspaper alone, black plastic alone, cover crop alone (no overlying sheet mulch), newspaper + cover crop, black plastic + cover crop, and a control (no cover crop or sheet mulch). A 60:40 mix of cowpea [*Vigna unguiculata* (L.) Walp.] (84 kg $ha^{-1}$) and buckwheat (*Fagopyrum esculentum* Moench) (107 kg $ha^{-1}$) was planted on June 7, 2011 and May 18, 2012, and was used based on the species' rapid growth and low C:N ratio. The cover crop treatments were killed with a tractor-mounted undercutting crimper attachment eight weeks after planting. In the sheet mulch treatments, a single layer of black plastic or two layers of newspaper were rolled over the cover crop residues or bare soil and anchored with soil and/or staples. Collards were transplanted after mulches were established at 24 plants $plot^{-1}$(August 5, 2011 and June 29, 2012). In general plots with newspaper sheet had lower soil temperature and higher soil moisture than black plastic. Adding newspaper over cover crop alone improved weed control and reduced hand weeding costs compared to cover crop alone. Plots with newspaper sheets yielded as well as plots with black plastic. The addition of a cover crop had no effect. Newspaper alone or the combination of newspaper + cover crop mulch should be considered for further research because of its positive impact on soil moisture and soil temperature and its potential to suppress weeds and improve crop performance with modifications to cover crop management practices.

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# LITERATURE REVIEW

## 1. **Introduction and Overview**

Agricultural production in the urban environment is becoming ever more popular and prevalent in the developing world as well as the United States because of increased abandoned property, increased demand for agricultural products grown in close proximity to communities, a desire to grow food to offset food expenditures due to increased cost of produce, and the simple interest in growing food. The urban environment, however, can be a difficult place to grow food. Although space is becoming more available, there are not large contiguous spaces in which an individual or group of individuals can produce a large amount of food. Urban substrates vary greatly in their composition from fine dark soils with high organic content to substrates composed primarily of rubble from leveled structures.

Temperatures in the urban environment increase faster and are often higher than those in rural areas. There is often a lack of a water source on site and the cost of restoring a water tap is excessive. Urban farmers are often limited by their access to agricultural implements, capital, processing facilities, and even experience. Growing crops in close proximity to people, plus an aversion to the use of chemicals, influences many urban farmers to produce food using organic practices.

Weed management based on organic standards and practices attempts to avoid the use of synthetic pesticides to increase plant productivity. Instead, the focus is on natural products or processes to limit the negative effects that weeds and other pests pose to crops. There are a variety of weed management practices that are used in organic agricultural systems and are accepted by federally defined organic standards. Methods such as manual removal, plowing, cultivation, space intensive planting, intercropping, organic-certified herbicide application, flame weeding, mulching, and roller crimped plant material can be used alone or in various combinations.

The most common, and oldest, organic weed management practice is mechanical removal. Mechanical removal can be as advanced as using heavy machinery with precise tool settings to remove weeds between crop plants, or as simple as removing weeds by hand. Use of heavy machinery is not possible for most urban farmers because they don't have the capital for purchase, maintenance, or the means for storage. Removing weeds by hand is both labor-intensive and expensive, especially if hired labor is a component of production.

As an alternative to planting crops in traditional rows in which plants within a row are spaced close together and individual rows are spaced wide apart, space-intensive planting involves growing crop plants in a triangular pattern wherein all plants are planted equidistantly from one another. The goal of this method is to maximize the use of a space, and to achieve canopy closure by the crop so that weeds are shaded out and suppressed. This method can be labor intensive during establishment, for it is time-consuming to plant in such a pattern and because weeds must be removed manually before canopy closure is achieved.

Closely related to space-intensive planting is intercropping. Intercropping is a method by which at least two crops are planted in close proximity to one another, with the goals of crop diversity, integrated pest management and attaining a high land equivalent ratio. Land equivalent ratio is a concept used when comparing the output of a multiple crop field versus a field planted in a single species, a monocrop. Intercropping relies on years of testing to determine which crops grow best in the region, how well will these crops grow together, and how such a complicated planting arrangement will affect crop rotation.

Another weed management strategy is to use organic-certified herbicides. Organic-certified herbicides are naturally derived compounds, mostly from plants, that when applied as a spray to weeds, can cause significant damage to weed tissue ranging from impediment of weed growth to weed death. These compounds are typically non-selective, contact herbicides, meaning that these compounds affect all plants negatively and that the effect of the compound is limited to where it is applied. They tend to be effective only on young, actively growing weeds and can damage crop plants if misapplied. They are also expensive, and application is time consuming when compared to other herbicides.

Flame weeding uses apparatuses that either put flames in direct contact with weeds, or heat up a plate or cone that concentrates heat waves toward the weeds. Flaming increases the temperature at the surface of the plant and disrupts cell membranes, leading to deterioration, wilting, and tissue death. Flame weeding can be an effective means for weed control; however, it relies on expensive specialized equipment and fuel.

Mulches, another weed suppression option, are materials that act as a physical barrier to resources that weeds depend on for germination, growth, and development such as water and sunlight. Mulches are applied on the surface of the soil in various ways and depths to create this barrier to weeds but not to the crop. Rolled and crimped plant material can be used as mulch for weed suppression in crops. This method relies on growing a densely planted cover crop which is killed and flattened into a vegetative mulch layer by a specialized roller-crimper implement before the next crop is planted. This method is expensive and specialized machinery is needed. In addition, a high seeding rate of cover crop is essential, the cover crop needs to be completely killed, and new crop plants need to be able to emerge from under the resulting mulch layer. Also, any surviving cover crop plants need to be killed before they set seed in order to prevent the subsequent establishment of weedy volunteer plants.

Finding the best weed management strategy in a given situation depends on the resources available and the environment in which crop plants are cultivated. Increased knowledge and advances in technology will improve the weed management strategies of organic farmers (Bond and Grundy, 2001).

An ideal strategy for urban farmers to manage weeds would be inexpensive, environmentally sensitive, organic-certified, and readily available. Of the strategies mentioned above, mulches fit these criteria. In addition, mulches are used for a variety of purposes: weed suppression, crop yield improvements, soil temperature regulation, and water retention. There are a variety of mulches ranging from paper mulch, to repurposed plant residue, and black plastic.

The goal and focus of this research was to explore the management of weeds in an autumn collard (*Brassica oleracea* L.) crop. The system tested included a mixture of two summer season cover crops that were intended to suppress weeds and control erosion before collard planting. After the cover crop was undercut and crimped, it may have provided additional benefits including nutrient mineralization, increased soil organic matter, and weed suppression after the collards were planted. The cover crops were used in treatments as 1) a stand-alone mulch, 2) in combination with newspaper as a mulch, and 3) in combination with black plastic as a mulch. These treatments were compared to 1) black plastic alone, 2) newspaper alone, and 3) no mulch. The treatments were compared for their efficacy of weed suppression, effects on soil moisture content and soil temperatures, and effects on collard crop performance.

### Urban Agriculture

Urban agriculture can be defined broadly as the growing of plants in an environment that is within the incorporated boundaries of a city. The scale of such a growing operation can be as small as a few square feet in a patio garden, and as large as multiple acres of arable land within city limits. It is not necessary to have an extensive education in plant biology or a background in plant production in order to undertake urban production. It simply takes space, a medium for plant growth, plant material, water, nutrients, time, and most importantly, desire. Where commodity agriculture is driven by classic factors such as land, labor, and capital, urban or civic agriculture is driven by social, economic, and demographic factors (Lyson and Guptill, 2004). One of these social factors is people's desire to find a link from a rural past to an urban present. Saldivar-Tanaka and Krasny (2004) found that urban gardens serve as a connective medium between generations and immigrants to their cultural heritage and also serve as social gathering places. Civic agriculture encourages citizenship and environmental awareness (DeLind, 2002). House-lot gardens in Santarém, Pará, Brazil not only link rural and urban communities and strengthen familial and social ties, but they also serve as a supplementary source of income, supporting families in both rural and urban locations (WinklerPrins, 2002).

Unique historical farm practices can influence how space is used in the city. In Mexico, chinampas are plots of land created by alternatively layering soil and plant material in shallow waterways. In Mexico City these chinampas still exist and allow farmers to maintain economic stability as the land around them changes (Torres-Lima et al., 1994). Another example is found in Havana, Cuba, where urban agricultural production has emerged after years of economic embargo, and with political support this has led to increased levels of food security (Altieri et al., 1999). Historical and political events have shaped urban agriculture.

An increased need for urban agriculture has arisen as food security has become increasingly threatened. A basic definition of food security is the ability of a person to access enough clean and nutrient-rich food in order to satisfy their daily nutritional needs and lead a healthy life. There is great concern regarding the amount of food that will be available in the future for the inhabitants of cities, nations, continents and the world. As the population and the cost to produce and ship food increase, issues of food security need to be addressed. Food deserts are created when communities have limited or no access to fresh, high quality produce. The greatest mitigating circumstances that influenced the food purchases of low-income individuals in both rural and urban areas were high price, low quality, and limited choice (Hendrickson et al., 2006). Residents without motor vehicles are at a great disadvantage because grocery stores are moving to the periphery or even outside of the community (Furey et al., 2001).

Food security is not just restricted to quantity of food products but also quality. Kortright and Wakefield (2011) found that overall health and well-being improves with the inclusion of a garden in the residential landscape, regardless of income level. Accessibility and the ability to acquire, and possibly produce, fresh meats and produce leads to a more well-rounded consumption of these goods and maintains a system of reciprocal non-market food exchange between friends and family (Morton et al., 2008). However, as local food costs are increasing, the bases of food security issues dealing with equity, community, accessibility, and affordability are being ignored (DeLind, 2011). It has been suggested that achieving food security relies upon an integrated strategy that includes localized and community supported food systems as well as the established government support system (Allen, 1999).

There are those who believe that a reformation in policy, especially the legalization of food cultivation practices within the confines of the city, needs to be enacted in order to invest in future food security (Bryld, 2003). However, there are food safety concerns with the actual production of food for dissemination to the public. Not everyone feels comfortable participating in the local food system, especially one involving animal husbandry. But as involvement with urban agriculture increases the inclusion of the urban food system has potential to be integrated into government policy, especially allotment of space by city planners (Pothukuchi and Kaufman, 1999).

### 1.3 Mulches

A mulch can be broadly defined as any material placed on the soil surface in proximity to where desirable plants are grown. Mulches act as a soil cover with the objective to prevent the loss of moisture by evaporation, decrease or prevent the loss by erosion of soil particles in the event of high wind or heavy rain, suppress the emergence of weeds by creating a physical barrier that weeds cannot penetrate, prevent the exposure of weed seeds to light and water required for germination, and increase soil nutrients as they decompose. Mulches may be applied in various physical forms, including particulate matter and continuous sheets. Particulate mulches are mulches that are comprised of small pieces of material applied en masse to create a deep porous layer on the soil's surface. Sheet mulches are typically thin, homogeneous layers of material that, when applied to the soil surface, create a uniform protective barrier. Both particulate and sheet mulches can be made of natural or synthetic materials. Natural particulate mulches include wood chips, straw, coir, shells, leaves, gravel, shredded paper, compost, and even dry soil. In contrast, an example of a synthetic particle mulch is recycled rubber buffings, which are a recycled from old tires. Examples of natural sheet mulches include woven, plant-based textile sheets and paper rolls. Synthetic sheet mulches are typically made of plastic and can vary in thickness and color.

### Paper mulch

Paper mulch is a natural mulch that is desirable to use because it is biodegradable, easy to apply, and can be left in the field after harvest. Depending on the timing and application depth of newspaper mulches, weed management and tomato (*Solanum lycopersicum* L.) yield levels comparable to those obtained with synthetic chemical treatments can be achieved (Monks et al., 1997). There are three causes for concern when using paper mulches: 1) they can degrade too quickly under field conditions, 2) paper when installed has a tendency to rip, and 3) paper may immobilize soil nitrogen as it degrades. Paper mulches can be less expensive than other mulches, however. Munn (1992) reported that wheat (*Triticum aestivum* L.) straw cost twice as much as newspaper, although they were comparable in weed suppressive ability.

Some researchers have reported that newspaper mulch is less effective for weed suppression than other mulches. Collard yield was consistently lower in shredded newspaper mulches when compared to bare soil, wood chips, and black plastic, and collards in the newspaper treatment also contained less tissue nitrogen at harvest than any of the other treatments (Guertal and Edwards 1996). In contrast, Munn (1992) found that the application of shredded newspaper was an inexpensive alternative weed control method in corn, and that it did not negatively affect corn performance in comparison to other weed control methods.

Sanchez et al. (2008) found that, eight weeks after application, though newspaper mulch degraded completely, this did not compromise weed suppression or cucumber (*Cucumis sativus* L.) yield. Others have reported that paper impregnated with oils delayed paper degradation; however, the oil allowed light to penetrate through the paper, thereby allowing weeds to grow and causing the paper to tear at rates similar to untreated paper (Anderson et al.1996). Weather conditions may play a part in the effectiveness of paper mulches. Cirujeda et al.(2012) found that sheet mulches composed of paper, black plastic, and degradable plastic were most effective at suppressing weeds during seasonal conditions that were dry. Inclement weather damaged the mulches, which led to decreased weed suppression.

Research has shown that the combination of newspaper with other substances can increase weed suppression and crop yield. Pellett and Heleba (1995) found that by wetting chopped newspaper and then applying pressure to it via a lawn roller, a mat was created that resisted weather effects; this resistance was further improved with the application of a tackifying agent. Applying phosphorus to geranium (*Pelargonium* x *hortorum* 'Ringo') plants mulched with newspaper byproducts improved plant performance when compared to plants without newspaper mulches (Smith et al.1997). Shogren (2000) found that by impregnating paper material with modified vegetable oil products, paper integrity could be increased an extra four weeks. Using polymers to stabilize and entangle particulate mulches, such as shredded newspaper, improves their ability to impede weed growth, retain water, and moderate soil temperature (Shogren and David, 2006). Yet, there are still drawbacks to many combinations. Paper sheet mulches, treated with polyethylene and wax, allowed for easier application via mechanical mulch laying equipment, but were cost-prohibitive and unsuitable for use with a mechanical water wheel planter (Coolong, 2010).

Newspaper used as mulch has been found to retain soil moisture. Smith et al. (1997) reported that when comparing two recycled paper products, paper pellets and crumble (pellets put through a granulator), to other mulches including pine (*Pinus* L.) bark, pine bark plus Geogard™ weedmat (a permeable fabric used to suppress weeds and provide erosion control), and herbicide application, that soil moisture levels across treatments were not significantly different. In 1997, Monks et al. found that when compared to an un-mulched control, mulches including pine bark, newspaper, or black plastic maintained higher soil moisture.

### Plastic Mulch

Black plastic is used as mulch in both large and small-scale agriculture and is effective in improving crop yield and suppressing weeds. Research comparing black plastic and natural mulches showed that bell pepper (*Capsicum annuum* L.) stands were higher in treatments with grass and peanut (*Arachis hypogaea* L.) living mulches as well as municipal solid waste and wood chip mulches, but yield was highest when peppers were grown in black plastic mulch (Roe et al.1994). However, black plastic is difficult to remove from the field and dispose of or recycle (Hemphill 1993), and it allows less moisture from overhead irrigation or rainfall to penetrate the soil and reach roots. Furthermore, it results in higher soil temperatures than bare soil or natural mulches, and high soil temperatures can be detrimental to crop yield. A combination of cultivation and wood chip mulch application in aisles, in conjunction with black plastic, improved weed suppression and yield of bell peppers (Law et al., 2006). Coolong (2010) found that black plastic mulch resulted in the highest soil temperatures compared to several paper-based mulches. Monks et al. (1997) reported that black plastic not only produced the highest soil temperatures of all mulch treatments but that it maintained higher soil temperatures even when exposed to cooler nighttime temperatures.

### Plant Residues as Mulch

Plant residues have been found to successfully suppress weeds. Plant residue mulching is desirable in that instead of importing mulch to apply to the field, it can be material from the previous season's harvest that remains for mulching the next crop (Erenstien, 2002). Plant residues used as mulch can indirectly decrease weed seed bank inputs and future weed emergence by increasing the presence of seed predators (Pullaro et al., 2006). Early establishment and late termination of cover crop species have been shown to increase weed suppression as well as decrease weed emergence in established plots (Mirsky et al., 2011).

Steinmaus (2008) reported that cover crops suppressed weeds as well as conventional methods (conventional tillage and herbicides) in vineyards, and that the overall profit margin was greatest in cover cropping systems. The ability of barley to suppress weeds is directly correlated to varietal vigor, or the ability to produce large quantities of plant biomass (Christensen 1995); however, in one study excessive levels of rye (*Secale cereale* L.) biomass (>9,000 kg $ha^{-1}$) contributed to lodging and seed yield reductions in soybean (Smith et al., 2011). Additionally, Ryan et al. (2011) found that having a higher seeding rate with low stand biomass is more effective at suppressing weeds than lower seeding rates producing higher biomass. Also, it is effective to use a roller-crimper when working with plant residues. When using a roller-crimper to kill a cover crop that is to be used as mulch it is best to roll/crimp cover crops at the anthesis stage or later (Ashford and Reeves 2003).

Soil can be improved by the use of plant residue mulch. Mulch application increased the populations of earthworms, reduced leaching of nitrogen, and replaced lost organic matter in temperate agricultural fields (Schonbeck et al., 1998). Mulvaney et al. (2010) found that the placement of plant residues on the soil surface maintained soil nitrogen levels longer than when residues were incorporated. Mulch-covered soil, even at low rates of mulch application, reduced soil erosion by 97% and reduced post-harvest N-leaching in organically grown potato plots (Doring et al., 2005). Mary et al. (1996) determined that decomposition of both incorporated and surface residue plant material increased with the amount of available nitrogen within the soil.

Plant residue mulches also affect soil temperature. Lal (1974) found that soil temperature was reduced by rice straw and forest litter mulch, and suggested that high temperature in shallow soil depths can have a negative effect on seedling vegetative productivity. Kohnke and Werkhoven (1963) reported that soil temperature under wheat straw in the winter was greater than ambient temperature, and that in the spring, summer, and fall, average soil temperatures under straw were lower than ambient temperatures. However, other studies show that mulches composed of natural materials can lower temperatures to the point where crop performance is compromised. For example, Pedreros et al. (2008) found that straw mulch reduced soil temperatures up to 6°C compared to bare soil and other natural mulches, causing raspberries to produce fewer and smaller primocanes resulting in reduced fruit yield.

Crop yield can also be affected by plant residue mulch. Cowpea mulch treatments resulted in higher marketable yield of no-tillage onions in comparison to foxtail millet [*Setaria italica* (L.) P. Beauvois] mulch and bare ground, and supplementing mulch treatments with soybean [*Glycine max* (L.) Merr.] meal achieved even higher yields (Vollmer et al., 2010). Plant residues with lower carbon to nitrogen ratios, as well as high micronutrient content, improved okra yield as well as increased nutrient levels in the pods (Moyin-Jesu 2007). A significant increase in catnip yield was observed when treated with plant residue mulches (Duppong et al., 2004). Leaf mulch contributed to increased pumpkin fruit size, fruit number, and number of orange fruits when compared to a no-mulch, bare soil treatment (Wyenandt et al., 2008).

One drawback to using plant residue mulches is that they degrade quickly, beginning with the leaves, leaving gaps between the remaining stems, which degrade at a much slower rate than the leaves. The gaps allow light to penetrate to the soil and provide empty space for colonization by persistent weeds (Reberg-Horton et al. 2005). There is a correlation between a weed's ability to grow around particulate mulch material and the tendency of certain mulches to leave large spaces and gaps that such weeds find advantageous (Teasdale and Mohler, 2000). Crops that are poor competitors (is this what you had in mind?) such as onions may not be ideal to grow when considering the use of natural mulches as a weed suppressing agent. Boyhan et al. (2006) found that natural mulches [ pine needles, oat (*Avena sativa* L.), wheat and bermudagrass [*Cynodon dactylon* (L.) Pers. hays] ] lodged in onion tops and reduced plant stands and yields.

Little research has been done on the effects of a combined use of paper and plant residues as mulches. Combining these treatments could increase weed suppression by filling gaps left by degraded leaves, lowering the C:N ratio by including higher N plant residues, allowing water to penetrate to the soil and root zone, and keeping soil temperatures constant and at a level conducive to high crop productivity.

### Mechanisms of weed suppression by mulches

The application of particulate mulches can vary in depth according to the mulch's proximity to the desired crop plants. Often, though not intentional, there is an increase in thickness from the crop plant to the edge of the bed. This thickness allows for three mechanisms of weed suppression to come into play: light extinction, water impediment, and seedling exhaustion. Several weed species such as *Rumex crispus*, *Senecia jacobea*, and *Sonchus asper* require light for seed germination (Wesson and Wareing, 1969). Simply cutting off this resource will impede the germination and thus establishment of these weed species. A similar statement can be made about water impediment. Either the mulch depth or another characteristic, such as water-repellency, can prevent water from reaching the soil and thus prevent weed seeds from imbibing and germinating.

Seedling exhaustion involves a seedling's inability to emerge through a mulch layer and become photoautotrophic before the seed reserves have been exhausted. The exhaustion of seedling or embryonic reserves is in direct relation to seed size. Smaller wheat and weed seeds interred in the soil deeper than 6 cm failed to emerge due to lack of embryonic reserve or abundance of soil cover (Bremner et al. 1963, Benvenuti et al 2001). The nature of the mulch can be such that the inter-particulate space is limited or discontinuous and creates a path so tortuous that a seedling exhausts all of its stored resources before reaching light. Therefore, Teasdale and Mohler (2000) suggest that the mechanisms most responsible for seedling emergence suppression are physical impedance and light deprivation.

Some plants emit chemical substances (allelochemicals) that prevent the germination or establishment of other plants. Allelopathic plants such as barley (Vasilakoglou et al. 2009), rye (Gavazzi et al, 2010), or black walnut have been effective used as mulches in suppressing weeds due to their prevention of germination and/or root growth of other plants. Cowpea residue and extract was also found effective in reducing weed emergence of livid amaranth [*Amaranthus blitum (ssp Oleraceus)*] and goosegrass (*Eleusine indica)*; however, it also reduced productivity of both tomato and pepper plants (Adler and Chase 2007). The use of phytotoxic legume species jumbiebean [*Leucaena leucocephala*(Lam.) de Wit] and wild tamarind [*Lysiloma latisiliquum* (L.) Benth.] as living mulches resulted in weed biomass reduction as well as an increase in corn yield over a two-year period (Caamal-Maldonado 2001).

### 1.4 Collards

Collards (*Brassica oleracea* L.) is a biennial species belonging to the Acephela group in the Brassicaceae family. Acephala is derived from the Greek word ακέφαλος, phonetic spelling akéfalos which, when translated, means 'without a head'. Other members of the acephala group are kale and spring greens. Members of the acephala group are characterized by a central upright stalk, edible leaves that grow from the stalk that do not develop a head like cabbage, with a leaf color ranging from light green and/or blue to dark green.

In the United States collards are grown primarily in the South and are an important crop to small farms that sell fresh, seasonal produce-to-go at farmer's markets, to local grocers, and to consumers that belong to cooperative community supported farms. Collards are a cool-season crop that can be produced in both spring and fall seasons. Although collards are tolerant to higher growing temperatures, they display more vigorous growth at low temperatures. Sudden changes in temperature can have adverse effects on spring-grown collards, one of which is bolting. Bolting is the premature entrance of a plant into the reproductive stage. In collards this means that instead of allocating resources to the production of leaves, the central stalk extends rapidly in a vertical direction and produces a flower stalk. The leaf growth rate decreases and glucosinolate levels increase and produce a bitter flavor in the leaves. Bolting occurs when collard plants are exposed to an extended period of cold temperatures, of 4.4 °C (40 ° F) or lower, followed by progressively increasing temperatures (Peirce, 1987). The best way to decrease the chances of bolting is to select varieties such as 'Vates' and 'Champion' that have lower incidences of bolting in fluctuating temperatures (Olson and Freeman, 2008). It is imperative for collard crop improvement to identify and preserve landrace cultivars, thus maintaining a diverse gene pool to prevent the negative effects of genetic bottlenecks (Farnham et al., 2008).

Collards perform well in deep soil that is slightly acid to neutral (pH 5.5 to 6), highly fertile, and well-drained (Motes et al., 2012). In preparing a field for collard cultivation, it is recommended that existing weeds be destroyed and plant residues, manure, and debris be completely incorporated into the soil. Residues such as the previous crop and leaves can harbor insects and disease that can lead to deleterious effects on the crop. Residues can also contaminate harvested materials leading to a decrease in post-harvest quality rating and foodborne disease vectoring. The mismanagement of manure spread on fields greatly increases the contamination of vegetable crops by bacteria such as *Escherichia coli* (Mukherjee et al., 2007).

When intercropped with cowpea and applied with 160 kg $ha^{-1}$ of N, collards yielded more than when planted alone with the same fertilizer rate (Itulya et al., 1997). Intercropping collards with onions increased the land equivalency ratio when compared to a collard crop alone (Mutiga et al., 2011). The optimal collard population for maximum yield is between five to seven plants per square meter (NeSmith 1998). In another study, highest yields were achieved when collard plants were fertilized with high rates of N and spaced in a high density planting of 15 cm within the row (Dangler et al., 1993).

There are several ways to manage weeds in collards, including the use of herbicides, soil solarization, and mulches. In direct-seeded collard production, S-metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(1*S*)-2-methoxy-1-methylethyl]acetamide] applied preemergence at 0.45 kg ai $ha^{-1}$ controlled large crabgrass, goosegrass, hairy nightshade, and common purslane, and caused little to no damage to collards (Norsworthy and Smith, 2005). However, collards exposed to cold temperatures were more susceptible to oxyfluorfen than those grown in warm temperatures (Harrison and Peterson, 1999). Soil solarization, the use of clear plastic to increase temperatures at the soil surface, is an effective preplant burn-down treatment for collard production. Solarizing the soil before planting collards in Alabama resulted in a 91% reduction of weeds and increased crop productivity (Stevens et al., 1990). Hairy vetch (*Vicia villosa* Roth.), grain sorghum [*Sorghum bicolor* (L.) Moench spp. *Bicolor*], and sudangrass [*Sorghum bicolor* (L.) Moench ssp. *Drummondii*] were effective at suppressing early season weeds in kale (closely related to collards), with kale yields being the highest in treatments planted with hairy vetch (Mennan et al., 2009). Continuous use of cover crop residues and natural mulches increased weed suppression effectiveness over a three-year period in no-tillage collard plots (Mulvaney et al., 2011).

Research has shown that mulches cannot adequately suppress insect pests in cruciferous crops (Masiunas et al., 1997). Collards are especially susceptible to insect damage. Whiteflies not only can cause damage to collards but are also vectors of transmittable viruses. Whitefly populations are lowest on collard cultivars that are glossy and that have been bred for resistance. Even when dispersed within a population of resistant collard types, non-resistant types are still subject to high whitefly populations (Jackson et al., 2000). A whitefly biocontrol study conducted by Stansly et al. (1997) revealed that predation of whitefly by *Encarsia pergandiella* was lower on collards when compared to sweet potato and tomato. Another study showed that whitefly populations on collards were correlated directly to plant quality and stages of maturity (Liu, 2000). As collard plants grew to optimal size, so did whitefly populations, and when collard sensescence began, whitefly population declined. A combination of fenpropathrin [cyano(3-phenoxyphenyl)methyl 2,2,3,3-tetramethylcyclopropanecarboxylate] (Danitol) and acephate [*N*-(Methoxy-methylsulfanylphosphoryl)acetamide] (Orthene) reduced whitefly populations resulting in increased plant quality and quantity of marketable collard leaves (Liu, 2000). When compared to commercial surfactants and crop oils, detergent with cocamide active ingredient controlled 95% of whitefly nymphs on collard plants (Liu and Stansly, 2000).

Another common insect pest on collards is the diamondback moth. When tested as a diamondback moth trap crop for cabbages, collards of waxy and glossy varieties were effective, for they both attracted moths more than cabbages. The effectiveness of collards as a trap crop for diamondback moth was attributed to high levels of plant volatiles that attracted the insect (Badenes-Perez et al., 2004). Intercropping collards with cover crops such as white clover has the potential to create an environment wherein predators such as red imported fire ant could be used to control diamondback moth (Harvey and Eubanks, 2004). LastCall™, a blend of Z-11-hexadecenyl acetate, 27%:Z-11-hexadecen-1-ol, 1%:Z-11-tetradecen-1-ol, 9%:Z-11-hexadecenal, 63%, and the insecticide permethrin (0.16% and 6% w/w of total formulated material, respectively, insect attractant, was found to be most effective in reducing pest damage caused by diamondback moth larvae when populations were already low, suggesting that there is an initial pest population threshold at which LastCall™ is effective (Maxwell et al., 2006).

### 1.5 Cowpea

Cowpea [*Vigna unguiculata* (L.) Walp.] is a warm-season dicotyledonous annual species belonging to the Fabaceae family. It is a species that can tolerate dry and hot conditions, as well as poor soils, making it well adapted to several biomes throughout the world. Like other members of the Fabaceae family, cowpea forms a symbiotic relationship with rhizobia, wherein the bacteria induce nodulation on the roots and derive nutrients from the host plant, and in return the rhizobia fix atmospheric nitrogen into plant-available form. These nodules can become very large, about the size of a nickel. Cowpea has an erect growth habit with a central stalk, and the trifoliate leaves are ovate shaped with stipules that are slightly pubescent. Cowpea can grow to a height of approximately 1.2 m, and has a tendency to lodge.

Cowpea is a multi-purpose vegetable primarily grown in the developing world, with limited production in the Southern United States where they are more commonly known as black-eyed peas. Vegetation and fruit are both harvestable units of cowpea. Vegetation is harvested primarily as young tender leaves, and fruits can be harvested either green or dry, whichever is culturally preferential or necessary. When planted as a monocrop, precision seeding is a common practice that can create a more uniform stand of cowpea that is more efficient to maintain and harvest than non-precision planted cowpea (Kahn et al., 1995).

Cowpea can be grown in mixed crop systems as a crop plant, weed suppressant, soil and nutrient conserver, and cover crop. In a mixed crop system it is grown in concert with commonly used crops such as cucurbit or maize species. In a mixed crop system with corn, cowpea can greatly enhance corn yields, total system land equivalency ratio, and both corn and cowpea total plant tissue nitrogen (PTN) levels (Saidi et al., 2010). Regular harvest of cowpea leaves increased corn yield and land equivalency ratio and lowered cowpea PTN while increasing corn PTN (Saidi et al., 2010). Cowpea intercropped with pumpkin (*Cucurbita moschata* Duchesne) had no effect on yield of long or short-vined pumpkin varieties; however, when grown with short-vined pumpkins, green-shelled cowpea yields exceeded 800 kg $ha^{-1}$ and demonstrated the potential for increased income to pumpkin farmers (Chesney et al., 1994).

Using cowpea as a pre-plant cover crop and incorporating it before tomato planting increased tomato yield and quality while reducing irrigation demand (Wang et al., 2005), thus leading to increased income, lower inputs, and lower soil nutrient leaching (Wang et al., 2005). Cowpea either incorporated or used as surface mulch improved lettuce growth and yield when compared to Sudangrass treatments, but muskmelons grown the following season had an adverse response to the mulch treatments (Wang et al., 2008). Hutchinson and McGriffen Jr. (2000) found that cowpea mulch reduced weed populations more than 80 or 90 percent while improving crop plant performance but not increasing yield. Extracts from cowpea had a negative effect on both weed and crop species, with the following species being especially sensitive: common chickweed, redroot pigweed, wild carrot, corn, tomato, and lettuce (Hill et al., 2006).

### 1.6 Buckwheat

Buckwheat (*Fagopyrum esculentum* Moench) is a multi-season annual dicotyledonous species of the Polygonaceae family. It is considered a pseudo-cereal crop for it is neither a grass nor a cereal. Buckwheat is characterized by a tall slender stalk with long, heart-shaped leaves growing upward in an alternating pattern. The stalk is reddish green and fleshy, and the leaves are light to dark green. It grows and matures quite rapidly, producing seeds continuously after reproduction begins. The seeds are hard and triangular.

Buckwheat is cultivated for many different purposes. It is principally grown as an alternative grain to cereals, for it lacks specific proteins, such as gluten, that are allergenic to some people. Buckwheat is also grown in cropping systems dependent on multiple crops and increased diversity for disease and pest control strategies. It is known to attract beneficial insects through prolific flowering, and it maintains beneficial organisms by producing a dense canopy for habitat. Platt et al. (1997) found that buckwheat planted in borders around a field increased natural pest enemy populations, creating a habitat sufficient for their survival. A higher population of parasitoid wasps and occurrence of parasitism occurred in plots containing buckwheat compared to plots maintained with herbicides (Stephens et al., 1998). Lastly, buckwheat has been used extensively in rotation and intercropping regimens as a cover crop that grows rapidly and in a dense population, out-competing weed species and earning the name ‘smother’ crop. It has the ability to sequester phosphorus, which upon senescence is released and available for future crop use. It also has a relatively low C:N (34:1) ratio when compared to other non-leguminous cover crop species.

When using buckwheat as a short, mid-season cover crop, establishment and weed suppression was found to be most successful if it was planted one week after light tillage to ensure a high germination rate (Björkman, 2006). Incorporated buckwheat provided 90% suppression of hairy galinsoga (*Galinsoga ciliata* L.), but it reduced crop performance of peas, chard, lettuce, and beans (Kumar et al., 2009). If the intended purpose is to use buckwheat as an intercrop, it is important to use the proper planting rate, 56 kg $ha^{-1}$, to achieve high levels of weed suppression without compromising the integrity and yield of the main crop (Treadwell and Creamer, 2000). Another possible use of buckwheat is in strip cropping. By planting alternating strips of buckwheat and muskmelon, melon yield losses were reduced by 70% when compared to a muskmelon-buckwheat intercrop (Amirault and Caldwell, 1998).

When using buckwheat in a cropping system as either a principal or auxiliary crop, growers should be aware of its tendency to produce several flushes of flowers and seeds, so there is not a predictable or consistent time to harvest for maximum yield. As a smother crop or cover crop, due to its low germination rate and slender plant architecture, it is necessary to plant buckwheat at high densities when compared to other more aggressive cover crops. The last note of caution is buckwheat's tendency to become weedy. It produces an abundance of seeds that over-winter well and germinate the following season.

### 1.7 Motivation for Research

Intense weed pressure causes crop yield losses in small-scale urban vegetable production. With this research I sought to understand the advantages and disadvantages of using newspaper in conjunction with a cover crop mixture in order to manage weeds in small-scale urban collard production. My approach to this research was to study the response of newspaper subjected to the external influence of weather events and weed pressure and the effects it had on collard performance.

Because the management of weeds dominates so much of a farmer's time, energy, and resources, I set out to find a practical weed management strategy for small-scale urban growers so that they can achieve their vegetable production goals. Hand-weeding, which is the principal means of weed management in urban production, can be expensive and time consuming. Cost of labor, scale of area in which vegetables are produced, and weed pressure are major factors in determining the cost of hand weeding (Melander, 1998). In fact, as each of these factors increases so does the cost of hand-weeding. The factor that is most important to my research question is weed pressure. If I can find the means to decrease weed pressure without increasing the cost of weed management, I can propose practical, accessible, and affordable strategies to help small-scale growers.

By decreasing the effort and cost of weed management, farmers benefit from the availability of time to focus on the other aspects of their farm needs, namely outputs. Output on a farm is measured by yield, which can be defined broadly as the amount of harvestable units that can be exchanged between participants in the fresh vegetable market. In the case of this research project, a harvestable unit is considered a single collard leaf. A single collard leaf must be up to the quality standard laid forth by the USDA, namely a collard leaf approximately 15-20 cm from petiole to leaf edge, of vibrant blue green color, tender texture, without any blemish or damage. The ideal outcome of this objective is to maintain yields that are comparable to or exceed those of weed-free plots.

High collard yields cannot be achieved by only decreasing or eliminating weed pressure. In order for collards to perform to their maximum potential, they must have sufficient water, nutrients, moderate temperature (18° to 23°C) and soil conditions, and high light quality. An additional objective of this research was to determine the effects that mulch treatments had on soil moisture and soil temperature. By analyzing the information acquired through field research, I can be better prepared to determine which mulch-based system will be of benefit to urban small-scale farmers.

# CHAPTER 2

# RESULTS AND DISCUSSION


**Chapter 2 Abstract**.

A cover crop mixture of cowpea [*Vigna unguiculata* (L.) Walp.] and buckwheat (*Fagopyrum esculentum* Moench) with and without other mulch treatments was compared to a no mulch control for its effects on soil moisture retention, soil temperature moderation, weed suppression, and collard [*Brassica oleracea* (L.) Acephala group] yield in a low input production system. Field studies were conducted in 2011 and 2012 at The Ohio State University Waterman Research Farm to compare the following mulch treatments: newspaper (the unprinted remains of the newspaper printing process) alone, black plastic alone, cover crop alone (no overlying sheet mulch), newspaper + cover crop, black plastic + cover crop, and a control (no cover crop or sheet mulch). The cover crop treatments were killed with a tractor-mounted undercutting crimper attachment eight weeks after planting. In the sheet mulch treatments, a single layer of black plastic or two layers of newspaper were rolled over the cover crop residues or bare soil and anchored with soil and/or staples. Plots with newspaper sheet generally had lower soil temperature and higher soil moisture than black plastic. Adding newspaper sheet over the cover crop improved weed control and reduced handweeding costs compared to the cover crop alone treatment. Collard yields in plots with newspaper sheet mulch were comparable to those in plots with black plastic mulch. The addition of a cover crop to sheet mulches had no effect on yield when compared to sheet mulches alone. Newspaper alone or the combination of newspaper + cover crop mulch should be considered for further research because of its positive impact on soil moisture and soil temperature, and its potential to suppress weeds and improve crop performance.

## INTRODUCTION

Small-scale urban agriculture production has become increasingly prevalent in the United States, due to an increased availability of abandoned property and demand for locally grown products. Several benefits come from urban food production. There is an increase of accessibility and availability of fresh food (Morton et al, 2008), overall community health and well-being is improved (Kortright and Wakefield, 2011), friend and family relationships are strengthened as well as connections to cultural heritage (Saldivar-Tanaka and Krasny, 2004), environmental awareness and citizenship is encouraged (DeLind, 2010), and possibilities for supplemental income are created (WinklerPrins, 2002).

As with most agricultural production, weed suppression is a major concern for urban growers. Mulch is attractive for managing weeds in urban settings because it is relatively inexpensive and readily obtainable, especially when derived from urban waste materials such as newspaper, municipal solid waste, and compost (Roe 1997). Recycled materials can not only reduce landfill disposal, but can also be effective as mulch. Studies have been conducted to enhance the effectiveness of recycled waste, particularly paper, as weed suppressant mulch (Anderson et al. 1996, Shogren 1999).

In addition to suppressing weeds, mulches have been found to be successful in conserving soil moisture, moderating soil temperature, and improving crop performance. Mulches can be placed in two categories: continuous and particulate. Within these two categories, there are a few common materials that are frequently used as mulch, including both black plastic and paper. Less common materials, such as plant residues, can also be used as mulch.

Black plastic functions as a continuous mulch and is the industry standard used in vegetable crop production worldwide. It is easy to apply, either by hand or with machinery, resists tearing, suppresses weeds (Law et al, 2006) and can improve crop performance (Roe et al, 1994; Guertal and Edwards, 1996). Newspaper mulches, both continuous and particulate, have been found to suppress weeds (Coolong, 2012; Cirujeda et al 2006; Sanchez et al, 2008) increase soil moisture (Monks et al, 1997), and achieve high yields (Cirujeda et al., 2006; Coolong, 2010). Paper can also be left in the field and incorporated. Plant residue mulch, a particulate, can be grown on site, cut, and then placed on the soil surface (Erenstein, 2002). Plant residues have been found to improve crop performance (Moyin-Jesu

2006, Akemo et al 2000, and Vollmer et al 2010), soil conditions (Schonbeck et al 1998, Mary et al 1996, Doring et al 2005), and weed suppression (Ryan et al 2011, Christensen 1995).

Mulches can have drawbacks, however. High ambient temperatures produced by black plastic can reduce plant populations (Roe et al, 1994; Guertal and Edwards, 1996). Black plastic is also non-biodegradable, and difficult to remove, dispose of, and/or recycle (Hemphill, 1993). Newspaper has a tendency to degrade quickly (Sanchez et al, 2008) and to have high C:N ratios (Edwards, 1997; Grassbaugh, 2007) which can lead to reduced yield and low crop tissue nitrogen (Guertal and Edwards, 1996). Plant residues are not always optimal, because in order to achieve weed suppression, high levels of plant residue biomass are needed, which requires high seeding rates (Smith et al 2011). This is necessary because gaps that are left between fragments of plant residue mulch allow weeds to emerge (Reborg-Horton et al 2005). It has been suggested that low plant residue biomass, especially leguminous biomass, can provide an environment conducive to improved weed performance when compared to bare soil (Teasdale and Mohler 2000). Ultimately, too little plant residue can reduce crop yield and quality of vegetable crops, due to its lack of effect on weed suppression (Boyhan et al 2006, Adler and Chase 2007, Pedreros et al 2008, Vollmer et al, 2010).

In order to combat these drawbacks to mulches, new strategies need to be developed. One possible strategy would be to combine newspaper and plant residues to provide adequate weed suppression while reducing mulch material needs and mulch C:N ratio. The goal of this research was to explore the management of weeds through various mulch combinations in an autumn collard (*Brassica oleracea* L.) crop.  Collard was selected for study because it is a cool season crop that is tolerant of high temperatures and is an important crop to small farmers who sell in smaller, localized markets. We compared two different continuous mulches, newspaper end roll sheet and black plastic sheet, in combination with or without residues of a cover crop mix, cowpea and buckwheat, previously grown and killed in place. Cowpea was used because it is a species that can tolerate dry and hot conditions, and poor soils (Clark, 2008). Also, cowpea forms a symbiotic relationship with rhizobia, which then fixes atmospheric nitrogen into a plant-available form. Buckwheat was selected because it grows rapidly and in dense populations, out-competing weed species. Furthermore, it has a low C:N ratio (34:1) and the ability to sequester phosphorus, which is then released for future crop use (Clark, 2008). In this study, mulch treatments were compared for their efficacy of weed suppression, effects on soil moisture content and soil temperatures, and effects on collard crop performance.

## Materials and Methods

### Experimental design and cultural practices

This study was conducted over a two-year period at the Waterman Agricultural and Natural Resources Laboratory farm in Columbus, OH (40°00' N, 83°02' W). The soil type was a Crosby silt loam (fine, mixed, active, mesic Aeric Epiaqualfs) with approximately 2% organic matter and pH of 6.5. Before initiating the study, 2.2 kg $ha^{-1}$glyphosate [*N*-(phosphonomethyl)glycine; Roundup Ultramax®, Monsanto Co., St. Louis, MO) was applied to the plot area to control several small patches of Canada thistle (*Cirsium arvense* L.). Plots measuring 1.2 m by 7.6 m were arranged in a randomized complete block design with five replications per treatment. Treatments consisted of the following mulch or mulch combinations: 1) black plastic; 2) unprinted newspaper; 3) cover crop 4) unprinted newspaper + cover crop; 5) black plastic +cover crop; and 6) no mulch. Dates of various cultural practices and data collection in 2011 and 2012 are shown in Table 1.

The cover crop treatments contained a mixture of 'California # 5' cowpea (*Vigna unguiculata (L.) Walp.*; Seedway, LLC, P.O. Box 250, 1734 Railroad Place, Hall, NY 11463) and buckwheat (*Fagopyrum esculentum*; H. W. Martin & Son Co., 10553 Swamp Road, Hebron, Ohio 43025). 'California # 5' cowpea is viney and vigorous, resistant to nematodes and wilt, and produces 'black-eyed' peas that are consumed both fresh and dried. Cowpeas and buckwheat were mechanically planted in alternating rows with three rows of cowpea and two rows of buckwheat. Rows were spaced 15 cm apart and the seeding rate was 13 seeds $m^{-1}$ of row (84 kg $ha^{-1}$ cowpea, 107 kg $ha^{-1}$ buckwheat). Cowpeas were inoculated with the proper strain of *Rhizobium* (INTX Microbials, 102 E. Bailie St., Kentland, IN 47951) just prior to planting.

Plots containing cover crops were undercut and flattened with a crimper-roller implement described by Creamer et al. (1996), and the remaining treatments were then installed in the field. Plastic treatments consisted of a single 1.2-m-wide sheet (polyethylene plastic, 0.032 mm thickness or 1.25 MIL (Hummert International , Earth City, MO, USA) ) covering the length of the plot and secured into place using 10-cm-long ground staples. Newspaper treatments consisted of two layers of unprinted newspaper (*The Columbus Dispatch*, 34 S. 3rd St., Columbus, Ohio 43215) covering the length of the plot and secured using ground staples as described for the plastic. Soil was shoveled onto the edges of the paper and plastic to further secure and protect them from wind damage.

Seedlings were grown at the Muck Crops Agricultural Research station in Willard, OH. Seeds of 'Champion' collards (*Brassica oleracea L.* Acephala group; Siegers Seed Company, 13031 Reflections Drive, Holland, MI 49424) were planted (7/8/2011, 5/18/2012) into moistened soil-less media (Sungro Horticulture Metromix 3B 35, 15831 N.E. 8th Street, Suite 100 Bellevue, WA 98008) in 144-cell plug flats. 'Champion' is an open-pollinated collard variety that matures in 78 to 82 days. They were irrigated as needed and fertilized one week before transplanting (August 11, 2011 June 29, 2012) at five weeks and six weeks of age, respectively. Each plot contained two rows of 12 collard plants each, with the rows and plants within each row spaced 0.6 m apart. Sprinkler irrigation was applied to deliver approximately 5.0 cm of water to the plots within 24 h of transplanting, and additional applications of 2.5 cm each were applied as needed for the remainder of the growing season. Collard plants that did not survive initial transplanting (primarily in the black plastic treatments due to excessive heat) were replaced within the first two weeks of the experiment.

Prior to crop transplanting, glyphosate was applied to non-cover crop plots at 0.6 kg $ha^{-1}$ to control weeds and 64 g $ha^{-1}$clethodim {(*E, E*)-($\pm$)-2-[1-[[(3-chloro-2-propenyl)oxy)imino)propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; Select®, Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596} was applied to cover crop plots to control annual grasses. Applications of 1.0 kg $ha^{-1}$ *Bacillus thuringiensis* (DiPel® DF, Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596) were made to plots as necessary to control larval-stage lepidopteran insect pests that were feeding on the collard leaves.

**Cover crop, soil, weed, and crop response data**

In 2011, before cover crops were crimped and mulches were installed weed and cover crop population density for each species was measured in a 0.5 $m^2$ quadrat placed randomly within each plot. Weeds and cover crops of each species within the quadrat were counted, cut at the soil level, and dried in a convection oven at 55 C for seven days and weighed to determine dry weed biomass.

Soil was sampled in each plot using a 1.8-cm-diam probe to a depth of 20 cm. Three core samples were taken from random locations within each plot and pooled. Samples were stored in a cold room at 5 C and 40% relative humidity and until sent for nutrient and C:N analysis to a commercial testing laboratory (CLC labs, 325 Venture Drive, Westerville, OH

43081). Soil temperature and moisture sensors were attached to dataloggers (HOBO - 10HS Soil Moisture Smart Sensor - S-SMD-M005, 12-Bit Temp Smart Sensor (2 m cable) - S-TMB-M002, Micro Station Data Logger - H21-002, Onset Computer Corporation, Inc., PO Box 3450, Pocasset, MA 02559-3450) and placed in the field at depths of 5 and 10 cm below the soil surface , respectively. Dataloggers recorded the 30-minute averages of readings taken each minute over the duration of each experiment.

To determine the influence of mulches on weed suppression and collard growth, weed population density and estimates of weed and collard growth were recorded periodically (Table 1). Weed population density for each species was measured in a 0.5 $m^2$ quadrat placed randomly within each plot. Weeds of each species within the quadrat were counted, cut at the soil level, and dried in a convection oven at 55 C for seven days and weighed to determine dry weed biomass. A non-destructive estimate of collard growth was obtained by measuring the height, length, and width of each collard plant. Height was measured from the soil surface to the terminal axis. Plant diameter was calculated from the average of length and width, and was multiplied by plant height to obtain canopy volume occupied per plant.

To determine the economic impact of manual weed removal and how crops and weeds would respond to manual weed management, main plots (mulch treatments) were each subdivided into two equal subplots, and subplot treatments of hand-weeded and non-weeded were assigned randomly to each main plot. Weeds were removed at the mulch surface using hand pruners. Time required for hand-weeding each subplot was recorded and converted to person-hours per hectare.

Harvested collard leaves were sorted and classified into the following groups: marketable leaves (no visible damage); minimum damage (1 to 10% leaf area damaged), medium damage (11-50% leaf area damaged), or maximum damage (>50% leaf area damaged). Leaf fresh weights and total leaf area (Licor LI-3100 Leaf Area Meter, Licor Biosciences, Inc., 4647 Superior St., Lincoln, NE 68504) were determined for each harvest category. At final harvest in both years, tissue samples from each plot were dried in a convection oven at 55 C for seven days and sent for nitrogen tissue analysis to a commercial testing laboratory (CLC labs, 325 Venture Drive, Westerville, OH 43081).

Table 1. Dates of various cultural practices and data collection in 2011 and 2012.

| | Establishment year | |
|---|---|---|
| Operation | 2011 | 2012 |
| Field surveyed | May 12 | April 29 |
| Glyphosate applied | May 23 | NA |
| Soil tilled | June 1 | May 18 |
| Raised beds made | June 3 | May 18 |
| Cover crops planted | June 7 | May 18 |
| Soil samples collected | June 8 | May 18 |
| Glyphosate/clethodim applied | June 13 | NA |
| Collards sowed in greenhouse | July 7 | June 3 |
| Early weed assessment | NA | August 2 |
| Cover Crop and Weeds Collected | August 1 | NA |
| Cover crops rolled | August 2 | June 28 |
| Soil samples collected | August 3 | June 28 |
| Treatments installed | August 5 | June 29 |
| Collards transplanted | August 11 | June 29 |
| Dead collards replaced | August 13 | June 30 |
| Temperature sensors installed | August 15 | June 22 |
| Initial crop performance monitored | September 7 | August 5 |
| First DiPel DF applied | Septmeber 13 | July 8 |
| Second DiPel DF applied | NA | July 15* |
| Third DiPel DF applied | NA | July 22 |
| Fourth DiPel DF applied | NA | July 29* |
| Fifth DiPel DF applied | NA | August 5 |
| Sixth DiPel DF applied | NA | August 12* |
| Seventh DiPel DF applied | NA | August 19 |
| Eighth DiPel DF applied | NA | August 26* |
| Ninth DiPel DF applied | NA | September 2 |
| Weed removal subplots established | September 14 | August 17 |
| First collard harvest | September 22 | August 10 |
| Soil moisture sensors installed | September 19 | June 22 |
| Second collard harvest | October 4 | August 17 |
| Late weed assessment | October 16 | September 24 |
| Third collard harvest | October 18 | September 7 |
| Fourth collard harvest | November 4 | September 21 |

*Indicates accompanied application of Malathion.

## Data analyses

### Statistical design and analysis

A randomized complete block design was used for soil moisture, soil temperature, collard plant volume, weed density, and first collard harvest data. Treatments were assigned randomly each year of the trail. Statistical analysis of these variables was performed using the PROC MIXED procedure for SAS (version 9.2; SAS Institute, Cary, NC). Weed density, weed dry weight plant$^{-1}$, total weed dry weight, and 2011 first collard harvest data failed normality tests and were therefore transformed using box cox transformations for analysis and then back-transformed for presentation.

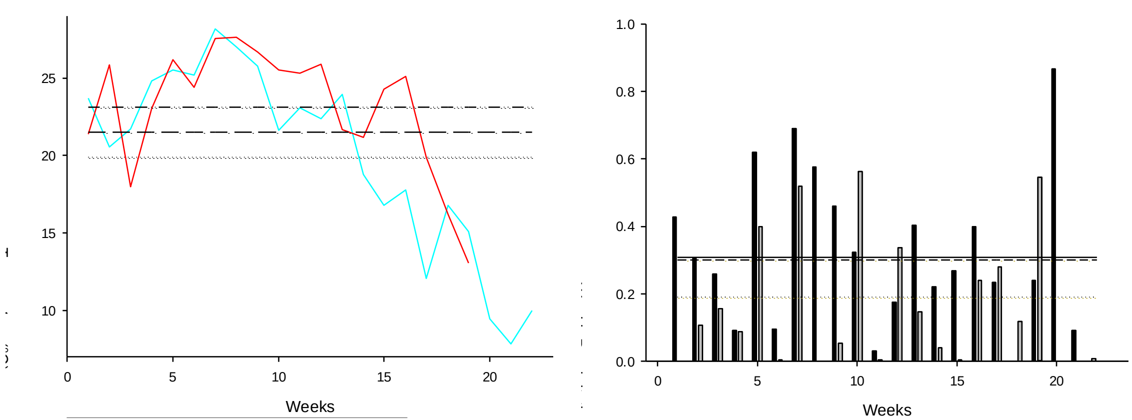
Data collected after weed removal treatments were imposed included collard damage data and collard yield data for the final three harvests. Collard damage data were analyzed only in the weedy subplots and were therefore analyzed as a randomized complete block design. Collard damage data were transformed using a square root transformation because data were distributed between 0 and 1.

Statistical analysis of the final three collard harvests in both 2011 and 2012 were performed using the PROC MIXED procedure of SAS for repeated measures (Littell et al. 2006) in a split plot design with mulch treatment as the main plot factor and weed removal (weeded or unweeded) as the subplot factor. The mulch by harvest date interaction within plots was designated as a random effect and mulch by harvest date interaction was also designated as the subject on which repeated measures were taken. The generalized linear model included weed removal treatments, the collard damage data did not, and its interaction with harvest date and mulch as fixed effects. Simple covariance was chosen as the model based on the Akaike Information Criterion fit statistic in comparison with other covariance structures that were tested (Littell et al. 2006). Least squares means of treatments within each year were compared using the DIFF option. A significance level of a $P \leq 0.05$ was used for all statistical tests.

## RESULTS AND DISCUSSION

### Weather Data

The two experimental seasons differed in average air temperature and precipitation (Figure 1). The 30-year normal average temperature and the average weekly precipitation for this time of year are 21.5 °C and 0.30 cm (Figure 1). The average ambient temperature and weekly precipitation in 2011 were 19.9 °C and 0.31 cm. The average ambient temperature and weekly precipitation in 2012 were 23.1 °C and 0.19 cm. In 2012, temperatures were warmer, and average weekly precipitation was lower than in 2011. In comparison to the long-term average air temperature and precipitation, 2011 had average precipitation but was cooler, and 2012 was drier and warmer (Figure 1).




. Figure 1. Temperatures and precipitation during the growing season in 2011 (6/7/2011 to 11/4/2011) and 2012 (5/18/12 to 9/21/12).

**Cover Crop**

There were no year by treatment interactions, however there was a difference between years in buckwheat populations. Therefore data from both years are presented to show the differences between buckwheat populations in 2011 and 2012 (Table 2).

Table 2. Cover crop populations before undercutting and installation of mulches, in 2011 and 2012. Populations were assessed by counting the number of plants in a row in each row in each plot. Data are averaged across rows.

| | Average Population (plants $m^{-1}$ of row) | | | |
|---|---|---|---|---|
| | 2011 | | 2012 | |
| Treatments | Buckwheat | Cowpea | Buckwheat | Cowpea |
| No Mulch | --- | --- | --- | --- |
| Cover crop | 7 b | 8 | 27 a | 8 |
| Newspaper sheet | --- | --- | --- | --- |
| Newspaper sheet + cover crop | 11 b | 6 | 27 a | 9 |
| Plastic sheet | --- | --- | --- | --- |
| Plastic sheet + cover crop | 12 b | 9 | 26 a | 8 |

[a]There were no significant differences within columns. Least squares means within a row followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05. Only buckwheat had differences between years.

Germination tests in 2011 showed 60% germination for buckwheat and 85% germination for cowpea. Germination tests in 2012 showed 92% germination in buckwheat and 89% germination in cowpea. In both years there were no differences in cover crop populations among treatments. However, there was a much larger population of buckwheat in 2012 than 2011. The average number of buckwheat plants per plot in 2011 was only 36% of the average number of buckwheat plants per plot in 2012 (Table 1).

In both years, both species were planted in the same pattern and at the same seeding rate. The germination results in conjunction with stand population densities suggest that the buckwheat seedlot in 2011 was of inferior quality. In addition, in 2012, the central cowpea row was replanted due to poor germination and seed predation by birds. Although total cover crop populations were consistent across cover crop treatments within each year, total cover crop populations were greater in 2012 than in 2011, due to higher buckwheat populations.

In 2011, cowpea plants were observed to grow at a faster rate than buckwheat plants, but in 2012 the trend was reversed, and buckwheat plants thrived while cowpeas showed slower growth. Cover crop biomass was measured in 2011 before the cover crop was undercut and crimped but was not measured in 2012. In 2011, treatments with cover crops (cover crop, newspaper sheet + cover crop, and plastic sheet + cover crop) did not differ in cover crop biomass (data not shown) and produced an average cover crop biomass of 2.7 ± 0.3 Mg $ha^{-1}$. There were no significant differences in weed biomass between treatments with cover crops vs without cover crops (no mulch, newspaper sheet, and plastic sheet) (Table 3), indicating that the cover crops did not suppress weed growth. However, treatments with cover crops had greater total plant biomass (weeds + cover crops) than the treatments without cover crops (Table 3).

Table 3. Weed and total plant biomass before sheet mulches were installed, in 2011.

| Treatments | Weed Biomass g m$^{-2}$ | | Total Biomass g m$^{-2}$ | |
|---|---|---|---|---|
| No Mulch | 264 | a | 264 | c |
| Cover Crop | 230 | a | 530 | a |
| Newspaper Sheet | 216 | a | 216 | c |
| Newspaper Sheet + Cover Crop | 236 | a | 458 | ab |
| Plastic Sheet | 324 | a | 324 | bc |
| Plastic Sheet + Cover Crop | 214 | a | 512 | a |

[a] Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

The cover crops were undercut at the anthesis stage of development. In both years the undercutter was successful in undercutting both weeds and cover crops and laying them flat onto the surface of the soil. However, in 2011, the undercutter failed to kill weeds and cover crops. According to Akemo et al (2000) a period of at least three sunny and dry days were necessary to ensure killing of cover crop after cutting, if it was to be used as a mulch. In the three days following crimping in 2011 and 2012 it rained a total of 1 cm in 2011 and 2 cm in 2012. However, in the week before and after crimping in 2011it rained 4 and 5.5 cm, respectively, where in 2012 it did not rain the week before crimping and 3 cm after. Though the criteria placed forth by Akemo et al (2000) were not met to ensure cover crop kill either year, low precipitation before and after crimping in 2012 may have resulted in conditions conducive to killing the cover crop.

### Soil temperature response data

There was a year by treatment interaction, so data were analyzed separately by year. In each year there was no week by treatment interaction, so data were pooled over weeks within each year (Tables 4 and 5).

### Soil temperature in 2011

Average and minimum soil temperatures in the plastic sheet and plastic sheet +cover crop treatments were higher compared to the other treatments (Table 4). The presence of a cover crop had no impact on average or minimum soil temperatures when comparing newspaper sheet to newspaper sheet + cover crop, plastic sheet to plastic sheet + cover crop, and when comparing cover crop to no mulch. Maximum soil temperatures were highest in the plastic sheet (19.9 °C), plastic sheet + cover crop (20.3 °C), and no mulch (20.00 °C) treatments. The weekly average maximum temperature in the cover crop alone treatment was lower than in the no mulch treatment, a difference of 1.1 °C. Temperature fluctuation data indicated greater average fluctuation in the no mulch treatment than in the plastic sheet treatment, plastic sheet + cover crop, and cover crop alone treatments. There was no difference in fluctuation among the no mulch, newspaper sheet, and newspaper sheet + cover crop treatments.

Table 4. Effect of mulches on average, maximum, and minimum soil temperature, and on average fluctuation in soil temperature (flux=maximum daily temperature - minimum daily temperature). Temperatures were monitored continuously at 30-min intervals at 5 cm depth from August 15, 2011 to November 1, 2011. Treatment means represent weekly averages and were computed from daily data.

| | Soil Temperature (°C) | | | |
|---|---|---|---|---|
| Treatments | Avg[a] | Max | Min | Flux |
| No mulch | 16.8 b | 20.0 a | 14.4 b | 5.5 a |
| Cover crop | 16.6 bc | 18.8 b | 14.9 b | 4.0 bc |
| Newspaper sheet | 16.5 bc | 18.8 b | 14.4 b | 4.5 abc |
| Newspaper sheet+cover crop | 16.2 c | 18.7 b | 14.2 b | 4.5 ab |
| Plastic sheet | 18.0 a | 19.9 a | 16.7 a | 3.2 c |
| Plastic sheet+cover crop | 18.1 a | 20.2 a | 16.3 a | 3.9 bc |

[a] Least squares means within a column followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

**Soil Temperature in 2012**

As in the previous year, the 2012 average and minimum soil temperatures in the plastic sheet and plastic sheet + cover crop mulch treatments were higher than in the other treatments (Table 5). Maximum soil temperature was higher in plastic sheet mulch than all of the other treatments except plastic + cover crop, with the major difference in maximum temperature being between the plastic sheet and both no mulch and newspaper + cover crop treatments. Minimum soil temperature was highest in the plastic sheet and plastic sheet + cover crop mulch treatments. Soil temperature fluctuation was highest in the plastic sheet and lowest in the newspaper + cover crop treatment (Table 5).

Table 5. Effect of mulches on average, maximum, and minimum soil temperature, and on average fluctuation in soil temperature (flux=maximum daily temperature - minimum daily temperature). Temperatures were monitored continuously at 30-min intervals at 5 cm depth from June 28, 2012 to September 24, 2012. Treatment means represent weekly averages and were computed from daily data.

| | Soil Temperature (°C) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | Avg | | Max | | Min | | Flux | |
| No mulch | 23.4 | b | 25.9 | c | 21.2 | bc | 4.7 | c |
| Cover crop | 23.7 | b | 27.1 | b | 20.9 | c | 6.2 | b |
| Newspaper sheet | 23.4 | b | 26.1 | b | 20.9 | c | 5.2 | c |
| Newspaper sheet + cover crop | 23.0 | b | 25.2 | c | 21.4 | b | 3.8 | d |
| Plastic sheet | 24.9 | a | 28.8 | a | 21.8 | a | 7.1 | a |
| Plastic sheet + Cover Crop | 24.9 | a | 27.9 | ab | 22.4 | a | 5.5 | b |

[a] Least squares means within a column followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

The presence of a cover crop had no impact on average soil temperatures when comparing plastic sheet, newspaper sheet, and no mulch to their counterparts with cover crops present. The presence of a cover crop decreased the maximum soil temperature in newspaper sheet mulches but increased the maximum soil temperature when comparing the cover crop to the no mulch treatment. However, the presence of a cover crop increased the minimum soil temperature under newspaper sheet mulch. When comparing treatments with and without cover crop, although cover crop reduced fluctuation in the plastic and newspaper treatments, fluctuation increased in the cover crop only treatment when compared to no mulch (Table 5).

As expected, the average soil temperatures in the plastic mulches were the highest. These results are consistent with those found by Coolong (2010), who reported that average soil temperature was highest in black plastic (21 °C) when compared to no mulch (19 °C). Monks et al. (1997) found that black plastic not only had the highest soil temperature of all treatments but that it maintained higher temperatures even when exposed to cooler nighttime temperatures. However, some research suggests that soil temperature, although higher under black plastic mulch than paper mulch, decreases and becomes more comparable to paper mulch over time as crop size and canopy increases (Anderson et al 1996).

Average, maximum, and minimum, soil temperatures (with the exception of maximum soil temperature in 2012) in both newspaper treatments were consistently lower when compared to both plastic treatments. These findings agree with past research by others, including Pellet and Heleba (1995) who reported that 2.5-cm-thick layer of shredded newspaper on the soil surface reduced soil temperatures by 10 °C to a soil depth of 7.5 cm when compared to non-mulched plots. Other results reported by Schonbeck and Evanylo (1998) showed that soil temperature under black polyethylene increased while temperatures under paper mulches, even when painted black, reduced mean soil temperature, indicating that although black is a heat absorptive color, paper is not a heat conductive material.

In 2011, the cover crop only treatment had a decrease in fluctuation and minimum soil temperatures when compared to the no mulch control. In 2012, the presence of a cover crop raised maximum soil temperature when compared to no mulch and lowered soil temperature when compared to the newspaper sheet treatment. The combination of cover crop and newspaper sheet raised minimum soil temperatures. Cover crop lowered soil temperature fluctuations in plastic and newspaper but resulted in increased fluctuation when compared to the no mulch treatment. The data are inconsistent between years and broad conclusions cannot be drawn regarding mulch treatment effects on soil temperatures; however, contrary to expectations there was no impact of cover crop on average soil temperature when comparing treatments within newspaper and plastic, e.g., newspaper sheet versus newspaper sheet + cover crop.

**Soil moisture response data**

There was a year by treatment interaction, so data were analyzed separately by year. In 2011, three discrete point measurements were taken before soil moisture was monitored continuously using dataloggers (Table 6). Beginning September 19 in 2011 and during the entire season in 2012, soil moisture was monitored continuously by dataloggers. For continuous monitoring, there was no week by treatment interaction so data were pooled over weeks (Tables 6 and 7).

**Soil Moisture in 2011**

The first two volumetric soil moisture measurements, on August 19 and September 2, were taken by inserting the probe right next to the transplanted collard seedling. On August 19 the highest average moisture contents were in the newspaper sheet, newspaper sheet + cover crop, plastic sheet, and plastic sheet + cover crop treatments (Table 6). The no mulch and cover crop alone treatments had the lowest average soil moisture content. The second soil moisture content reading on September 2 indicated that plots containing mulches with plastic sheet or newspaper sheet had similar moisture content, and that the plastic sheet + cover crop treatment had higher moisture content than plots with the cover crop alone or no mulch. The third moisture measurement on September 16, was taken by placing the soil probe in the center of the plot between four plants and indicated that the soil moisture level under both of the plastic sheet treatments was >50% lower than the remaining four treatments (Table 6).

Table 6. Effect of mulches on soil moisture in collard plots on August 19, September 2, and September 16, 2011.

| | Soil volumetric water content ($mm^3/mm^3 \cdot 10^3$) | | | | | |
|---|---|---|---|---|---|---|
| Treatments | 8/19/2011[a] | | 9/2/2011 | | 9/16/2011 | |
| No Mulch | 205 | b | 180 | bc | 272 | a |
| Cover Crop | 193 | b | 165 | c | 266 | a |
| Newspaper Sheet | 264 | a | 250 | b | 242 | a |
| Newspaper Sheet + Cover Crop | 238 | ab | 209 | abc | 266 | a |
| Plastic Sheet | 278 | a | 218 | abc | 126 | b |
| Plastic Sheet + Cover Crop | 227 | ab | 256 | a | 121 | b |

[a] Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

Average soil moisture was highest in the plastic + cover crop and lowest in the no mulch treatment (Table 7). Plots with newspaper treatments contained intermediate levels of average, maximum and minimum soil moisture content. Cover crop presence in treatments increased average soil moisture content, except in newspaper sheet treatments. Maximum and minimum soil moisture contents were highest in the plastic + cover crop treatments when compared to all other treatments except plastic, with the no mulch treatment having the lowest soil moisture content. Fluctuation in moisture content was greater in the plastic sheet + cover crop treatment than in all other mulch treatments except for the plastic sheet treatment. Soil water content fluctuations were similar for the plastic sheet, newspaper treatments, cover crop, and no mulch control (Table 7).

Table 7. Effect of mulches in collards on average, maximum, and minimum soil moisture, and on average fluctuation in soil volumetric soil moisture content (flux=maximum daily volumetric soil moisture content - minimum daily volumetric soil moisture content). Volumetric soil moisture contents were monitored continuously at 30-min intervals at 20 cm depth from September 19, 2011 to November 1, 2011. Treatment means represent weekly averages and were computed from daily data.

| | Soil volumetric water content ($mm^3/mm^3 \cdot 10^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | Avg | | Max | | Min | | Flux | |
| No mulch | 187 | d | 199 | d | 181 | d | 18.5 | b |
| Cover crop | 233 | bc | 244 | bc | 229 | b | 14.9 | b |
| Newspaper sheet | 223 | c | 274 | c | 217 | c | 17.1 | b |
| Newspaper sheet + cover crop | 222 | c | 233 | c | 214 | c | 18.8 | b |
| Plastic sheet | 246 | b | 262 | ab | 241 | ab | 20.7 | ab |
| Plastic sheet + Cover Crop | 266 | a | 285 | a | 258 | a | 26.9 | a |

[a]Least squares means within a column followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

### Soil Moisture in 2012

Average, maximum, and minimum soil moisture contents were highest in the newspaper plus cover crop treatment (Table 8). Maximum soil moisture content was lowest in the no mulch treatments. Minimum soil moisture content was lowest in the no mulch and newspaper sheet treatments and was intermediate in the plastic sheet, plastic sheet + cover crop, and cover crop treatments. Cover crop presence increased average, maximum, and minimum soil moisture in newspaper sheet and no mulch treatments. Cover crop presence under plastic had no effect. Soil moisture fluctuation was lowest in plastic treatments. Soil moisture content fluctuations were similar in the no mulch, newspaper mulches, and cover crop treatments (Table 8).

Table 8. Effect of mulches in collards on average, maximum, and minimum soil moisture, and on average fluctuation in soil volumetric soil moisture content (flux=maximum daily volumetric soil moisture content - minimum daily volumetric soil moisture content). Volumetric soil moisture contents were monitored continuously at 30-min intervals at 20 cm depth from June 28, 2012 to September 24, 2012. Treatment means represent weekly averages and were computed from daily data.

| | Soil volumetric water content ($mm^3/mm^3 \cdot 10^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | Avg | | Max | | Min | | Flux | |
| No mulch | 103 | d | 121 | c | 91.6 | c | 29.3 | a |
| Cover crop | 142 | b | 156 | b | 132 | b | 23.9 | ab |
| Newspaper sheet | 114 | cd | 132 | b | 102 | c | 29.6 | a |
| Newspaper sheet + cover crop | 192 | a | 212 | a | 181 | a | 31.0 | a |
| Plastic sheet | 145 | b | 157 | b | 138 | b | 19.2 | b |
| Plastic sheet + Cover Crop | 134 | bc | 147 | b | 127 | b | 19.6 | b |

[a]Least squares means within a column followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

In 2011, all treatments had higher soil moisture content than treatments in 2012 because the precipitation was higher and the method of installation resulted in larger areas of soil left exposed. To install the soil moisture sensors in 2011, slits were made in the plastic to create the holes in which the sensors were placed. After installing the sensors, the slits remained open until the termination of the experiment. Liptay and Tiessen (1970) discovered that approximately one-third of rain or irrigation water that falls on plastic mulch cascades toward the alleys and into holes made for transplants. The slits made to install the moisture sensors probably acted like funnels, directing rainwater to the soil surrounding the soil moisture sensor. Although this may give an inaccurate monitoring of soil moisture content underneath the plastic, it can lend an idea of what may have happened at the openings where collards were transplanted and along the edges of the plastic sheet mulch. Holes in the plastic may direct larger quantities of rainwater to the target than if there were either no mulch present or if an alternative water-permeable mulch were present. In 2012, soil moisture sensors were installed before sheet mulches were applied to plots in order to obtain more representative data of the average soil moisture conditions over the entire plot area.

Overall results agreed with previous research that the presence of a mulch increased soil moisture content. Monks et al. (1997) found that shredded newspaper at a shallow depth (2.5 cm) and black plastic were sufficient to conserve soil moisture. Lal (1974) reported that mulched treatments of rice straw and forest leaf litter had higher soil moisture content throughout a growing season when compared to non-mulched plots. Mohler and Teasdale (1993) found that substantial quantities of cover crop biomass, including rye (1710 g $m^{-2}$) and vetch (1150 g $m^{-2}$) at 4 times the rate of natural biomass levels, were necessary to reduce soil moisture loss during periods of seasonal dryness.

## WEEDS

### Weeding labor cost analysis

In 2011, the costs associated with manual weed removal were higher in the cover crop alone treatment than all other treatments except the no mulch control (Table 9). Costs associated with manual weed removal were lowest in both of the plastic treatments. Costs associated with manual weed removal in the newspaper sheet and newspaper sheet + cover crop were higher than for the plastic sheet and plastic sheet + cover crop treatments and were similar to the no mulch control. Similarly, in 2012, the manual weed removal costs were highest in the no mulch and cover crop treatments, and lowest in the treatments with plastic sheet.  The cost associated with weed removal was higher for the newspaper sheet+cover crop than for the newspaper sheet alone (Table 9).

Table 9. Effect of mulches on weed removal cost in collards in 2011 and 2012. Cost was calculated recording the time required to remove weeds from each plot (sec plot$^{-1}$) and then converting to \$ ha$^{-1}$ using U.S. federal minimum wage of \$7.25.

| Treatments | Cost of weeding (\$ ha$^{-1}$) 2011[a] | 2012 |
|---|---|---|
| No Mulch | \$1,086 ab | \$2,135 a |
| Cover Crop | \$1,272 a | \$1,910 a |
| Newspaper Sheet | \$897 b | \$569 c |
| Newspaper Sheet + Cover Crop | \$903 b | \$1,053 b |
| Plastic Sheet | \$95 c | \$78 d |
| Plastic Sheet + Cover Crop | \$135 c | \$93 d |

[a]Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

Weed removal was least costly in the plastic sheet mulch treatments in both years. Few weeds were removed from plastic mulch plots and in most instances, the time allocated to manual weed removal was used primarily for scouting. In 2011, both of the newspaper treatments had similar costs associated with manual weed removal. However, in 2012, the cost of weed removal in the newspaper + cover crop treatment was greater than for the newspaper sheet mulch alone. This might have been due to differences in weed pressure in the newspaper treatments between the two years. In both years, all plots were undercut and rolled prior to newspaper and plastic sheet mulch installation. In 2011, weed pressure before mulches were applied was high in all treatments without a cover crop. Residue and stalks from the weeds in those plots contributed a tremendous amount of physical stress on the sheet mulches. The integrity of the paper mulches was compromised due to both well-established weeds and cover crops that survived undercutting that tore the newspaper.

A week prior to undercutting and rolling the cover crop in 2012, aisles between plots were sprayed with glyphosate. Damage was caused to weeds via spray drift during application. The newspaper sheet and plastic sheet treatments were installed on a relatively clean surface with little weed residue. Also, prior to glyphosate application in 2012, weed pressure in non-cover crop plots was relatively low possibly due to high temperature and little precipitation (Figure 1). The integrity of the newspaper sheet mulch, via installation on a weed-free surface, provided a continuous sheet mulch surface that physically impeded weed seedling emergence.

Reduction in weed pressure via herbicide application or mechanical means can reduce the labor requirement necessary to manage weeds manually in cotton crop production (Holstun et al., 1960). Melander and Rasmussen (2001) found that cultural practices, including brush and flame weeding, reduced weed populations and led to reduced time necessary for manual weed removal. By combining herbicide application with hand-weeding, Lanini and Le Strange (1994) found that weed pressure was reduced by >50% compared to just herbicide application or hand-weeding alone. In short, an integrated approach to weed management using combined techniques can reduce costs associated with manual weed removal, as suggested by previous research.

**Weed Populations and Biomass**

The four most common weed species present in 2011 were yellow foxtail [*Setaria glauca* (L). Beauv.], common lambsquarters (*Chenopodium album* L.), wild buckwheat (*Fagopyrum esculentum* Moench), and common purslane (*Portulaca oleracea* L.). Together, these species comprised 41% of the total number of weeds observed in the no-mulch treatment. On the first measurement date (August 2) in 2012, the four most common weed species were common lambsquarters, common purslane, barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], and redroot pigweed (*Amaranthus retroflexus* L.). Together, these species comprised 70% of the total number of weeds observed in the no-mulch treatment. On the second measurement date (September 25), the most common weed species were common lambsquarters, common purslane, henbit (*Lamium amplexicaule* L.) and redroot pigweed. These species together comprised 87% of the total number of weeds observed in the no-mulch treatment. Yellow foxtail was the most common weed in 2011 and it was present in the highest number of plots, although its contribution to total weed biomass ranged from only one to nine percent. The most common weed on both measurement dates in 2012 was redroot pigweed. It comprised 10 to 38% of the total weed biomass in the no mulch treatment.

In 2011, the first weed population density counts were taken on October 16, nine weeks after collards were transplanted. The highest weed population density occurred in the no mulch treatment (Table 10). Intermediate weed population densities occurred in the newspaper sheet, cover crop, and newspaper sheet + cover crop treatments. Also as expected, no weeds were present in the plastic sheet and plastic sheet + cover crop treatments. Comparing mulch treatments to the no mulch control, newspaper + cover crop reduced weed population density 73% (Table 10), and the newspaper sheet treatment reduced weed population density 60%. The cover crop treatment provided 67% weed suppression, and the plastic sheet mulch treatments, with or without cover crop, suppressed weeds completely.

In 2012, weed population densities were measured on August 2 and September 25, five and 13 weeks after collards were transplanted (Table 10). At the first weed count, the no mulch treatment and the cover crop mulch treatment had the highest weed population densities. The newspaper + cover crop treatment had lower weed populations than the no mulch and cover crop alone treatment. No weeds were present in the newspaper alone treatment, or in the plastic mulch treatments. Compared to the no mulch treatment, the newspaper + cover crop suppressed weed population density 93%, the newspaper sheet treatment provided 100% suppression, the cover crop treatment gave no suppression, and the plastic sheet mulch treatments, with or without cover crop, suppressed weeds completely (Table 10).

Weed population density on September 25, 2012 was similar in the no mulch, the cover crop alone, the newspaper sheet + cover crop and the newspaper sheet alone (Table 10). No weeds were present in the plastic treatments.

Table 10. Effect of mulches on total weed population density in collards, in 2011 and 2012.

| Treatments | Oct 16, 2011 | | Aug. 2, 2012 | | Sept. 25, 2012 | |
|---|---|---|---|---|---|---|
| | Population[a] plants $m^{-2}$ | | Population plants $m^{-2}$ | | Population plants $m^{-2}$ | |
| No Mulch | 50 | a | 32 | a | 108 | a |
| Cover Crop | 16 | b | 36 | a | 76 | a |
| Newspaper Sheet | 20 | b | 0 | c | 38 | a |
| Newspaper Sheet + Cover Crop | 14 | b | 2 | b | 78 | a |
| Plastic Sheet | 0 | c | 0 | c | 0 | b |
| Plastic Sheet + Cover Crop | 0 | c | 0 | c | 0 | b |

[a]Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

Weed biomass was greatest in the no mulch treatment in 2011,and no weed biomass was collected from the two plastic sheet treatments (Table 11). The newspaper sheet and cover crop alone treatments had intermediate levels of weed biomass. Of the treatments in which weeds occurred, the lowest weed biomass was in the newspaper + cover crop treatment. Comparing the mulch treatments to the no mulch treatment, newspaper + cover crop reduced weed biomass 92%, the newspaper sheet treatment reduced weed biomass 67%, the cover crop treatment provided 68% suppression, and the plastic sheet mulch treatments, with or without cover crop, suppressed weeds completely.

Weed biomass in August 2012 was highest in the no mulch treatment, and in the cover crop treatment (Table 11). Weed biomass in the newspaper + cover crop treatment was lower than the no mulch and cover crop alone treatments but higher than the newspaper alone and black plastic treatments. Compared to the no mulch treatment, newspaper and black plastic reduced weed biomass 96 to 100%.

Weed biomass in September 2012 was highest in the no mulch, the cover crop mulch, and the newspaper + cover crop mulch treatments (Table 11). Weed biomass in the newspaper sheet mulch was lower than the no mulch, cover crop alone, and newspaper + cover crop treatments, but higher than in both plastic treatments. No weeds were in the plastic treatments. Compared to the no mulch treatment the newspaper sheet treatment provided 97% suppression, and the plastic sheet mulch treatments, with or without cover crop, suppressed weeds completely (Table 11).

Table 11. Effect of mulches on total weed biomass in collards, in 2011 and 2012.

| Treatments | Oct 16, 2011 | | Aug. 2, 2012 | | Sept. 25, 2012 | |
|---|---|---|---|---|---|---|
| | Biomass[a] $g\ m^{-2}$ | | Biomass $g\ m^{-2}$ | | Biomass $g\ m^{-2}$ | |
| No Mulch | 176 | a | 76 | a | 206 | a |
| Cover Crop | 56 | b | 68 | a | 114 | a |
| Newspaper Sheet | 58 | b | 0 | c | 8 | b |
| Newspaper Sheet + Cover Crop | 14 | c | 4 | b | 118 | a |
| Plastic Sheet | 0 | d | 0 | c | 0 | c |
| Plastic Sheet + Cover Crop | 0 | d | 0 | c | 0 | c |

[a] Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

In both seasons, complete weed suppression was achieved in the plastic sheet and plastic sheet + cover crop treatments. These results are consistent with those found in past experiments. Masiunas et al (2005) found that weed populations in black plastic were lower when compared to no mulch treatments in late season weed population counts in tomatoes. Monks et al. (1997) found that plastic sheet mulch controlled 99% of grasses and 91% of broadleaf weeds when compared to no mulch treatment.

When compared to the no mulch treatments in 2011, the cover crop mulch treatment provided higher weed suppression; however, in 2012 weed suppression was comparable although the cover crop population was higher in 2012 compared to 2011, and would be expected, as a result, to provide greater suppression of weeds (Table 1). Results in this study in 2012 are consistent with those reported by Vollmer et al. (2010) that a cowpea cover crop treatment had consistently high weed densities comparable to the no mulch treatment, due to cowpea residue degradation. However, Hutchinson and McGiffen (2000) found that cowpea plant residue reduced weed biomass from three- to 10-fold when compared to no mulch. In another study, 89% weed suppression occurred in cowpea residue mulch when compared to the no mulch treatment (Harrison et al 2004). Both of these latter studies had high levels of cowpea residue, 9 Mg $ha^{-1}$ and 6 Mg $ha^{-1}$, respectively.

Weed biomass in plots with newspaper alone was lower when compared to the no mulch treatment. This result is comparable to previous research. Sanchez et al (2008) reported that newspaper sheets reduced weed populations by 9% in 2005 and 33% in 2006 when compared to no mulch treatment. Pellett and Heleba (1995) found that low rates of shredded newspaper (2.5 cm layer) reduced weed populations when compared to no mulch treatment.

Weed biomass in both newspaper treatments was higher when compared to black plastic treatments, except early in 2012. Cirujeda et al (2012) reported that paper mulches suppressed weeds with efficacy ranging from 78% to 100%, with results comparable to black plastic sheet mulch, which generally achieved efficacy ratings ranging from 97% to 100%. Plastic, butcher paper, and polyethylene-coated Kraft paper achieved 100, 80, and 90% weed control, respectively, when compared to no mulch treatment (Coolong 2010). The differences in these results may be attributed to the preserved integrity of the paper mulches in early 2012 and also in the Cirujeda and Coolong studies cited above.

In 2012, the surface on which the newspaper alone treatment was installed was weed free due to low weed pressure and possible glyphosate drift. In contrast, in 2011 not only did weeds grow more before sheet mulch installation, but they also survived undercutting. In 2011, newspaper was installed either over cover crops or undercut weeds, such as common lambsquarters and redroot pigweed. The tough, rigid stems that remained after undercutting compromised the integrity of the mulch by creating points of pressure against the paper which led to tears, negating the weed suppressive quality of the paper. Furthermore, previous research suggests that although cowpea residue can reduce pigweed seed germination by 20%, it can also stimulate pigweed growth up to 114% when compared to a control (Adler and Chase (2007). Also, Teasdale and Mohler (2000) suggest that plant residues at a low rate (1-2 Mg $ha^{-1}$) can simulate weed emergence and, especially with leguminous species, and provide an environment better suited for weed performance than non-mulched plots. In 2011, cover crop biomass reached ~ 2.7 Mg $ha^{-1}$ and thus could account for greater weed growth.

## CROP PERFORMANCE

### Preliminary Crop Data

In 2011 within a few days of transplanting, several collards in the plastic treatments and some in the newspaper sheet mulch treatments died and had to be replaced. Plant population ranged from 14 to 15 plants $plot^{-1}$ (Table 12). In 2011 there was no difference between treatments for collard plant population (Table 12).

In 2012, every collard plant died in the plastic treatments within the first two weeks of transplanting and had to be replaced. Plant populations ranged from 9 to 16 plants $plot^{-1}$ (Table 12). Collard plant population in the newspaper sheet treatments was higher than all treatments except the no mulch treatment. Roe et al (1994) also found that plastic mulch resulted in higher crop mortality than compost or wood chip mulch treatments. Concordantly, Guertal and Edwards reported that collard plant population density was higher in newspaper mulch than in black plastic mulch. Increased plant mortality in 2012 in black plastic can be attributed to higher temperatures. Also, on the day plants were transplanted, high winds damaged mulches and several of the transplants. In addition, this inclement weather left the research farm without power for two weeks, and plants did not receive irrigation during that period of time.

Table 12. Effect of mulches on plant volume and population, in 2011 and 2012.

| Treatments | Plant population (plants $ha^{-1}$ $10^{-3}$) | | | | Plant volume (cm3 $plant^{-1} \cdot 10^{-3}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2011[a] | | 2012 | | 2011 | | 2012 | |
| No Mulch | 27 | a | 23 | ab | 3 | b | 23 | bc |
| Cover Crop | 26 | a | 19 | bc | 3 | b | 23 | bc |
| Newspaper Sheet | 26 | a | 27 | a | 10 | a | 51 | a |
| Newspaper Sheet+Cover Crop | 27 | a | 21 | b | 10 | a | 32 | b |
| Plastic Sheet | 24 | a | 17 | bc | 7 | ab | 18 | bc |
| Plastic Sheet + Cover Crop | 26 | a | 16 | c | 4 | b | 12 | c |

[a]Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

In 2011, collard plants in the newspaper sheet and newspaper+cover crop treatments occupied significantly more volume than those in the no mulch, plastic sheet + cover crop, and cover crop treatments. Plant volumes in the plastic sheet treatment were not statistically different from the other treatments.

In 2012, collard plant volume in the newspaper alone treatments was greater than in the other treatments (Table 12). The presence of a cover crop reduced plant volume in newspaper treatments. In both years, the generally smaller plant size in the plastic sheet treatment compared to other treatments could be directly attributed to early mortality and replacement as well as higher surface temperatures. However, in 2012 plant volumes were much larger across all treatments than those in 2011. These data suggest that although plant mortality was higher in 2012, once plants were established, the increased soil temperature in 2012 compared to 2011, possibly led to increased crop performance.

### Collard Damage

There was a year by treatment interaction, so data were analyzed separately by year. In each year there was no harvest by treatment interaction, so data were pooled over harvests (Tables 13 and 14).

In 2011, marketable collard proportions were only higher in the newspaper sheet + cover crop and plastic alone treatments when compared to the no mulch treatment. The proportions of collards with minimal damage were highest in the plastic treatments, while maximum damage collard proportions were higher in the cover crop alone than the newspaper and plastic treatments.  In 2012, there were no differences among treatments in terms of marketable, minimal damage, and medium damage proportions. In both years there were no differences among treatments in terms of medium damage collard proportions.

The principal pests found on collards in both years were imported cabbageworm and cabbage looper. In both 2011 and 2012 the presence of a cover crop had no influence on pest damage compared to the other mulch treatments. Other research has found similar results when using cover crop to decrease pest damage. Masiunas et al. (1997) found that plant residue mulches including hairy vetch, cereal rye, and perennial ryegrass, could not adequately suppress insect pests in cabbage. Cranshaw (1984) also found that straw mulch was not effective in decreasing imported cabbageworm or cabbage populations in Minnesota. One possible reason there was no influence of cover crop on pest damage may be attributed to the fact that the cover crop was not incorporated into the soil. Recent research has shown that it is necessary to incorporate plant residue from previous crops in order to decrease incidence of Brassica pests and diseases (Motes et al 2012).

A majority of leaves in both 2011 and 2012 were unmarketable across all treatments. However, there was a higher proportion of marketable and minimally damaged leaves in 2011 than in 2012. In 2011, there was only one application of *Bacillus thuringensis,* whereas in 2012 it was applied weekly, with an accompanying application of malathion every other week. Although the collards received regular pesticide applications, they were not effective, possibly because the insects were primarily located in the center cluster of young leaves of the collards and did not come in contact with the pesticide.  Another possible reason that there was a higher proportion of marketable leaves in 2011 can be attributed to temperature. Oatman (1966) found that cabbage looper and imported cabbageworm populations were highest in the months of June, July and August and then steadily declined from September on. Not only were temperatures lower in 2011, but collards grew later into the year, with final harvest on November 4, 2011 compared to the final harvest of September 21 in 2012. These later growing collards in 2011 were likely exposed to lower overall pest populations compared to those in 2012.  Overall, these results suggest that farmers would not benefit from using cover crops for pest suppression. However, a fall collard crop planted and harvested later into the season would benefit from lower insect pressure and a decreased need for insecticide application. Thus, a farmer would save not only time, but ultimately, money.

Table 13. Effect of mulches on collard leaf damage in 2011. Harvested collard leaves were sorted and classified into the following groups: marketable leaves (Mark; no visible damage); minimum damage (Min; 1 to 10% leaf area damaged), medium damage (Med; 11-50% leaf area damaged), or maximum damage (Max; >50% leaf area damaged). Data is expressed as percent total of total crop biomass.

| | Damage Ratings (%) [a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | Mark | | Min | | Med | | Max | |
| No mulch | 14 | b | 28 | b | 26 | a | 15 | ab |
| Cover crop | 23 | ab | 31 | b | 18 | a | 25 | a |
| Newspaper sheet | 28 | ab | 37 | b | 19 | a | 13 | b |
| Newspaper sheet + cover crop | 33 | a | 37 | b | 20 | a | 7 | bc |
| Plastic sheet | 40 | a | 44 | a | 14 | a | 0 | c |
| Plastic sheet + Cover Crop | 32 | ab | 51 | a | 15 | a | 1 | c |

[a]Least squares means within a column followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

Table 14. Effect of mulches on collard leaf damage in 2012. Harvested collard leaves were sorted and classified into the following groups: marketable leaves (Mark; no visible damage); minimum damage (Min; 1 to 10% leaf area damaged), medium damage (Med; 11-50% leaf area damaged), or maximum damage (Max; >50% leaf area damaged). Data is expressed as percent total of total crop biomass.

| | Damage Ratings (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | Mark | | Min | | Med | | Max | |
| No mulch | 8 | a | 21 | a | 56 | a | 14 | b |
| Cover crop | 3 | a | 24 | a | 47 | a | 13 | b |
| Newspaper sheet | 6 | a | 17 | a | 50 | a | 27 | ab |
| Newspaper sheet + cover crop | 4 | a | 25 | a | 50 | a | 19 | b |
| Plastic sheet | 3 | a | 19 | a | 43 | a | 42 | a |
| Plastic sheet + Cover Crop | 5 | a | 17 | a | 47 | a | 34 | ab |

[a]Least squares means within a column followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

**Harvest Data**

A high percentage of collard leaves were classified as not marketable due to invertebrate pest damage in both the 2011 (>60%) and 2012 (>92 %) growing seasons (Tables 13 and 14); therefore, total plant biomass is presented rather than marketable yield. In 2011 at the first harvest, collard plants in the cover crop and no mulch treatments had no leaves of harvestable size to collect, and there were no differences in leaf number among the remaining treatments (Table 15). Collard biomass production in the plastic sheet + cover crop, plastic sheet, newspaper, and newspaper + cover crop treatments was similar, and all produced greater biomass than the plastic sheet + cover crop treatment. There were no differences in leaf area among the treatments containing newspaper or plastic.

Table 15. Effect of mulches on first harvest leaf number, total leaf biomass, and leaf area, in 2011 and 2012.

| Treatments | 2011 # (leaf $ha^{-1} \cdot 10^{-3}$) | | 2011 biomass (kg $ha^{-1} \cdot 10^{-1}$) | | 2011 Area ($cm^2$ $m^{-2} \cdot 10^{-2}$) | |
|---|---|---|---|---|---|---|
| No Mulch | 0 | b | 0 | c | 0 | b |
| Cover Crop | 0 | b | 0 | c | 0 | b |
| Newspaper Sheet | 203 | a | 411 | a | 62 | a |
| Newspaper Sheet+Cover Crop | 197 | a | 457 | a | 66 | a |
| Plastic Sheet | 223 | a | 331 | a | 41 | a |
| Plastic Sheet + Cover Crop | 194 | a | 228 | b | 34 | a |

| Treatments | 2012 # (leaf $ha^{-1} \cdot 10^{-3}$) | | 2012 biomass (kg $ha^{-1} \cdot 10^{-1}$) | | 2012 Area ($cm^2$ $m^{-2} \cdot 10^{-2}$) | |
|---|---|---|---|---|---|---|
| No Mulch | 21 | b | 46 | b | 7 | b |
| Cover Crop | 5 | b | 11 | b | 1 | b |
| Newspaper Sheet | 128 | a | 514 | a | 57 | a |
| Newspaper Sheet+Cover Crop | 30 | b | 91 | ab | 11 | ab |
| Plastic Sheet | 5 | b | 11 | b | 1 | b |
| Plastic Sheet + Cover Crop | 5 | b | 11 | b | 1 | b |

[a] Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

In 2012, plots with the newspaper sheet mulch treatment produced the highest number of collard leaves. Total leaf biomass and leaf area in newspaper were higher than all other treatments except the newspaper + cover crop treatment. (Table 15).

The early season, first harvest data (Table 15) suggest that weather conditions played a major role in early crop performance. In the wetter and cooler season of 2011, there were no differences among treatments containing any type of sheet mulch. However, in 2012 when conditions were warmer and drier, collard performance in the newspaper sheet mulch was far superior to other treatments. Therefore, the proper application and use of newspaper sheet appears to have the potential to give farmers the ability to market collards earlier and this could give them an advantage over competitors.

Analysis of the remaining harvest data showed a significant year by treatment interaction, so data were analyzed separately by year. In 2011, there was neither a harvest by mulch nor a weed removal by mulch interaction so data for mulch, harvest, and weed removal are presented as main effects in Table 16. Collard leaf number and biomass increased from harvests two to four; however, leaf area was largest at the third harvest.

Table 16. Main effects of mulch, harvest time, and weeding on collard leaf number, area and biomass, in 2011.

| | Treatment main effects | | | | | |
|---|---|---|---|---|---|---|
| Mulches | Leaf number (leaf $ha^{-1} \cdot 10^{-3}$) | | biomass (kg $ha^{-1} \cdot 10^{-1}$) | | Leaf area ($cm^2\ m^{-2} \cdot 10^{-2}$) | |
| No Mulch | 34 | ab | 58 | b | 7 | bc |
| Newspaper Sheet | 39 | a | 94 | a | 11 | a |
| Newspaper Sheet + Cover | 35 | ab | 89 | a | 10 | ab |
| Plastic Sheet | 38 | ab | 98 | a | 11 | a |
| Plastic Sheet + Cover Crop | 34 | ab | 89 | a | 10 | a |
| Cover Crop | 27 | b | 53 | b | 6 | c |
| Harvest | | | | | | |
| 2 | 21 | c | 58 | b | 8 | b |
| 3 | 32 | b | 83 | a | 11 | a |
| 4 | 51 | a | 98 | a | 9 | b |
| Weeding | | | | | | |
| Yes | 38 | a | 88 | a | 10 | a |
| No | 31 | b | 72 | b | 8 | b |

Least squares means within a column that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

Harvest data indicated that the only clear difference among treatments in terms of leaf number was between newspaper alone and cover crop alone treatments. As with the first harvest of 2011, collard biomass was greater in the sheet mulch treatments than in the cover crop and no mulch treatments. Plants in the newspaper sheet, plastic sheet, and plastic + cover crop produced more leaf area than the no mulch and cover crop alone treatments. Cover crop presence generally had little impact on crop performance. These results are in contrast with previous research that shows that using cowpeas as a mulch can improve crop performance. Vollmer et al (2010), found that even though cowpea mulch did not suppress weeds, onion yield was improved. In a separate study, Wang et al (2008) found that cowpea mulch improve lettuce growth. Our results suggest that the cover crop density was too low to have a positive effect on collard performance.

Initially the collard plants in the plastic treatments had to be replaced. Despite this delay in collard establishment, plants in all of the sheet mulch treatments ultimately performed equally well. This may be attributable to several factors. First, weed suppression was continuous all season long with plastic sheet whether with or without cover crops and therefore collards could grow without weed competition. Although newspaper treatments degraded over time, weed suppression was sufficient during early stages of development ti allow collard plants to gain a competitive advantage over weeds. Initial seedling loss and small collard size in the plastic sheet treatment was overcome by adequate precipitation events and weed control, which encouraged collard growth. As the plants grew and the season progressed, the water restriction imposed by the plastic sheet apparently did not hinder the ability of collards to acquire sufficient water.

Lastly, temperatures under the plastic were higher than those under other treatments. At the beginning of the season, high temperatures reduced crop establishment; however, as average air temperatures decreased over the season (Figure 1), plastic mulch maintained high soil temperatures, supporting improved crop growth throughout the remainder of the season. Monks et al. (1997) found that black plastic mulch not only had the highest soil temperature compared to wheat straw and newspaper mulch treatments, but it also maintained higher temperatures even when exposed to cooler nighttime temperatures. Furthermore, studies have found that although crop plant populations may be reduced in black plastic treatments due to mortality, yields at the end of the season were often highest in black plastic treatments when compared to wood chips (Roe et al., 1994) and newspaper (Guertal and Edwards, 1996) mulches.

In 2012, there were both mulch by harvest and mulch by weed removal interactions (Table 17). Collard plants in the newspaper sheet alone produced the highest number of leaves, biomass, and leaf area in both weeded and non-weeded plots. Weeding in the cover crop alone and newspaper + cover crop treatments increased the number of leaves produced, biomass, and leaf area. When weeds were present, plants in the newspaper +cover crop, plastic sheet, and plastic sheet + cover crop performed equally. When hand-weeded, collards in the newspaper + cover crop treatment produced more leaves, leaf biomass, and leaf area than the plastic + cover crop treatment. The presence of cover crops reduced the number of collard leaves, leaf biomass and leaf area in the newspaper sheet treatment in both weeded and non-weeded plots. There were no differences in crop yield parameters in plastic sheet treatments with or without cover crops. In the no mulch compared to cover crop only treatment, there were no differences in collard yield components in weeded plots; however, in non-weeded plots cover crops decreased collard leaf number and leaf area. The newspaper sheet treatment continued to outperform the other mulches, presumably by producing an environment conducive to increased plant productivity (Table 17).

Table 17. Mulch by weeding interaction effects on collard leaf number, biomass, and leaf area in 2012.

| Mulches | Weed Removal | | | |
|---|---|---|---|---|
| | Yes[a] | | No | |
| | Leaf Number (leaf $ha^{-1} \cdot 10^{-3}$) | | | |
| No Mulch [b] | 40 | C a | 41 | B a |
| Newspaper Sheet | 82 | A a | 75 | A a |
| Newspaper Sheet + Cover Crop | 61 | B a | 47 | B b |
| Plastic Sheet | 53 | BC a | 50 | B a |
| Plastic Sheet + Cover Crop | 47 | C a | 40 | B a |
| Cover Crop | 43 | C a | 16 | C b |
| | Leaf Biomass (kg $ha^{-1} \cdot 10^{-1}$) | | | |
| No Mulch | 50 | D a | 42 | CD a |
| Newspaper Sheet | 160 | A a | 171 | A a |
| Newspaper Sheet + Cover Crop | 113 | B a | 79 | B b |
| Plastic Sheet | 90 | BC a | 82 | B a |
| Plastic Sheet + Cover Crop | 70 | CD a | 53 | BC a |
| Cover Crop | 49 | D a | 10 | D b |
| | Leaf Area ($cm^2$ $m^{-2} \cdot 10^{-2}$) | | | |
| No Mulch | 7 | D a | 7 | B a |
| Newspaper Sheet | 19 | A a | 18 | A a |
| Newspaper Sheet + Cover Crop | 14 | B a | 10 | B b |
| Plastic Sheet | 11 | BC a | 10 | B a |
| Plastic Sheet + Cover Crop | 9 | CD a | 7 | B a |
| Cover Crop | 7 | D a | 2 | C b |

[a] Upper-case letters represent the differences between mulch treatments within the weed removal treatment. [b] Lower-case letters represent the differences of mulch treatments between weed removal treatments. Least squares means within columns and rows that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

In 2012, the number of collard leaves plot$^{-1}$ was highest in the newspaper alone treatment at all three harvests (Table 18). At the second harvest, the fewest collard leaves were produced in the cover crop alone treatment. At the third and fourth harvest, collards in the newspaper sheet treatment produced more leaves than all remaining treatments. At the fourth harvest, all treatments except the newspaper alone treatment resulted in similar leaf number. Across harvests, leaf number was greatest in all treatments for the first harvest except the cover crop alone treatment, where leaf number across harvest dates was the same. The presence of a cover crop reduced collard leaf number at harvest two in the newspaper treatments. Collard leaf number was also lower in the cover crop treatment alone than in the no mulch treatment. At harvests three and four, cover crop only affected leaf number in the newspaper plots (Table 18).

Table 18. Mulch by harvest interactive effects on leaf number, biomass, and area in collards, in 2012.

| Mulches | Harvest Number 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|
| | | Leaf Number (leaf $ha^{-1} \cdot 10^{-3}$)[a] | | | | |
| No Mulch [b] | 64 | BC a | 25 | BC b | 33 | B b |
| Newspaper Sheet | 110 | A a | 62 | A b | 66 | A b |
| Newspaper Sheet + Cover Crop | 80 | B a | 39 | BC b | 42 | B b |
| Plastic Sheet | 72 | BC a | 42 | B b | 41 | B b |
| Plastic Sheet + Cover Crop | 58 | C a | 35 | BC b | 35 | B b |
| Cover Crop | 37 | D a | 22 | C a | 41 | B a |
| | | Leaf Biomass (kg $ha^{-1} \cdot 10^{-1}$) | | | | |
| No Mulch | 68 | C a | 34 | C a | 29 | B a |
| Newspaper Sheet | 251 | A a | 160 | A b | 86 | A c |
| Newspaper Sheet + Cover Crop | 148 | B a | 103 | B ab | 46 | AB b |
| Plastic Sheet | 126 | B a | 103 | B ab | 38 | AB b |
| Plastic Sheet + Cover Crop | 80 | C a | 68 | BC a | 31 | B a |
| Cover Crop | 34 | C a | 34 | C a | 22 | B a |
| | | Leaf Area ($cm^2$ $m^{-2} \cdot 10^{-2}$) | | | | |
| No Mulch | 11 | C a | 6 | C ab | 3 | AB b |
| Newspaper Sheet | 29 | A a | 19 | A b | 9 | A c |
| Newspaper Sheet + Cover Crop | 18 | B a | 13 | B a | 6 | AB b |
| Plastic Sheet | 15 | BC a | 14 | AB a | 5 | AB b |
| Plastic Sheet + Cover Crop | 10 | CD a | 9 | BC ab | 3 | AB b |
| Cover Crop | 5 | D a | 5 | C a | 2 | B a |

[a] Upper-case letters represent the differences between mulch treatments within the harvest. Lower-case letters represent the differences of mulch treatments among harvests. Least squares means within columns and rows that are followed by the same lower case letter are not significantly different according to pairwise t-tests with a comparisonwise error rate of alpha = 0.05.

Collard leaf biomass plot$^{-1}$ was highest in the newspaper alone treatment at the second and third harvests. However, at the fourth harvest collard leaf biomass plot$^{-1}$ was highest in the newspaper alone, newspaper + cover crop, and plastic sheet mulch treatments. Collard leaf biomass in newspaper alone was higher than in no mulch, plastic sheet + cover crop, or cover crop mulch treatments. Across harvests, leaf biomass plot$^{-1}$ was similar in the no mulch, plastic + cover crop, and cover crop alone mulch treatments. The amount of collard biomass steadily decreased with each successive harvest in the newspaper sheet mulch treatment. In the newspaper + cover crop and plastic sheet treatments, the only clear differences in collard biomass were between the second and fourth harvests. The presence of a cover crop reduced collard leaf biomass at the second harvest in the newspaper and plastic treatments, while at the third harvest cover crop only affected the newspaper treatments and by the fourth harvest, the cover crop+sheet mulch treatments were not different than the corresponding sheet mulch alone treatments.

Collard leaf area plot$^{-1}$ during the second harvest was highest in the newspaper sheet mulch treatment. (Table 18). Collard total leaf area plot$^{-1}$ at the third harvest in the newspaper sheet treatment was higher than all treatments with the exception of the plastic sheet mulch. At the fourth harvest the only difference was between the newspaper alone and the cover crop alone treatments. The only treatment with similar results across harvest times was the cover crop alone treatment.  Leaf area in the newspaper alone treatment decreased at each successive harvest. In the newspaper sheet + cover crop and plastic sheet mulch treatments, leaf area was highest at the first two harvests, while in the no mulch and plastic sheet + cover crop treatments there were only differences between the second and fourth harvests. At the third harvest, the newspaper sheet+cover crop mulch treatment resulted in lower collard leaf area than the newspaper sheet alone treatment.

In 2011, the newspaper alone treatment had collard yields among the highest of all treatments tested, and in 2012 collard performance was the highest in the newspaper alone treatment. Previous research suggests that although newspaper mulch can increase yield compared to no mulch, it can also have negative effects on plants and fruit number. Smith et al. (1997) noted that as recycled paper mulch application depth increased (1.25 to 5.0 cm), geranium plant stem weight decreased in a linear fashion. Also, Monks et al. (1997) found that shredded newspaper applied at a shallow depth (2.5 cm) reduced tomato fruit production compared to black plastic, but increased tomato fruit production when compared to a no mulch treatment. Guertal and Edwards (1996) found that collards in newspaper mulch not only had lower yields when compared to black plastic, but they also had lower tissue nitrogen content. The difference between the results in this experiment and previous research may be attributed to the differences in quantity of newspaper applied as mulch. In previous research, the minimal mulch depth was 1.25 cm where in this experiment there were only two sheets of newsprint (~0.19mm thick) representing .02% of the 1.25 cm depth. These results suggest that a low quantity of newspaper will not compromise crop performance by immobilizing soil nitrogen.

Collard performance in the plastic sheet mulch was generally lower when compared to the newspaper sheet mulch. Previous research reported that crops in black plastic usually achieved comparable or higher yield when compared to paper mulch. Cirujeda et al (2012) found that tomato yield in plots with sheet paper mulch was comparable to yield in plots mulched with plastic sheet. Coolong (2010) found that total summer squash yield was similar in plots mulched with black plastic or several paper mulch treatments, including polyethylene coated Kraft paper, waxed paper, and butcher paper, when compared to non-weeded no mulch treatments. Lastly, collard yields were higher in plots mulched with black plastic compared to those mulched with newspaper (Guertal and Edwards, 1996). Lower collard performance in the plastic sheet treatments in 2012 can be attributed to seedling population reduction. Fewer surviving plants led to reduction in overall yield.

The cover crop alone treatment performed worst for all crop yield parameters and at all harvests, usually but not always having comparable results to the no mulch treatment. Previous research with cowpea or other legumes as mulch report contrasting results to those found in this experiment. The presence of a legume, in crimped/undercut cover crop plant residue mulch, increased tomato yield when compared to a cover crop mulch of pure ryegrass (Akemo et al 2000). Vollmer et al. (2010) reported that onion yield was highest in cowpea and no mulch treatments when compared to foxtail millet mulch. Harrison et al (2004) found that broccoli yield in cowpea residue mulch was higher when compared to no mulch. The reduced collard performance in cover crop alone can be attributed to the inability of cover crop residue to suppress weeds.

## CONCLUSION

The hypothesis of this research was that spring-sown cover crops in combination with newspaper sheet mulch would effectively suppress weeds and increase crop performance.

### Soil moisture

In this experiment, soil moisture was not as important as other factors and their effects on crop performance. In the black plastic treatments, depending on the location in the plot and the depth at which soil moisture was measured, data were variable. If the soil moisture was measured close to the plant, or through a hole in the plastic, then soil moisture was observed to be on par or wetter than soil in other treatments. If soil moisture measurements were taken away from plants or holes, and at a shallow depth, then the soil was observed drier than in other treatments. The newspaper mulches generally had moderate soil moisture levels and the no mulch treatment had the driest soil. Simply stated, soil cover by newspaper retained higher moisture levels than bare or weedy soil.

### Soil temperature

High soil surface temperatures can wreak havoc on transplanted seedlings. At the beginning of each season, transplants in plastic treatments had to be replaced. In the second season, all plants in plastic mulches were replaced at least once, many twice. Plastic treatments had the highest levels of plant mortality and this can be attributed directly to high surface temperatures. High soil temperatures, however, are not all negative. At the end of 2011, plants in the plastic treatments with higher soil temperatures caught up to the other mulch treatments, and in one instance in 2011, crop performance in the plastic sheet treatment surpassed the initial leading mulch, the newspaper sheet + cover crop treatment.

**Weed pressure**

Weeds have negative effects both on labor cost and ultimately on crop performance. The two treatments that were the weediest, the cover crop alone and the no mulch treatments, were more expensive to manage and had collards with the lowest overall yield. Mulch integrity plays a major role in weed suppression over the course of the season. A simple and continuous physical barrier that retains its integrity and quality can be very effective in weed suppression. There is no need for increased mulch mass and depth if sheet mulch can maintain its integrity.

**Mulch observations**

Plastic with or without a cover crop underneath is effective at suppressing weeds. In this experiment, plastic suppressed all weeds and was the least expensive in terms of hand-weeding costs. Plastic is relatively easy to install and maintains its integrity, stretching at points of pressure and resisting tearing. It can be used on large and small scales. Soil temperature increases caused by black plastic's heat absorptive and conductive properties can have negative effects on freshly transplanted seedlings. In wet or dry seasons, black plastic performed at the highest levels for weed suppression in this experiment.

When using newspaper sheet as a mulch it is imperative to 1) have a level surface, of either soil or rolled plant material, on which to apply the sheet(s); 2) ensure that the plant material, cover crop, or weed residues underneath the newspaper be dead or not present before application, and finally 3) have the edges of newspaper sufficiently anchored to the surface of the soil.  The best way to install the newspaper sheet in this experiment was by manually rolling out and anchoring it to the ground with staples and soil. This experiment demonstrated that when used properly, newspaper sheet mulch can outperform both plant residue and plastic mulches; however, its use is limited to small-scale agricultural production where the use of mechanical equipment is both location and cost prohibitive, and manual methods are preferred.

The cover crop alone mulch was the poorest performer of all of the treatments. Although its soil temperature and moisture under cover crop were moderate, it suppressed weeds poorly and led to poor crop performance. In order for cover crops to be effective as mulches, the crop residue layer has to be relatively thick and without gaps. The density at which the cover crops were planted was too low to achieve effective weed control for optimal crop performance. Generally, the combination of a crimped cover crop with either of the plastic or newspaper sheet mulches led to negative outcomes. The hypothesis of this research was that spring-sown cover crops in combination with unprinted newspaper would effectively suppress weeds and increase plant performance. Based on the results of this experiment, the hypothesis cannot be supported.

## FUTURE CONSIDERATIONS

This set of thesis experiments were designed to determine the effects of various mulches on soil, weeds, and crop yield in a low external input system. It would be beneficial to conduct another experiment using the same treatments, only varying input levels from minimal to high for inputs such as fertilizer, irrigation, pesticides, continued weed removal, and various crop protection and season extension strategies such as high and low tunnels, row covers, and shade cloth.

The cover crops used in this study fit nicely into the design of the experiment: an early summer cover crop to be used as a mulch for late summer/early fall collard crop. There are many other species, including oats, rye, sorghum-sudangrass, radish (*Raphanus sativus* L.), soybean, velvetbean [*Mucuna deeringiana* (Bort) Merr.], sunnhemp (*Crotalaria juncea* L.), berseem clover (*Trifolium alexandrinum* L.), crimson clover (*Trifolium incarnatum* L.), hairy vetch, subterranean clover (*Trifolium subterraneum* L.), sweet clover (*Melilotus officinalis* L.), lana vetch, and lablab [Lablab purpureus (L.) Sweet], that could be tested for their ability to suppress weeds in fall-grown collards. The cover crops used in this research and others could be studied at various densities, and ratios, and in different species mixes to determine which cover crop regime is most effective at improving soil conditions, weed management, and crop performance.

Preparing the cover crop prior to mulch installation was a large obstacle in this experiment. We undercut, rolled and crimped the cover crop before sheet mulch installation. This method was ineffective in completely killing the cover crop and also in distributing the plant material evenly over the soil surface. It would be worthwhile to test different ways to manage the cover crop before mulch installation via physical methods such as flail chopping, mowing with both sickle-bar and rotating blades, and incorporating the cover crop via mold-board plow or rototiller. Using these different techniques could create a uniform surface in order to facilitate sheet mulch installation.

The plastic and newspaper sheets used in conjunction with the cover crops were chosen based on availability and ease of installation. Lacking in this experiment was an understanding of the qualities of newspaper and plastic, such as water holding capacity and percolative properties, and degradation rates when exposed to environmental effects such as wind and water. Simple tests could be run to determine tensile strength of dry, wet, old and new newspaper. As we learned, collards transplant well in newspaper mulch but not in black plastic sheet mulch. By testing different colors of plastic sheet mulch we could determine if color played a part in early transplant mortality via heat radiation. The main drawback of the newspaper sheet mulch was that it tore easily, and although easy to roll out, it was difficult to keep it firmly anchored to the ground. It would be interesting to learn if impregnating the paper with a chemical or polymer would modify and improve its ability to stretch or resist tearing. Also the paper has a translucent quality that could have allowed weeds below the mulch surface to photosynthesize, grow, and push through the paper, so reducing light penetrability of paper with dyes could possibly increase its ability to suppress weeds.

In order to gain a better understanding of mulch effects on soil characteristics, soil temperature and moisture could be measured at various depths and locations throughout individual plots. Further soil tests could be conducted to determine how mulches affect soil chemistry during and after the growing season. Soil characteristics could be measured when mulches are left in place, on the soil surface, incorporated, or removed to determine long and short term effects.

The crop chosen was collards because it fit within the desired late summer/early fall niche and because it usually performs well as a transplant. There are several other crops that could be tested to determine if they are a better or comparable fit for this planting design. Also, collards can overwinter and be harvested in the spring, so investigations could be continued over a longer period.

Ultimately, it would be most beneficial to conduct mulch experiments in grower's fields or urban lots. It would be beneficial to obtain qualitative data from growers, and to gauge their reaction to the aesthetics and overall impressions of an integrated system using renewable mulches. Grower and consumer input will drive future research in urban agriculture.

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