UTILIZATION OF COMMON BUCKWHEAT AS A SHORT-CYCLE COVER CROP BEFORE DIRECT-SEEDED PROCESSING CUCUMBER PRODUCTION

BY

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THESIS

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ABSTRACT

Weeds are difficult to control in processing cucumber (*Cucumis sativus*) production because of the growth habit of cucumber and its sensitivity to herbicides. One alternative method is utilizing short-cycle summer cover crops, such as common buckwheat *(Fagopyrum esculentum)* prior to planting cucumber. However, this needs to be tested to assess any potentially negative influences of buckwheat on cucumber yields. To examine the effects of buckwheat on cucumber growth, four field experiments were conducted in 2008 and 2009 in northern and central Illinois and two greenhouse experiments were conducted in Urbana, IL in 2010.

Using buckwheat as a cover crop prior to direct-seeding cucumber had negative effects on overall cucumber growth and yield in both field and greenhouse experiments. . In the field experiments, buckwheat reduced weed growth during the buckwheat stand, but did not provide long-term weed suppression during the cucumber growth period, and caused inhibition of cucumber growth and reduction of cucumber yield, making it unsuitable to be used as cover crop prior to cucumber if there is only a seven-day period between incorporation and seeding processing cucumbers. In the greenhouse experiments, cucumber plants grown in soil that had previously grown buckwheat seven days earlier were smaller and less vigorous than those grown in soil with no buckwheat residues or containing only buckwheat shoots. Direct-seeding cucumber into buckwheat residues only one week after killing the buckwheat is not advisable as cucumber growth and yield will be reduced as a result.

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CHAPTER ONE: LITERATURE REVIEW

INTRODUCTION

Vegetables have a high market value, and as such, are a popular choice for many farmers. According to the USDA, vegetables and melons made up 14 percent of all U.S. farm cash receipts, even though the production of these crops occurred on only 2 percent of all the harvested cropland in the country (Ali and Lucier, 2011). A variety of vegetable crops are grown commercially in the Midwestern United States, including tomatoes, cabbage, peppers, potatoes, pumpkins, cucumbers, sweet corn, horseradish, and snap beans. In Illinois, nearly 25,000 hectares are used for fresh and processed vegetable production, producing 221,036 and 177,273 metric tons (MT) in fresh and processed vegetables, respectively, generating 28.5 million dollars in exported vegetables alone (NASS 2010, 2011). It is clear that while corn, soybean, and alfalfa hay are Illinois' major commodities, vegetable production is very important to the state's economy and warrants attention to make it as efficient and environmentally responsible as possible.

Vegetable production has a number of difficulties associated with it, and farmers are constantly seeking alternative ways to increase yields and quality and decrease costs. Intensive tillage used to prepare the seed bed and control weeds can lead to soil erosion and destruction of the delicate soil structure needed to provide an adequate rooting environment and access to water and nutrients. Excessive use of synthetic fertilizers can cause a buildup of soluble salts in the soil, leading to reductions in plant vigor and growth. Weeds are a significant problem for vegetable farmers because they can interfere with every stage of production, from seeding to harvest (Sullivan, 2003b), and they can cause significant reductions in marketable yield if not managed within the first four to six weeks after planting the crop (Loux *et al.*, 2011). Not only are weeds a problem at all times of the growing season, but there are high costs associated with herbicides and labor to remove the weeds, and vegetable farmers are always seeking alternatives to reducing herbicide inputs and labor costs. In addition, herbicide resistance in many crops is a major concern for many farmers (Owen and Zelaya, 2005), and this is one of the reasons that many vegetable growers are turning toward more sustainable weed management systems.

Many practices used in sustainable agriculture production systems, including conservation tillage, crop rotation, and cover cropping, can be applied to all vegetable production systems to provide farmers a profit, meet society's needs for organic and sustainably produced vegetables, and to protect the environment. These methods must be assessed and applied knowledgeably to ensure efficacy, farmer utility and profitability while protecting the environment (Earles, 2005; Sullivan, 2003b). Using cover crops in particular is one way to reduce fertilizer, pesticide, and herbicide inputs; increase soil organic matter; and control pests, diseases, and weeds. However, cover crops are just as diverse as vegetables, and they can interact differently with different crops (Clark, 2007), presenting a number of challenges for the grower, such as difficulty killing the cover crop completely and on time before the scheduled cash crop plant time, as well as possible inhibition of the cash crop caused by the cover crop. Therefore, cover crops need to be evaluated specifically and with particular vegetable crops before implementing a cover-cropping program.

COVER CROPPING IN VEGETABLE PRODUCTION

The implementation of cover cropping in vegetable production is becoming more common as growers are seeking out alternative ways of improving soil fertility and pest and weed management without synthetic chemical inputs. By definition, a cover crop is any crop planted to cover the soil, including green manures, the latter being incorporated into the soil upon killing (Sullivan, 2003a). In general, cover crops are used to occupy the soil when there is no cash crop production (Liebman and Davis, 2000; Sullivan, 2003b), and they can remain for long durations of several months to a couple years, or short periods of one to three months, depending on the cover crop and time of year they are being grown (Clark, 2007). This makes them a versatile and valuable addition to many cropping systems, capable of supplying growers many short- and long-term benefits.

Benefits of Cover Cropping

Improvement of Soil Structure and Fertility

Cover crops improve soil structure and water holding capabilities, increase the organic matter content of the soil, reduce nitrate leaching, and sequester and supply nutrients to subsequent crops (Fennimore and Jackson, 2003; Kumar *et al.,* 2008; Sullivan, 2003a). They improve the soil's physical structure in a variety of production systems by adding substantial amounts of organic matter to the soil, improving tilth, aeration, drainage, and aggregation (Sullivan, 2003a). Cover crops release root exudates, including labile polysaccharides, which bind soil particles together. These aggregate-forming polysaccharides are also added to the soil by microorganisms degrading crop residues. Increased aggregation improves soil structure by increasing porosity, thus alleviating compaction and low water infiltration (Liu *et al.*, 2005).

Intensive tillage can control weeds, but it also can damage soil aggregates and pore spaces, leading to soil compaction and poor water drainage (Lonsbary *et al.*, 2004). Reduced tillage or no-till systems can help preserve soil structure, but if the soil is finely textured, such as heavy clay, reduced tillage can lead to similar problems as those mentioned above for intensive tillage systems. Treadwell, *et al.* (2007) found that reduced tillage caused lower sweet potato yields and reduced vine biomass, regardless of whether a cover crop of hairy vetch or rye was used. However, the cover crops produced enough hairy vetch or rye biomass to adequately suppress weeds during the three-year study, while the reduced tillage treatment without cover crops had higher weed densities than any of the other treatments (Treadwell *et al.*, 2007).

Cover crops provide additional organic matter to the soil surface and topsoil, increasing the water holding capacity. On soil that is left fallow, only 40 percent of water that the field receives remains in the soil, the rest is lost to evaporation and runoff (Peterson *et al.*, 1996; Tanaka *et al.*, 2007). Heavy rainfall during fallow periods can cause significant nitrogen leaching, phosphorous loss, and soil erosion (Farahani *et al.*, 1998; Udawatta *et al.*, 2004). However, keeping plant residues on the soil during times of fallow can diminish these losses. Farahani *et al.* (1998) found that incorporating a summer annual cover crop of corn (*Zea mays* L.) or sorghum (*Sorghum bicolor* (L.) Moench) can increase the soil's ability to hold soil water by 47 percent.

Cover crops not only improve the physical structure, they also enhance the fertility of the soil and the availability of nutrients to the following crops (Snapp and

Borden, 2005; Sullivan, 2003a and b). One major limiting factor in vegetable production is the amount and availability of nitrogen (Neeteson and Carton, 2001). Most soil nitrogen is in organic matter and not immediately available, while the remainder is very soluble and mobile, and therefore, easily leached through the soil profile. Nitrogen supply and demand must be balanced to maximize crop productivity while minimizing the environmental impacts of nitrogen in processes such as eutrophication (Neeteson and Carton, 2001).

Planting cover crops when cash crops are not present reduces nitrogen leaching and runoff (Farahani *et al.*, 1998; Snapp *et al.*, 2005; Strock, *et al.*, 2004). They slow water percolation and decrease the amount of soluble nitrogen leaching through the soil (Guo *et al.*, 2008; Strock *et al.*, 2004). Guo *et al.* (2008) found that growing sweet corn as a summer catch crop (a cover crop used to capture excess nitrogen present in the soil) in a cucumber production system resulted in a 19 to 22% reduction in nitrogen loss from the top layers of soil. Cover crops use nitrogen during growth, storing it in their tissue, and upon decomposition release the nitrogen to the succeeding cash crops (Guo *et al.*, 2008; Kumar *et al.*, 2008). The carbon to nitrogen ratio of the cover crop is important because if it is higher than 25, nitrogen can be immobilized by soil microbes and will be unavailable to the crop until released by the microbes (Sullivan, 2003a). This immobilization is only temporary, however, and the nitrogen will be released for plant uptake eventually.

Phosphorus is another nutrient that can be inaccessible to plants because it is mostly water insoluble and does not move through the soil (Clark, 2007). Phosphorus is one of the most utilized nutrients by plants, but it is one of the least available nutrients in the soil, its bioavailability rarely exceeding 10 µM even in fertile soils (Zhu *et al.*, 2002). Cover crops modify the chemical and biological properties of soil to mobilize and sequester phosphorus and, upon decomposition, provide phosphorus to cash crops (Eichler-Lobermann, 2008; Sullivan, 2003a). The cover crops phacelia (*Phacelia tanacetifolia*) and serradella (*Ornithopus sativus*) increased phosphorus uptake of summer rape, summer barley, and summer wheat as well as increasing the phosphorus sequestered in the soil (Eichler-Lobermann, 2008). However, common buckwheat (*Fagopyrum esculentum* Moench) is considered to be the most effective cover crop at scavenging and sequestering phosphorous, and has been shown to be able to utilize all forms of phosphate in the soil, making it invaluable in soils with limited phosphorous or in production systems with high phosphorous requirements (Creamer and Baldwin, 1999; Sullivan, 2003a; Van Ray and Van Diest, 1979).

Increased Control of Weed Populations

Weeds are a major limiting factor in both conventional and organic production. They compete with the crops for water, light, and nutrients, and harbor pests (Linares *et al.*, 2008; Sullivan, 2003a). Weeds can also make production more difficult by interfering with tillage, irrigation, and harvest, increasing the amount of labor needed to grow crops (Linares *et al.*, 2008). Weed control is also very important for preventing perennial weed establishment, particularly in reduced tillage production systems (Kumar *et al.*, 2008).

Cover crops are very useful for weed control. They compete with the weeds for water, light, and nutrients, and also help by disrupting the ecological niches that weeds occupy and rely on for growth and reproduction (Haramoto and Gallandt, 2005). They can also be very effective in suppressing weeds during the fallow period of the field, and even during the growing period of the cash crop (Charles *et al.*, 2006; Fennimore and Jackson, 2003; Kumar *et al.*, 2008; Linares *et al.*, 2008; Ngouajio and Mennan, 2005; Sullivan, 2003a). There is an inverse relationship between cover crop dry weight and weed biomass. However, volunteer emergence of cover crops in the cash crop can become just as inhibitory as the weeds, so it is important to kill the cover crop before it sets seed.

Many studies have investigated the effects of cover crops on weed densities, species composition, and populations. Sorghum-sudangrass, cereal rye (*Secale cereale*), and hairy vetch cover crops result in lower weed densities (40, 56, and 65 plants m^{-2}, respectively) than do bare ground treatments (372 plants m^{-2}) (Ngouajio and Mennan, 2005). Charles *et al.* (2006) found oilseed radish provided as much as 98% weed suppression, accumulated the most biomass and resulted in highest celery yields than an overwintering cereal rye – hairy vetch cover crop treatment. In the control treatment plots with no cover crops there were 200-313 weeds m^{-2}, while in the oilseed radish treatment plots, there were only 49-51 weeds m^{-2} (Charles *et al.,* 2006). Many other studies support the conclusion that cover crop residues suppresses weed growth (Campiglia *et al.*, 2010; Haramoto and Gallandt, 2005; Walters *et al.*, 2007; Williams II *et al.*, 1998). A cereal rye cover crop reduced redroot pigweed and smooth crabgrass densities up to 69 and 89%, respectively, without any herbicide inputs (Walters *et al.*, 2007). However, at least one other study shows that cover crop residues may have the potential to stimulate some weed species (*Chenopodium album* L.) to emerge and grow (Kruidhof *et al.*, 2009).

Competition for resources and effects on weed seed germination and emergence are major factors in the effectiveness of cover crops in reducing weed densities. Seed size is often associated with germination and survival of plants during periods of stress (Haramoto and Gallandt, 2005). Due to their larger seed reserves, crops species are often more tolerant of low soil fertility than are weed species with smaller sized seeds (Kumar *et al.*, 2008). Cover crops also alter the microenvironment of the seedbed, often creating cooler, moister conditions, negatively affecting weed seed survival and subsequent emergence and growth (Linares *et al.*, 2008). There is a positive correlation between soil moisture and organic matter in cover cropped soils and increased weed seed degradation (Lewis, 1973). Higher levels of biological activity near the soil surface negatively affect weed seed viability (Cardina *et al.*, 1991; Kremer, 1993), and cover crops increase soil microbiological activity (Fennimore and Jackson, 2003; Linares *et al.*, 2008).

Cover crops may also reduce weed populations by affecting the nitrogen dynamics of the soil. Many weeds are adapted to rapid early growth and nitrogen uptake, so the decrease in soil nitrogen under cover crops may decrease weed emergence and growth. Weeds generally have a high relative growth rate (RGR_{max}) under optimal nutrient conditions, and they may suffer the largest decline in RGR_{max} under nutrient stress (Kumar *et al.*, 2008). Nitrate may stimulate weed germination and emergence, so in cropping systems with high inputs of nitrogen fertilizer, weeds can be more of a problem than in systems with no added nitrogenous compounds or no leguminous crops (Kumar *et al.*, 2008; Charles *et al.*, 2006).

Some cover crops, such as buckwheat and cereal rye, also suppress weeds through the release of allelopathic chemical compounds (Eskelsen and Crabtree, 1994; Golisz *et* *al.*, 2007a; Khanh *et al.*, 2005; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004). Allelopathy is the inhibitive or promotive interaction between plants caused by chemicals released through decomposition, leaching from aerial plant parts, and root exudates (Golisz *et al.*, 2007b; Khanh *et al.*, 2005). It is important to achieve the highest allelopathic activity during weed germination and initial growth. The effects of these allelochemicals will eventually decrease, but reduced weed germination and early growth may give the crop a competitive advantage and allow the crop to shade out the weeds (Khanh *et al.*, 2005).

Plants containing allelochemicals tend to have the highest concentrations in the aerial plant parts, such as the leaves, flowers, and stems (Golisz, 2007b; Iqbal *et al.*, 2002, 2003; Kumar *et al.*, 2009). These allelochemicals are held in the plant tissue until either the plant dies and the allelochemicals are released by decomposition, or until they leach out of the leaves and flowers and enter the soil. Otherwise, plant roots can release allelopathic exudates that can suppress another plant species directly or indirectly by altering the soil environment and that plant's ability to absorb mineral nutrients (Balke, 1985; Radosevich *et al.*, 1997). This effect on the soil environment is something the allelochemicals from the aerial parts accomplish as well; however, the mechanisms of allelopathic action are still not entirely understood.

Problems Associated With Using Cover Crops

Even though cover crops have the potential in a vegetable production system to improve soil and reduce weed pressure, there are potential drawbacks and challenges to using cover crops. Unfortunately, the same qualities that make cover crops effective at controlling weeds can also cause reduced growth and yield in the cash crop. Cover crop residues on the soil surface reduce soil surface airflow and increase soil insulating effects, creating much cooler and wetter conditions in the spring that can inhibit crop seed germination and growth. In addition, as cover crop residues decompose, nutrients sequestered by the cover crop can be immobilized by microbes and be initially unavailable to the cash crop. Cover crops that have allelopathic properties can also inhibit cash crop seed germination and plant growth if the cash crop is planted too soon after cover crop incorporation (Roos, 2006). Therefore, it is possible that cover crops can cause reduced growth and yield in the subsequent cash crop.

The method and timing of planting, killing and incorporating the cover crop is also an important consideration for the grower, and if not done appropriately, can cause problems for the subsequent cash crop. If the weather or soil conditions prevent the grower from planting the cover crop on time, the cover crop may not accumulate enough biomass to suppress weeds or provide much organic matter or other soil improving contributions. Likewise, if the grower is unable to kill the cover crop at the right time, or inadequately kills the cover crop, the cover crop can possibly set seed and become a volunteer weed problem for the cash crop. Clearly, due to the diversity of cover crops and production systems, more evaluation of specific cover crop interactions with vegetable crops needs to be accomplished before regular, widespread use of cover cropping can occur.

BUCKWHEAT AS A SHORT-CYCLE COVER CROP

Short-cycle summer cover crops, such as common buckwheat and sorghum-sudangrass, that are grown and killed just before or after the cash crop, give the grower the opportunity to limit competition with the cash crop, complete both the cover crop and cash crop's life cycles in one growing season, and reap the benefits of cover crops (Sullivan, 2003b). These cover crops grow rapidly in the warm temperatures of late-spring to early fall, and are often effective at out-competing common summer weeds, such as pigweeds, purslane, and common lambsquarter. Summer cover crops accumulate significantly more biomass than winter cover crops because the latter face colder temperatures leading to slower growth and potential winterkill. Since weed biomass is inversely related to cover crop dry mass, winter cover crops are not as successful in suppressing weeds as are summer cover crops (Linares *et al.*, 2008). Another problem with winter cover crops is that they may cover the soil too quickly, causing weed seeds to remain dormant instead of germinating and being killed by either frost or competition (Charles *et al.*, 2006). These weed seeds are able to germinate after the land has been prepared for planting, creating a weed problem for the cash crop (Charles *et al.*, 2006).

Buckwheat, in particular, is considered a short-cycle cover crop because of its rapid growth and frost sensitivity, making it great for filling small niches in the growing season when other cover crops would need more time to establish. It needs only 35 – 45 days to effectively control weeds and improve soils, and it is killed before seed maturation occurs, no more than ten days after the onset of flowering (Bjorkman *et al.*, 2009). Buckwheat is a warm season plant that can be utilized during a part of the growing season when cold season cover crops, such as rye and oats, may not be as vigorous. Because buckwheat is extremely frost sensitive, it must be planted after the last chance of frost or approximately 40 days before the first frost is expected (Clark, 2007).

Buckwheat establishes canopy cover faster than most weeds, minimizing weed emergence and requiring few inputs (Edwardson, 1996; Kumar *et al.*, 2008). It prefers low nitrogen environments, making it a good cover crop in systems with limited nitrogen inputs or availability (Berglund, 2003; Edwardson, 1996; Van Ray and Van Diest, 1979). Buckwheat seedlings typically emerge after only four days and will quickly occupy the soil, being fully established and ready to mow down approximately six weeks after sowing (Bjorkman *et al.*, 2009).

Buckwheat is of interest because of its ability to increase soil fertility and organic matter content and decrease weed emergence and growth (Clark, 2007; Creamer and Baldwin, 1999; Kumar *et al.*, 2009). Since buckwheat grows best in cool to warm weather, it could be planted from late May through late August in the Midwest and killed before planting the cash crop. Growing buckwheat in late spring would potentially control weeds closer to the time of planting a following cash crop. Also, after harvesting a spring-planted vegetable crop, buckwheat could be planted in the early fall to fill a niche before the planting of a winter cover crop (Clark, 2007).

Potential Benefits of Using Common Buckwheat as a Cover Crop

Buckwheat has potential as a short-cycle cover crop. Buckwheat flowers are quite pungent and attract beneficial insects (English-Loeb *et al.*, 2003; Kumar *et al.*, 2008; Nicholls *et al.*, 2000; Platt *et al.*, 1999). The plant has few problems with pests and diseases (Edwardson, 1996; Kumar *et al.*, 2008; Lachmann and Adachi, 1990).

Buckwheat improves soil structure through its extensive lateral root system (Clark, 2007). Buckwheat has an average root density of 4.7 cm cm^{-3} with the greatest density in the 0-20 cm layer of soil (Murakami, 2002). Many farmers who have used buckwheat as a cover crop refer to its ability to “mellow” the soil, leaving it in a friable and fertile state, ready for planting (Petrich, 2000).

Buckwheat can efficiently adsorb nutrients, as well as sequester them in the soil by modifying the chemical and biological properties of the soil surrounding the plant roots (Van Ray and Van Diest, 1979; Zhu *et al.*, 2002). Buckwheat tissue contains higher amounts of potassium, calcium, magnesium, and phosphorus than do tissues of clover, wheat, maize, and soybean (Van Ray and Van Diest, 1979; Warman, 1991). Kumar *et al.* (2008) found that potassium is higher in soils containing buckwheat residues compared to soils containing no residues. Once the buckwheat is killed and incorporated as a green manure, these accumulated nutrients become available to subsequent crops. Since buckwheat vegetation is succulent, decomposition occurs rapidly (Creamer and Baldwin, 1999), making the nutrients more readily available to the next crop.

Buckwheat sequesters phosphorus and is highly efficient at its uptake and use in physiological processes. Zhu *et al.* (2002) found that total phosphorus uptake by buckwheat was ten times higher than phosphorus uptake by wheat, a crop regarded as being efficient in taking up phosphorus. One explanation for the high phosphorus uptake is buckwheat's ability to acidify the rhizosphere by excreting protons; that dissolves the calcium-bound phosphorus in the alkaline soil, making all forms of phosphate more available to the crop (Van Ray and Van Diest, 1979; Zhu *et al.*, 2002).

Buckwheat is effective in managing weeds, reducing weed biomass 75 to 99%, compared to bare-ground treatments (Creamer and Baldwin, 2000; Iqbal *et al.*, 2003; Kumar *et al.*, 2008; Tominaga and Uezu, 1995). Kumar *et al.* (2008) found that buckwheat incorporated immediately after killing, reduced the emergence and biomass of several weed species, including redroot pigweed, shepherd's purse (*Capsella bursa-pastoris*), and corn chamomile (*Anthemis arvensis*), but was not effective at inhibiting barnyardgrass (*Echinochloa crus-galli*). However, when buckwheat residue decomposed for fifteen days before being incorporated, the residues only reduced redroot pigweed emergence (Kumar *et al.*, 2008). These results suggest that timing of buckwheat incorporation after killing is important for weed management, and should be incorporated at the time of killing.

One mechanism of buckwheat's ability to control weeds is the effect of buckwheat on soil nitrogen availability, which influences weed emergence and growth. Buckwheat has a C:N ratio of 34, immobilizing nitrogen during buckwheat decomposition (Creamer and Baldwin, 1999). Many weeds are adapted to rapid early growth and nitrogen uptake, so the decrease in soil nitrogen after the incorporation of a buckwheat cover crop may decrease weed emergence and growth (Kumar *et al.*, 2008). Soil with low levels of nitrogen (0-40 kg ha^{-1} added N) containing fresh buckwheat cover crop residues have been shown to suppress the emergence and growth of shepherd's purse, corn chamomile, and Powell amaranth, but once nitrogen levels increased, emergence was stimulated in shepherd's purse and corn chamomile, overcoming the inhibitory effects of the buckwheat residues (Kumar *et al.*, 2008). However, Powell amaranth inhibition was not improved by the addition of nitrogen, which suggests another mechanism of weed control by the buckwheat cover crop, such as allelopathy (Kumar *et al.*, 2008). Since buckwheat decomposes quickly, this nutrient tie-up does not persist, and therefore, the adverse effects on weed seeds may be short-lived. Nitrogen immobilization could also inhibit the emergence of the cash crop, and the impact of nitrogen tie-up after buckwheat incorporation on large-seeded crops, such as cucumber, is unknown.

Buckwheat also suppresses weeds through the release of allelopathic chemical compounds (Eskelsen and Crabtree, 1994; Golisz *et al.*, 2007a; Iqbal *et al.*, 2005; Kalinova, 2007, 2008; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004). Buckwheat contains many allelochemicals, which are predominately flavonoids and phenolic acids, found in the highest concentrations in buckwheat leaves or dried or necrotic plant parts (Golisz *et al.*, 2007b; Kalinova, 2007, 2008). Golisz (2007b) noted that although significantly more allelochemicals are found in the leaves and inflorescens than in the stems, buckwheat stems can make up to 52% of the total biomass. So the stems may still play an important role in allelopathy (Iqbal *et al.*, 2002, 2003). There is a positive correlation between the concentration of rutin, the main allelochemical found in buckwheat, and weed inhibition (Kalinova, 2008), but the effectiveness of buckwheat allelochemicals is weed species dependent (Golisz *et al.*, 2007a; Iqbal *et al.*, 2005; Kalinova, 2007, 2008; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004). Regardless of the weed species, buckwheat is most inhibitive towards total weed biomass, not weed density, suggesting more of an inhibitory role in weed growth compared to weed emergence (Iqbal *et al.*, 2005; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004).

Problems Associated With Using Buckwheat as a Cover Crop

Although buckwheat has potential as a short-cycle summer cover crop for soil improvement and weed control, its vigorous growth is highly dependent on both temperature and rainfall, and therefore, may not be suitable in some climates or years with very wet conditions (Clark, 2007; Matsura *et al.*, 2005). Buckwheat is very frost sensitive, so in a very cool spring it may be difficult to get it established before a summer vegetable crop.

Excessive rainfall causing flooding and saturation of soil reduces the growth of buckwheat, causing reduced number of leaves and leaf area, leading to plants that are not as effective at out-competing weeds (Matsuura *et al.*, 2005). This reduction in growth could reduce weed suppression, and therefore, too much water is undesirable for potential weed control by buckwheat. In addition, too much rain will make it difficult, if not impossible, to kill and incorporate the buckwheat just after flowering, and this could lead to delayed planting of the subsequent vegetable crop and the potential risk of adventitious buckwheat.

The difficulties with using buckwheat as a cover crop may cause delays in planting, poor buckwheat growth, or the inability to grow buckwheat at all in a particular season. It could also cause reductions in cash crop yield if buckwheat produces seed and grows as a weed in the crop, where it competes with the vegetable crop. The allelopathic characteristics of buckwheat could inhibit the emergence, growth and yield of the subsequent vegetable crop. Therefore, it is very important to research the effects of buckwheat on vegetable crops, as well as to determine the adequate amount of time between killing and incorporating buckwheat and planting the cash crop. The best method of killing and incorporating buckwheat is also important to determine. Some vegetable growers may adhere to low-till, or no-till cultivation methods, and may only mow buckwheat down before planting the cash crop, while others may till or disk the buckwheat in. These different methods also need to be investigated before a recommendation of a cover-cropping program including buckwheat can occur.

CUCUMBERS

Cucumbers (*Cucumis sativus* L.) belong to the family *Cucurbitaceae* that also includes melons, pumpkins, and squash. Per capita cucumber consumption was three kilograms per year in the United States (Rowell and Coolong, 2010). Cucumbers are an important crop in the United States, and maintaining high cucumber yields is extremely important to vegetable growers in the United States.

Cucumber Cultivation

Cucumber thrives in warm temperatures and well-draining soils containing high amounts of organic matter (Precheur, 2009). The vining annuals are planted when there is no chance of frost and when the soil has warmed to at least 21°C (Bradley *et al.*, 2009). The average growth cycle for pickling cucumber is 40 to 55 days (Wang and Ngouajio, 2008).

Commercial cucumber production practices include the reliance on intensive tillage, high planting densities, and pesticides (Lonsbary *et al.*, 2004; Van Gessel, 2007). Intensive tillage is very damaging to the soil structure, leading to soil erosion, compaction, and surface water runoff (Lonsbary *et al.*, 2004). In addition, processing cucumber is grown on bare soil, which also leads to soil erosion after repeated tillage and planting (Pollack, 1995).

Weeds are a major limiting factor in both conventional and organic cucumber production. Weeds can also make production more difficult by interfering with tillage, irrigation, and harvest, increasing the amount of labor needed to grow crops (Linares *et al.*, 2008; Van Gessel, 2007). Processing cucumbers are typically machine-harvested, which requires weed control to limit damage and maximize yield (Van Gessel, 2007).

However, once cucumber vines spread onto the paths between rows, using mechanical cultivation for late season weed control will be very difficult (Seaman *et al.*, 2009). Early emerging weeds cause more cucumber yield loss than later emerging weeds because canopy closure occurs three or four weeks after planting, allowing early season weeds the opportunity to establish and out-compete the cucumber plants (Wang and Ngouajio, 2008). Weed interference plays a part in cucumber yield reductions, and cucumber yields have been shown to be negatively correlated to high densities of common weeds, such as redroot pigweed (*Amaranthus retroflexus*) and smooth crabgrass (*Digitaria ischaemum*) (Walters *et al.*, 2007).

Weed control in conventional cucumber production systems is highly dependent on preemergent herbicides, particularly ethalfluralin and clomazone, although cultural methods of weed control, including tillage and hand weeding, are often needed to supplement the incomplete weed control from preemergent herbicides (Van Gessel, 2008; Zandstra, 2008). Ethalfluralin and clomazone can cause crop injury and common weeds such as nightshade and pigweeds are tolerant of them (Van Gessel, 2008).

Generally, weeds are able to out-compete the cucumbers for water, nutrients, and light if the weeds are able to emerge before cucumber canopy closure (Al-Khatib *et al.*, 1994; Guo *et al.*, 2008; Wang and Ngouajio, 2008). Since processing cucumber is direct-seeded, there is a three to four week window when weeds can establish before cucumber canopy closure occurs, so the critical time for weed control is the first three to five weeks after cucumber emergence (Al-Khatib *et al.*, 1994; Friesen, 1978; Wang and Ngouajio, 2008; Weaver, 1984). Cucumber yields are also reduced if weeds infest the field for longer than four weeks at any time throughout the growing period (Weaver, 1984).

Planting cucumber transplants lessen this critical period due to faster canopy closure, but growers of processing cucumber most commonly use direct-seeding to achieve higher crop densities with less cost than transplanting (Seaman *et al.*, 2009).

Cucumber contains allelopathic compounds that have been shown to inhibit the germination and growth of a few common weeds, including wild proso millet (*Panicum miliaceum* L.), redroot pigweed (*Amaranthus retroflexus*), barnyardgrass (*Echinochloa crus-galli*), and crabgrass (*Digitaria spp.*) (Lockerman and Putnam, 1979, 1981; Putnam and Duke, 1974; Thi *et al.*, 2008). Lockerman and Putnam (1979) and Putnam and Duke (1974) showed that cucumber seeds could reduce wild proso millet fresh weight by 58 – 87%, and Thi *et al.* (2008) demonstrated that extracts from only 0.3 g of dry cucumber tissue suppressed root and shoot growth of crabgrass by 98.8 and 88%, respectively. However, the cucumbers that had the most inhibitive effects were wild types, and the common cultivar 'Pioneer' showed no allelopathic effects when compared to the control (Lockerman and Putnam, 1981).

Temperature and rainfall also appear to play a large role in determining the effectiveness of cucumber's allelopathic properties. Lockerman and Putnam (1979) noted that there was very little weed suppression during a very rainy year, implying that the allelochemicals leached out before being able to inhibit weeds. Under high temperatures (30°C day / 25°C night), cucumber was very inhibitive of the germination and growth of lettuce seedlings, although this could have been due in part to lettuce germination and growth being inhibited by the high temperatures (Pramanik *et al.*, 2000). There is also debate over when cucumber is the most allelopathic. Some studies have shown that allelopathic toxicity reduces to non-toxic levels ten days after the onset of seed imbibition (Lockerman and Putnam, 1981; Putnam and Duke, 1974), while others have found evidence that cucumber is the most inhibitive during their reproductive stage, starting at 40 days after planting (Yu and Matsui, 1994). With this disparity in evidence, cucumber growers should not rely on cucumber's possible allelopathic potential for adequate weed control, and should seek out alternatives to damaging herbicides to control weeds in processing cucumber.

CONCLUSION

Production of processing cucumber could possibly benefit from the addition of buckwheat cover crops. Intensive tillage commonly used in cucumber production is very damaging to the soil structure, leading to soil erosion, compaction, and surface water runoff (Lonsbary *et al.*, 2004). Buckwheat could improve the soil, preventing many of these problems (Linares *et al.*, 2008). In addition, the potential weed control provided by buckwheat may be beneficial and would reduce the need for the large quantity of herbicides regularly used in cucumber production. Weeds are difficult to control in cucumber production because of the growth habit of cucumber and its sensitivity to herbicides.

While the use of common buckwheat to control weeds may sound promising, growing it prior to processing cucumber presents many challenges for the cucumber grower. Delayed buckwheat planting due to cold spring temperatures or excessive rainfall may cause delays in planting of the cash crop, poor buckwheat growth, or the inability to grow buckwheat at all in a particular season. Delayed buckwheat killing due to saturated soils and the risk of compaction or incomplete killing of buckwheat due to inadequate incorporation methods could cause reductions in cucumber yield if the buckwheat sets seed and causes interference as a volunteer weed with the cucumber crop. Also, although buckwheat's mechanisms of weed control are effective in suppressing weeds, they may also inhibit the emergence, growth, or yield of the cucumber crop. Clearly, these potentially harmful effects of buckwheat on cucumber are just as important to determine as the potential beneficial effects on weed control.

There have been numerous studies conducted on the effectiveness of buckwheat on weed control (Eskelsen and Crabtree, 1994; Golisz *et al.*, 2007a; Iqbal *et al.*, 2005; Kalinova, 2008; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004), as well as on the use of cover crops in various *Cucurbit* crops (Ngouajio and Mennan, 2005; Vanek *et al.*, 2005; Walters *et al.*, 2007; Wang and Ngouajio, 2008; Zandstra *et al.*, 1998), but no previous research has looked specifically at the effect of buckwheat on cucumber growth or the competitiveness of cucumber with common weeds such as large crabgrass (*Digitaria sanguinalis* (L.) Scob). Studies need to determine the interactions between buckwheat and cucumber in the Midwestern United States.

The purpose of this research was to investigate the effectiveness of various buckwheat cultivation techniques prior to growing processing cucumber, and to evaluate the effects of buckwheat residues on weed growth both during buckwheat and cucumber growth, and the effects of buckwheat on the growth of processing cucumber. To accomplish this, both field and greenhouse studies were conducted from 2008 through 2010 in northern and central Illinois.

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CHAPTER TWO: EFFECTS OF A BUCKWHEAT COVER CROP ON WEED AND PROCESSING CUCUMBER GROWTH

ABSTRACT

Weeds are difficult to control in processing cucumber (*Cucumis sativus*) production because of the growth habit of cucumber and its sensitivity to herbicides. One alternative method is utilizing short-cycle summer cover crops, such as common buckwheat *(Fagopyrum esculentum)* prior to planting cucumber. However, this needs to be tested to assess any potentially negative influences of buckwheat on cucumber yields. To examine the effects of buckwheat on cucumber growth, four field experiments were conducted in 2008 and 2009 in northern and central Illinois and two greenhouse experiments were conducted in Urbana, IL in 2010.

Using buckwheat as a cover crop prior to direct-seeding cucumber had negative effects on overall cucumber growth and yield in both field and greenhouse experiments. . In the field experiments, buckwheat reduced weed growth during the buckwheat stand, but did not provide long-term weed suppression during the cucumber growth period, and caused inhibition of cucumber growth and reduction of cucumber yield, making it unsuitable to be used as cover crop prior to cucumber if there is only a seven-day period between incorporation and seeding processing cucumbers. In the greenhouse experiments, cucumber plants grown in soil that had previously grown buckwheat seven days earlier were smaller and less vigorous than those grown in soil with no buckwheat residues or containing only buckwheat shoots. Direct-seeding cucumber into buckwheat residues only one week after killing the buckwheat is not advisable as cucumber growth and yield will be reduced as a result.

INTRODUCTION

Processing cucumber (*Cucumis sativus* L.) thrives in warm temperatures and well-draining soil containing high amounts of organic matter (Precheur, 2010). The vining annuals are planted when there is no chance of frost and ideally when the soil has warmed to at least 21°C (Bradley *et al.*, 2009). The average growth cycle for processing cucumbers is 40 to 55 days (Wang and Ngouajio, 2008).

Weeds are a major limiting factor in both conventional and organic processing cucumber production. Generally, weeds are able to out-compete the cucumbers for water, nutrients, and light if the weeds are able to emerge before cucumber canopy closure (Al-Khatib *et al.*, 1995; Guo *et al.*, 2008; Wang and Ngouajio, 2008). Since processing cucumbers are direct-seeded, there is a three to four week window when weeds can establish before cucumber canopy closure occurs, so the critical time for weed control is the first three to five weeks after cucumber emergence (Al-Khatib *et al.*, 1995; Friesen, 1978; Wang and Ngouajio, 2008; Weaver, 1984). Cucumber yields are also reduced if weeds infest the field for longer than four weeks at any time throughout the growth period (Weaver, 1984). Planting cucumber transplants would lessen this critical period due to faster canopy closure, but growers of processing cucumbers commonly direct-seed to achieve higher crop densities with less cost than transplanting (Seaman *et al.*, 2009).

There is some evidence that cucumber contains allelopathic compounds that have been shown to inhibit the germination and growth of a few common weeds, including wild proso millet (*Panicum miliaceum*), redroot pigweed (*Amaranthus retroflexus*), barnyardgrass (*Echinochloa crus-galli*), and crabgrass (*Digitaria sanguinalis*) (Lockerman and Putnam, 1979, 1981; Putnam and Duke, 1974; Thi *et al.*, 2008).

Weeds can also make production more difficult by interfering with tillage, irrigation, and harvest, increasing labor needed to grow crops (Linares *et al.*, 2008; Van Gessel, 2007). Processing cucumber is typically machine-harvested, which requires excellent weed control to limit damage and maximize yield (Van Gessel, 2007), yet weed control that relies on mechanical cultivation becomes nearly impossible due to the vining habit of cucumbers, especially once the cucumbers vine out into the aisles (Seaman *et al.*, 2009).

Conventional practices for growing processing cucumbers dominate production and include the reliance on intensive tillage, high planting densities, and pesticide use (Lonsbary *et al.*, 2004; Van Gessel, 2007). Intensive tillage is very damaging to the soil structure, leading to soil erosion, compaction, and surface water runoff (Lonsbary *et al.*, 2004).

Weed control in cucumber production is highly dependent on preemergent herbicides, particularly ethalfluralin and clomazone, although cultural methods of weed control, including tillage and hand weeding, are often needed to supplement the incomplete weed control resulting from the use of preemergent herbicides (Van Gessel, 2007; Zandstra, 2008). Ethalfluralin and clomazone can cause crop injury and common weeds such as nightshade and pigweeds are tolerant of them (Johnson and Mullinix, 1998; Van Gessel, 2007).

There is a need for alternative methods of weed control for processing cucumber produciton. One alternative method is using cover crops to suppress weeds, while at the same time improving the soil. Short-cycle summer cover crops, such as common buckwheat *(Fagopyrum esculentum* Moench*)*, that are grown and killed just before or after the cucumber crop, may give the grower the opportunity to limit weed interference with the crop while completing both the cover crop and cucumber's life cycles in one growing season (Sullivan, 2003).

Cover crops can suppress weeds using a variety of mechanisms, including altering the soil surface and top soil layers environmentally, physically, and chemically (Cardina *et al.*, 1991; Kremer, 1993; Lewis, 1973; Linares *et al.*, 2008), and suppressing weed growth through the release of allelopathic chemical compounds (Eskelsen and Crabtree, 1994; Khanh *et al.*, 2005; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004). Common buckwheat is effective in managing weeds, and has been shown to reduce weed biomass 75 to 99% (Creamer and Baldwin, 2000; Kumar *et al.*, 2008; Tominaga and Uezu, 1995). It grows vigorously, and can smother out most weeds due to its rapid growth rate (Oplinger *et al.,* 1989).

One mechanism of weed control is the effect of buckwheat on soil nitrogen availability, which influences weed emergence and growth. Buckwheat has a C:N ratio of 34:1, immobilizing nitrogen during buckwheat decomposition (Creamer and Baldwin, 1999). Many weeds are adapted to rapid early growth and nitrogen uptake, so the decrease in soil nitrogen after the incorporation of a buckwheat cover crop may decrease weed emergence and growth (Kumar *et al.*, 2008).

It is has been well documented that buckwheat also suppresses weeds through the release of allelopathic chemical compounds (Eskelsen and Crabtree, 1994; Golisz *et al.*, 2007a; Iqbal *et al.*, 2005; Kalinova, 2007, 2008; Tominaga and Uezu, 1995; Xuan and

Tsuzuki, 2004). Allelopathy is the inhibitive or promotive interaction between plants caused by chemicals released through decomposition, leaching from aerial plant parts, and root exudates (Golisz *et al.*, 2007b; Khanh *et al.*, 2005).

While the use of common buckwheat to control weeds may sound promising, growing it prior to processing cucumbers presents many challenges for the cucumber grower. Delayed buckwheat planting due to cold spring temperatures or excessive rainfall may cause delays in planting of the cash crop, poor buckwheat growth, or the inability to grow buckwheat at all in a particular season. Delayed buckwheat killing due to saturated soils and the risk of compaction or incomplete killing of buckwheat due to inadequate incorporation methods could cause reductions in cucumber yield if the buckwheat sets seed and causes interference as a volunteer weed with the cucumber crop. Also, although buckwheat's mechanisms of weed control are effective in suppressing weeds, they may also inhibit the emergence, growth, or yield of the cucumber crop. Clearly, these potentially harmful effects of buckwheat on cucumber are just as important to determine as the potential beneficial effects on weed control.

There have been numerous studies conducted on the effectiveness of buckwheat on weed control (Eskelsen and Crabtree, 1994; Golisz *et al.*, 2007a; Iqbal *et al.*, 2005; Kalinova, 2008; Tominaga and Uezu, 1995; Xuan and Tsuzuki, 2004), as well as on the use of cover crops in various *Cucurbit* crops (Ngouajio and Mennan, 2005; Vanek *et al.*, 2005; Walters *et al.*, 2007; Wang and Ngouajio, 2008; Zandstra *et al.*, 1998), but to the author's knowledge, no previous research has looked specifically at the effect of buckwheat on cucumber growth or the competitiveness of cucumber with common weeds such as large crabgrass (*Digitaria sanguinalis* (L.) Scop).

Processing cucumber production may benefit from using buckwheat cover crops before planting. Because of its rapid growth, if planted in May after the chance of frost has ended, buckwheat could be planted prior to direct-seeding cucumber in late June or early-July. Since buckwheat is effective at smothering weeds, limiting weed growth and weed seed set prior to a cucumber crop would be helpful for cucumber growers and might reduce their need for weed control methods such as tillage and herbicides. Buckwheat could also help improve the soil, preventing or repairing many of the problems associated with tillage, such as soil erosion, compaction, and poor water drainage (Clark, 2007; Edwardson, 1996; Linares *et al.*, 2008; Sullivan, 2003).

Using a cover crop in the same growing season as the cash crop presents a number of challenges, and the main objectives of this research were to investigate the effectiveness of various buckwheat cultivation techniques prior to growing processing cucumbers, to evaluate the effect of buckwheat residues on weed growth both during buckwheat and cucumber growth, and to assess the effect of buckwheat on the growth of processing cucumber, including whether the presence of weeds interferes with observing direct effects of buckwheat on cucumber.

Buckwheat cultivation techniques included timing of planting and killing of buckwheat, buckwheat kill and incorporation method, and length of delay between incorporating buckwheat and direct-seeding processing cucumber. Timing is especially important since both the buckwheat and cucumber have to grow within the same warm growing season with no chance of frost. However, wet springs can delay the planting of cover crops at the desired time. Similarly, if buckwheat is not killed at the start of flowering (35 – 41 days after planting) due to saturated soils or other delays, it risks setting seed that will emerge during the cucumber crop, becoming a volunteer weed crop. The method that a grower may choose to kill and incorporate buckwheat can also affect the impact of the buckwheat cover crop on weeds and cucumber growth. Tillage is commonly used by many growers, but some growers may use mowing alone to kill buckwheat, only tilling just before planting the cucumber crop. The hypothesis for this study is that tillage will be more effective than mowing at killing buckwheat and will lead to more rapid decomposition of buckwheat tissues, reducing the risk of inhibition of cucumber growth caused by buckwheat residues.

Given the evidence from past research (Creamer and Baldwin, 2000; Iqbal *et al.*, 2003; Kumar *et al.*, 2008; Tominaga and Uezu, 1995), the hypothesis of this study is that buckwheat will reduce weed growth during buckwheat growth and may also provide residual weed suppression. However, although it is desirable to direct-seed cucumber as soon as possible after a buckwheat crop, in order to allow time for a full growing season and avoid the risk of early fall frost, the buckwheat residues may inhibit the growth and yield of cucumbers. If buckwheat does inhibit the cucumber crop, the absence of additional interference from weeds may lessen the inhibition seen in the buckwheat treatments in the weedy plots.

Field experiments were conducted in 2008 and 2009 in northern and central Illinois, assessing different buckwheat kill methods, plant and kill times, and the effects of buckwheat residues on cucumber and weed growth. To further examine the effects of buckwheat on cucumber growth, a greenhouse experiment was conducted in 2010 to determine whether buckwheat inhibited cucumber growth and if so, which plant part of buckwheat was responsible for the most inhibition. Additionally, a replacement series greenhouse experiment was conducted in 2010 to evaluate whether the presence of incorporated buckwheat shoot and root residues caused a shift in either intraspecific or interspecific interference between cucumber and large crabgrass.

METHODS AND MATERIALS

Field Experiments

General Experiment Methodology

For all of the field experiments in both years and locations, sub-sub plots or sub plots were 3.1 m by 15.2 m (sub-sub plots in experiments 1 and 3, and sub plots in experiments 2 and 4). The bare ground treatments were created by applying 48.7% glyphosate [N-(phosphonomethyl) glycine] at a rate of 1.1 kg ha^{-1}, within one week of buckwheat emergence. Just prior to planting cucumber seeds the bare ground control plots were disked to prepare the seedbed and kill any emerged weeds. In each plot two rows of 'Eureka' hybrid pickling cucumber (*Cucumis sativus* 'Eureka') were machine planted at 85,990 plants ha^{-1}. Cucumber plants were thinned by hand, two to three weeks after planting, to 40 cm apart within a row.

Sevin (carbaryl (1-naphthyl N-methylcarbamate) and Cabrio (pyraclostrobin: (carbamic acid, [2-[[[1-(4-chlorophenyl)-1*H*-pyrazol-3-yl]methyl]phenyl]methoxy-, methyl ester)) were applied at 2.65 kg ha^{-1} (1.14 kg ha^{-1} active ingredient) and 0.77 kg ha^{-1} (0.15 kg ha^{-1} active ingredient), respectively, as needed throughout the experiment to control cucumber beetles and fungal diseases.

Data was collected on buckwheat biomass, weed biomass during buckwheat growth and during cucumber growth, and cucumber vine length, biomass and yield.

Field Experiment 1: Buckwheat Kill Method and Duration

The experiment in St. Charles 2008 compared mowing or tillage as effective methods for killing buckwheat before planting cucumbers. The experiment was a split-split-plot within a randomized complete block design with three replications. Buckwheat was planted on May 29, and buckwheat stand duration [Short (50 days) or Long (56 days)] was the whole plot treatment, the sub plot treatment was buckwheat kill method (Mow or Till), and the sub-sub plot treatment was a buckwheat cover crop (BW) or a bare ground control (Bare). The seeding rate of buckwheat was 112 kg ha^{-1} in 2008. This is very high and corresponds to a 100 lbs/A seeding rate. Buckwheat was either cut with a rotary mower or tilled with two passes of a 3.7 m wide field disk on July 18 and 24, at 50 and 56 days after planting (DAP), respectively.

In experiment 1 the preemergent herbicides Curbit (35.4% active ingredient ethalfluralin: N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)bensenamine), applied at a rate of 4.83 kg ha^{-1} (1.71 kg ha^{-1} active ingredient), Command 3ME (31.1% active ingredient clomazone: 2-(2-Chlorophenyl)methyl-4,4-dimethyl-3-isoxazolidinone) applied at a rate of 1.38 kg ha^{-1} (0.43 kg ha^{-1} active ingredient), and Sandea (75% active ingredient halosulfuron-methyl), applied at a rate of 0.04 kg ha^{-1} (0.03 kg ha^{-1} active ingredient), were applied on July 28 and 31, 2008, one to three days after planting cucumber.

Buckwheat and weed shoot biomass levels were collected in the buckwheat stands (38 and 55 DAP buckwheat) and cucumber stands (44 and 38 DAP cucumber) using three randomly placed 0.1 m^2 quadrats in each sub-sub plot. The plants were cut at the soil surface, dried at 80 °C to constant mass and weighed. Data was collected on the number of expanded cucumber leaves per plant, but not vine length or biomass due to unexpected flooding that terminated the experiment one week prior to that data being collected. On September 7 (44 and 38 DAP cucumber), the number of fully-expanded cucumber leaves (> 45° to stem) was counted on three representative plants from the center of each sub-sub plot and averaged; however, twenty-four centimeters of rain fell between September 12 – 14 and flooded the plots, preventing cucumber harvest and terminating the experiment. Therefore, the number of cucumber leaves per cucumber plant was used as an indication of the health of the plant and the access to resources needed to obtain energy for vegetative production.

Field Experiment 2: Buckwheat Duration

Experiment 2 in St. Charles 2009 assessed the effect of the duration and presence of buckwheat on weed communities and cucumber growth and yield. The experiment was established using a split-plot design within a randomized complete block design with three replications. Buckwheat was planted on June 4, and buckwheat stand duration [Short (50 days) or Long (55 days)] was the whole plot treatment, and buckwheat cover (BW) or bare ground control (Bare) was the sub plot treatment.

For experiments 2 – 4, the seeding rate of buckwheat was 101 kg ha^{-1} to correspond with the highest recommended rate of 90 lbs/A (Clark, 2007). Mowing did not control buckwheat in experiment 1, and in experiments 2 – 4 all plots were tilled to control buckwheat. In experiment 2, buckwheat was incorporated by cutting with a stalk chopper and then tilling with a field disk on July 24 and 29, 50 and 55 DAP, respectively.

To control weeds during cucumber emergence, the preemergent herbicide Strategy [18.2% active ingredient ethalfluralin: N-ethyl-N-(2-methyl-2-propenyl)-2,6-

dinitro-4-(trifluoromethyl)bensenamine and 5.6% active ingredient clomazone: 2-(2-chlorophenyl)methyl-4,4-dimethyl-3-isoxazolidinone] was applied at 5.03 kg ha^{-1} (0.92 kg ha^{-1} active ingredient ethalfluralin and 0.28 kg ha^{-1} active ingredient clomazone) as well as Sandea (75% active ingredient halosulfuron-methyl), applied at 0.04 kg ha^{-1} (0.03 kg ha^{-1} active ingredient), on July 30 and August 5, one to two days after planting cucumbers.

Buckwheat and weed shoot biomass levels were collected in the buckwheat stands (39 and 34 DAP buckwheat) and cucumber stands (64 and 59 DAP cucumbers) using three randomly placed 0.1 m^2 quadrats in each subplot. The plants were cut at the soil surface, dried at 80 °C to constant mass and weighed. Weed data also included the number of buckwheat, grasses, and the most common broadleaf weeds that were counted in the same three randomly placed 0.1 m^2 quadrats. Data on cucumber above ground biomass, length of longest vine, and the number and weight of cucumbers fruits (> 5 cm in length) per plant were collected and averaged from three representative plants in the center of each of the subplots.

Cucumber fruits were graded according to market standards for pickling cucumbers (USDA, 1997) with the following specifications. Grade U.S. No. 1 are less than or equal to 3.5 inches in length and 1.25 inches in diameter, firm and well formed and free from blemishes and damage. Grade U.S. No. 2 and Grade U.S. No. 3 have the same standards as U.S. No. 1 except the sizes are less than or equal to 5.5 inches in length and 1.88 inches in diameter, or are less than or equal to 6 inches in length and 2.25 inches in diameter, respectively. Culls were any cucumber that did not meet the above requirements.

Field Experiment 3: Buckwheat Planting Date and Duration

Experiment 3 in Champaign 2009 assessed the effect of planting date and duration of buckwheat on weed communities and cucumber growth and yield. The experiment was established using a split-split-plot design within a randomized complete block design with four replications. Buckwheat planting time [Early (May 30) or Late (June 17)] was the whole plot treatment, buckwheat stand duration [Short (36 days) or Long (44 or 41 days for Early or Late plant times, respectively)] was the sub plot treatment, and the sub-sub plot treatment was a buckwheat cover crop (BW) or a bare ground control (Bare). Weed-free plots were added and maintained by weekly hand-weeding after cucumber energence.

Buckwheat and cucumber was planted in the same manner at the same rates as described for experiment 2. In experiment 3, buckwheat was incorporated by tilling using two passes of a 3.1 field disk on July 13, 23, and 28, 44, 36, and 41 DAP, respectively.

To control weeds during cucumber emergence, the same preemergent herbicide routine described in experiment 2 was applied on July 21, 31 and August 5, 2009 at Champaign, one to two days after planting cucumber.

Buckwheat and weed shoot biomass levels were collected in the buckwheat stands (25 and 27 DAP buckwheat) and cucumber stands (58 – 62 DAP cucumbers) using three randomly placed 0.1 m^2 quadrats in each sub-subplot. The plants were cut at the soil surface, dried at 80 °C to constant mass and weighed. The number of buckwheat, grasses, and the most common broadleaf weeds were counted in the same three randomly placed 0.1 m^2 quadrats.

Data on cucumber above ground biomass, length of longest vine, and the number and weight of cucumbers fruits (> 5 cm in length) per plant were collected (58 – 62 DAP cucumbers) from three representative plants in the center of each of the subplots and were averaged. Cucumber emergence and final stand counts were recorded to assess any emergence inhibition caused by buckwheat and/or weeds. Cucumber fruits were graded according to market standards for pickling cucumbers (USDA, 1997) with the specifications stated in experiment 2.

Field Experiment 4: Buckwheat Duration and Delay

This experiment in Champaign 2009 evaluated the effect of the duration of buckwheat growth and the delay between killing buckwheat and direct-seeding cucumber on weed and cucumber growth and yield. The experiment was established using a split-plot design within a randomized complete block design with four replications. Buckwheat was planted on May 30, and buckwheat duration was the whole plot treatment, and length of delay between killing buckwheat and direct-seeding cucumber was the sub plot treatment. The LowBW/Early treatment had 26 days of buckwheat growth and a 19 day delay, while the RegBW/Early treatment had 38 days of buckwheat growth and a 7 day delay. The cucumber plants for both of these treatments were planted on July 14. The LowBW/Late treatment had 26 days of buckwheat growth and a 25 day delay, while the RegBW/Late treatment had 44 days of buckwheat growth and a 7 day delay. The cucumber plants for both of these treatments were planted on July 20.

Buckwheat and cucumber were planted in the same manner at the same rates as described for experiment 2. In experiment 4, buckwheat in both of the RegBW treatments as incorporated by tilling with two passes of a 3.1 field disk on July 7 and 13, 38 and 44 DAP, respectively. The low buckwheat (LowBW) treatments were created by applying 48.7% glyphosate [N-(phosphonomethyl) glycine] 26 days after planting at a rate of 1.1 kg ha^{-1}.

Cucumber in the Early treatments (both LowBW and RegBW) was planted and harvested at the same time, and cucumber in the Late treatments (both LowBW and RegBW) was planted and harvested at the same time. Therefore, all weed and cucumber data collected during the growth of the cucumber stand occurred on the same dates and days after planting cucumber (62 and 59 DAP for Early and Late treatments, respectively) to ensure that any differences observed were due to the effects of the duration of the buckwheat stand or the delay between killing buckwheat and direct-seeding cucumber.

To control weeds during cucumber emergence, the same preemergent herbicide routine as described for experiment 2 was applied on July 16 and July 21, one to two days after planting cucumber.

Data collected both during buckwheat and cucumber crop stands were collected in the same manner as described for experiment 3, including buckwheat, weed, and cucumber shoot biomass, cucumber emergence, final stand count, cucumber vine length, weed counts, and cucumber yields and fruit grading information.

Statistical Analysis

In all field experiments, after testing for homogeneity of variance within each year and location, and meeting the other assumptions of normality, data were subjected to an ANOVA appropriate for a split-plot or split-split-plot randomized complete block design with a PDMIX procedure to determine sources of variation and significant interactions. Differences in treatment means were determined using Tukey's Mean Significant Difference test at $P \leq 0.05$. All data analyses in the studies were accomplished by means of the SAS version 9.1.3 (SAS Institute, 2004).

Greenhouse Experiments

General Experiment Methodology

Greenhouse experiments were conducted from February to May in 2010, at the University of Illinois Urbana-Champaign, Plant Care Facility to determine the effects of buckwheat residues on cucumber and large crabgrass growth and interference between the weed and crop. Due to time constraints the experiments were conducted only once. The containers used were 9.5 liter pots (24.1 cm in diameter by 16.5 cm deep) filled with a 1:1 mix of Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquoll) field soil and coarse sand. Once seeded, the pots were watered once a day to the water flow-through point and were fertilized once a week with 20-20-20, 250 ppm (1.04 lbs N, 2.39 lbs P, 1.25 lbs K per gallon) liquid synthetic fertilizer. They were given 4580 µmol m^{-2} s^{-1} of supplemental lighting for 14 hours each day, and set point temperatures were 27 °C day and 21 °C night.

Buckwheat grew to an average height of 90 cm in 38 - 39 days and was cut down after flower initiation but prior to seed formation. Buckwheat aboveground fresh biomass averaged around 3.6 kg per pot. Buckwheat lateral roots were very fibrous and fine and extended throughout the entire volume of the pots.

Buckwheat Residue Type

This study was conducted from February 12 to May 3, 2010 to determine the effects of buckwheat residue type (eg. roots, roots and shoots, and shoots) on cucumber growth. The experiment was a completely randomized design with eight replications. The soil treatments with buckwheat residues that had grown buckwheat were roots (BW+Roots) and roots and shoots (BW+Roots/Shoots), and the soil treatment that had not grown buckwheat but contained buckwheat shoot residues were shoots (Bare+Shoots). A control with no buckwheat residues was also used (Bare).

Common buckwheat was seeded at a depth of 2.5 cm on February 12 at 0.46 g pot^{-1} (18-19 seeds), which corresponds to a 110 kg ha^{-1} field seeding rate. This is a very high density seeding rate, but it was used to ensure high plant populations and adequate biomass for the greenhouse experiment. Buckwheat was allowed to grow for 38 days, until March 22, when shoots were cut at the soil surface and cut into 2.5 cm pieces. Pots were then emptied, and the soil, including buckwheat roots, was broken up to remove clods and masses of roots. One hundred grams of buckwheat shoot pieces were added to the soil for the roots and shoots treatment and shoots treatment, evenly hand mixed into the soil from each pot, and evenly incorporated. After returning the soil with buckwheat residues to the pots, the pots were watered until water came out of the bottom. The soil in the no buckwheat control treatment was not removed, but rather broken up in the pot.

Processing cucumber (‘Eureka’ hybrid) seed was planted at a depth of 2 cm, on March 29, seven days after incorporating the buckwheat, which mirrored the cucumber planting in most field experiments. On April 5, cucumber seedlings were thinned to one plant per pot.

On April 5, 12, 19, 26, and May 3, the length of the longest cucumber vine was measured from the soil surface to base of the base of the apical bud. On May 3, the experiment was terminated and the cucumber shoots were cut at the soil surface and weighed. The samples were dried at 80 °C to a constant mass and weighed again.

Replacement Series Trial

This study was conducted from February 19 to May 11, 2010 to determine the effects of buckwheat residues on large crabgrass growth and interference with processing cucumber. The experiment was a replacement series arranged using a completely randomized design with eight replications. In the replacement series experiment we modified the number and ratio of large crabgrass and cucumber plants. The treatments were with (BW) and without (Bare) buckwheat with 4:0 (100% crabgrass, 0% cucumber), 3:1, 2:2, 1:3, and 0:4.

Common buckwheat was seeded and grown in the same manner as in greenhouse experiment 1, except when cut down on March 30, both shoot and root residues were incorporated into all of the buckwheat treatment pots. Processing cucumber (‘Eureka’ hybrid) and large crabgrass were seeded at depths of 2 and 0.3 cm, respectively on April 6, seven days after incorporating buckwheat, which mirrored the cucumber planting in most field experiments. Seven days later, cucumber and large crabgrass seedlings were thinned to a total of four plants per pot in the appropriate ratios.

On April 13, 20, and 27, and May 4 and 11, the lengths of the longest cucumber vine and the longest large crabgrass leaf blade were measured from the soil surface to base of the apical bud and to the tip of the leaf, respectively. On May 11, the experiment was terminated and the cucumber and large crabgrass shoots were cut at the soil surface and weighed per plant. The samples were dried at 80 °C to a constant mass and weighed again for dry weight.

Statistical Analysis

After testing for homogeneity of variance, and meeting the other assumptions of normality, the data were subjected to ANOVA and analyzed using PROC GLM in the Statistical Analysis System (SAS 2001). Treatment mean values were separated using Tukey's honest difference (HSD) test and were declared different at $P \leq 0.05$. In the replacement series trial, independent t-tests were performed on both fresh and dry shoot biomass at each species ratio level to test if there were differences between residue cover (bare or buckwheat).

RESULTS AND DISCUSSION

Field Experiments

Average air and soil temperatures and precipitation during the years of the experiment, as well as the preceding six years are summarized in Figures 1 and 2. Both locations and years had cooler and wetter growing conditions than the previous six year average.

Field Experiment 1: Buckwheat Kill Method and Duration

Buckwheat biomass levels were not different between the Short and Long buckwheat duration treatments (Table 1). The Short/Till Bare treatment had the lowest weed biomass of 57.26 g m-2, and the Short/Mow BW treatment had the highest weed biomass of 414.73 g m-2 (Table 2).

The Long buckwheat duration treatments had more significant effects of buckwheat and buckwheat kill method on weed biomass accumulation. Treatment Long/Till Bare had much lower weed dry weight (7.32 g m^{-2}) than any of the other treatments, particularly treatment Long/Mow Bare, which had a weed dry weight accumulation of 185.89 g m^{-2} (Table 2).

Experiment 1 was terminated one week early due to a severe rain event that occurred on September 7, 2008 that flooded the cucumbers. Therefore, only the number of leaves per longest vine per plant was collected. There were no significant differences in leaf counts resulting from buckwheat cover or method of buckwheat incorporation treatments. The buckwheat treatments had 26 – 44% fewer leaves in the buckwheat treatments in the Long buckwheat duration treatments (Table 2).

Experiment 1 in 2008 at St. Charles demonstrated that tilling buckwheat in was more effective overall at controlling weeds and not hindering cucumber growth than just mowing buckwheat. It could be that the extra cultivation by tilling improved weed control by disrupting their growth and improved cucumber growth by both lowering weed interference as well as causing buckwheat residues to break down quicker than mowing alone. From this experiment, we decided that in all subsequent experiments we would use tillage as the means of killing and incorporating buckwheat.

Field Experiment 2: Buckwheat Duration

In experiment 2 there was a strong relationship between high buckwheat biomass and low weed biomass. There was significant association between the presence of buckwheat biomass and the reduction in weed biomass levels (Table 3). However, both grass and broadleaf weed populations were not affected by the buckwheat cover crop in this experiment (Table 4).

Weed dry weight in the buckwheat treatments was 37 – 59% higher in both the Short and Long buckwheat duration treatments compared to the bare control treatments, conflicting with other studies, which have shown a reduction in weed biomass following a buckwheat cover crop (Kumar *et al.*, 2008, 2009; Tominaga and Uezu, 1995).

Cucumber yield was recorded at 59 – 64 DAP in experiment 2. Both cucumber dry weight and vine length per plant were not affected by buckwheat residues, and yield was only different in the Short buckwheat duration treatments, where number of cucumber fruits per plant was higher than the bare treatment (Table 5).

In experiment 2, buckwheat had a significant effect on weed control, lowering weed biomass by 89% during buckwheat growth. However, no residual weed control was observed during the cucumber crop. In addition, buckwheat did not appear to have any negative effects on cucumber growth and yield. Due to these observations, the added expense of planting a buckwheat cover crop, as well as not being able to plant cucumbers until July or August, may not be desirable for cucumber growers.

Field Experiment 3: Buckwheat Planting Date and Duration

Buckwheat biomass ranged from 186 g m^{-2} in the Early buckwheat planting treatments (May 30) to 56.25 g m^{-2} in the Late buckwheat planting treatments (June 17), however, this did not result in adequate weed control during buckwheat growth (Table 6). In addition, in the Late treatments, broadleaf weed populations were higher in the buckwheat treatments compared to the bare ground control treatments (Table 7).

The residual effects of the incorporated buckwheat cover crop on total weed aboveground biomass varied among treatments, but overall, buckwheat did not have a continuous suppressive effect on weed growth by the time of cucumber harvest. The only significant effect ($P \leq 0.05$) was in the Late Short/BW treatment, which had 71% lower weed dry weight than the bare ground treatment (138.10 g m^{-2} compared to 478.03 g m^{-2}).

In the other treatments, Early Long and Late Long, the presence of buckwheat residues led to slightly higher weed growth than the bare ground control treatments (Table 8).

While the effect of buckwheat residues on weed growth varied among the treatments, the presence of buckwheat residues had a clearer, and adverse, effect on cucumber growth and yield in all of the treatments. Cucumber emergence and survival ranged from 12 to 49.6 and 7.5 to 17 plants, respectively, for the treatments with no buckwheat, and 1.50 to 6.5 and 1.25 to 5.5, respectively, for treatments with buckwheat (Table 8). In the weed-free treatment plots that were kept weed-free by weekly manual weeding, cucumber emergence was significantly lower in the buckwheat treatment compared to the bare ground treatments of the Early Long treatment (Table 9). Because large seeds need little nutrients to germinate and emerge (Kumar *et al.*, 2008), it is unlikely that this inhibition was caused by nutrient tie-up and was most likely caused by buckwheat allelopathic interference that inhibited germination and emergence. Cucumber vine length and biomass per plant were also inhibited by buckwheat. Cucumber vine length was reduced by as much as 68% and vine dry weight by as much as 82% in the buckwheat treatments compared to the bare ground controls (Table 8).

Cucumber yield was recorded at 58 to 62 DAP, though the only significant difference was seen in total fruit weight per plant (Table 10 and 11). In the Early Long treatment, the bare ground treatment had higher fruit weight than the buckwheat treatment (41.50 compared to 12.25 grams per plant). Cucumber yield was highest in the bare ground treatments of the Late buckwheat planting treatments, with fruit weight ranging from 323.3 – 444.5 grams per plant (Table 10). These Late Short and Long treatments were direct-seeded with cucumber on July 30 and August 4, respectively, while the Early treatment was planted with cucumber on July 20, and it is possible that the later plant times improved cucumber yield because of warmer weather.

In Field Experiment 3 in Champaign, growing buckwheat prior to growing cucumbers did not lead to adequate weed control either during buckwheat growth or during cucumber growth. In addition, the buckwheat treatments resulted in inhibited cucumber growth. Cucumber growers would not tolerate this reduction in cucumber growth without a significant reduction in weeds, which was not seen in these experiments.

Field Experiment 4: Buckwheat Duration and Delay

During the buckwheat stand at 26 DAP (before the LowBW treatments were killed with glyphosate), there were no differences in either buckwheat or weed dry weight between the LowBW and RegBW treatments (Table 12). However, the RegBW treatments had an additional 12 to 18 days of growth after the buckwheat in the LowBW treatments was killed, and it is likely that more buckwheat biomass was put on during that time.

Buckwheat did not have a continuous suppressive effect on weed growth by the time of cucumber harvest. One would expect treatments RegBW/Early and RegBW/Late to be more inhibitive of weeds than the treatments with low buckwheat populations (LowBW/Early and LowBW/Late) because the former had 12 to 18 more days of buckwheat growth and 12 to 18 fewer days between killing buckwheat and planting cucumber, theoretically having higher buckwheat residue amounts and therefore higher potential for inhibition. However, it appears that any inhibitory effects that buckwheat may have had on weeds during the buckwheat growth period were overcome or diminished by approximately 65 days after incorporating buckwheat residues (Table 13). Both grass and broadleaf weed populations were also not different between LowBW/Early and RegBW/Early or between LowBW/Late and RegBW/Late (Table 14).

Treatments LowBW/Early and LowBW/Late resulted in cucumber emergence rates that were 74% and 90% higher than treatments RegBW/Early and RegBW/Late, respectively, suggesting that only 26 days of buckwheat growth and 19 to 25 days of delay before planting cucumber does not lead to inhibition of cucumber emergence (Table 13). Similar results were seen for the final cucumber stand count. Additionally, treatments RegBW/Early and RegBW/Late resulted in lower cucumber dry weight and vine length compared to the LowBW/Early and LowBW/Late treatments (Table 13).

Cucumber yield was also more inhibited by the RegBW treatments than the LowBW treatments, again demonstrating that growing buckwheat for a short period of time (26 days) and with a long delay before planting cucumber (19 to 25 days) overcomes the negative impact on cucumber yield resulting from the presence of buckwheat residues (Table 15).

The results of experiment 4 show that when buckwheat is grown for only a short amount of time (26 days) with a substantial delay between killing buckwheat and direct-seeding cucumber (19 to 25 days), the cucumber crop is less inhibited by buckwheat residues. However, there were disparities in the effect of these LowBW treatments on weed biomass and weed populations, and overall results were similar to those resulting from the RegBW treatments at the time of cucumber harvest. While this implies that the LowBW treatments do not necessarily lead to an increase in weed growth, it is also apparent that the presumed higher buckwheat residues in the RegBW treatments do not lead to superior weed control. Because cucumber growers are trying to grow buckwheat and cucumbers in the same warm growing season, waiting an additional 12 to 18 days to ensure lower cucumber inhibition while not receiving any substantial weed control is not advisable.

The earlier plant times (May 29 to June 4) for buckwheat are more appropriate for central Illinois locations, where temperatures tend to be higher; mid-June to July would be appropriate times for planting buckwheat in northern Illinois locations in order to ensure no late-season cold temperatures. However, excessive rainfall inhibited buckwheat biomass development, which supports existing literature that shows that flooding causes cessation of buckwheat growth (Bjorkman, 2010). In addition to these climatic considerations, buckwheat seeding rate does not have to surpass 62 to 101 kg ha-1 (equivalent to 55 to 90 lbs/A) to achieve high buckwheat biomass.

Despite the range in buckwheat biomass accumulation in both St. Charles and Champaign, weed suppression during buckwheat growth was similar in both locations and years. When there was higher buckwheat biomass accumulation there was higher weed suppression, and generally, the buckwheat treatments resulted in lower weed biomass than the bare ground treatments. However, buckwheat was unable to suppress weeds by the time of cucumber harvest, suggesting that buckwheat-induced weed suppression is exhibited most strongly during buckwheat growth and possibly shortly after incorporation, and buckwheat residues will not provide consistent weed suppression through the full cucumber growing cycle.

<u>Greenhouse Experiments</u>

Effect of Buckwheat on Cucumber Growth

In the buckwheat residue type experiment, the most cucumber vine growth occurred during week four, and by the end of the experiment, the average longest cucumber vine length was 91 cm from soil surface to the base of the apical bud, and cucumber fresh shoot biomass per plant was 91.4 g.

Cucumber plants grown in soil containing buckwheat root tissue residues were smaller, less vigorous, and slightly chlorotic compared to plants grown in bare soil, with or without the presence of buckwheat shoots tissue. Differences ($P \leq 0.05$) occurred between buckwheat-grown soil treatments containing buckwheat roots (BW+Roots/Shoots and BW+Roots) and the bare soil treatments not containing buckwheat roots (Bare and Bare+Shoots). Soil treatments containing buckwheat root residues caused inhibition of cucumber plants. The longest cucumber vine length per plant in the buckwheat-grown soil treatments was, on average, 23% shorter than the vines of the bare soil treatments three to five weeks after planting (Table 16). Cucumber shoot biomass was also negatively affected by the presence of buckwheat residues and soil containing buckwheat root tissues. Dry shoot biomass was reduced by 36% in these soil treatments containing buckwheat root residues compared to the bare soil treatments (Table 16). Adding buckwheat shoots to the bare soil control and soils containing buckwheat root tissues caused no additional effects on vine length or shoot biomass (Table 16).

The critical weed-free period of cucumber is the first three to five weeks after seeding (Al-Khatib *et al.* 1995; Friesen 1978; Weaver 1984). At this stage, the cucumber canopy is not fully closed, leading to greater resource competition with weeds. BW + Roots and BW + Roots/Shoots treatments had as much as a 33% reduction in vine length occurring during week four of this study (Table 16), making canopy cover even more difficult to obtain, and making the cucumber even more susceptible to weed interference. These results suggest that buckwheat would make cucumber even less effective at competing with weeds during this critical weed-free time by inhibiting the growth of cucumber vines and gain in shoot biomass.

In the replacement series experiment, buckwheat reduced cucumber growth across all treatments, regardless of the crabgrass to cucumber plant ratios tested. Buckwheat inhibited total cucumber growth, and by the end of the experiment, cucumber vines in the buckwheat amended treatments were 15% shorter than those in the bare soil control (Table 17). Buckwheat reduced cucumber shoot biomass to a greater extent than it did vine length. Overall, buckwheat residues and soil used for growing buckwheat reduced cucumber dry shoot biomass per plant by 38% (Figure 3). Buckwheat was the most inhibitive of cucumber biomass levels in treatments with higher cucumber plant densities. At the 1:3 ratio, cucumber dry shoot biomass was 41% lower in the buckwheat treatment than the bare control treatment, and at 100% cucumber density (treatment 0:4), cucumber dry shoot biomass was reduced by 51% with the addition of buckwheat residues (Figure 3).

While it is clear that buckwheat inhibited cucumber growth in both experiments, it is unclear as to the exact mechanisms of inhibition. Whether this inhibition was caused directly by buckwheat allelochemicals released into the soil by root exudates, leaching, or decomposition, or indirectly by changes in the soil chemical or physical environment caused by the growth or incorporation of buckwheat (i.e. nutrient tie-up), it is not clear. Roots were present in both treatments showing the most inhibition; however, both of those treatments also grew buckwheat. The roots of allelopathic plants release allelochemicals by exuding them through living roots or leaching them during decomposition. Studies have found that aqueous extracts from soil that previously grew buckwheat have inhibitory effects on early growth of weed species, including barnyard grass (*Echinochloa crus-galli* var. *crus-galli*) and common purslane (*Portulaca oleracea*) (Kalinova *et al.*, 2007; Tominaga and Uezu, 1995). Nitrogen immobilization caused by the decomposing buckwheat residues could have been another inhibitive mechanism, and even with additional weekly fertilization, it is possible that cucumbers in the buckwheat treatments had less access to available nitrogen.

Cucumber plants grown in soil containing buckwheat root residues were less vigorous and had lower vine lengths and shoot biomass than cucumbers grown in bare soil with or without buckwheat shoot residues. It has been noted that buckwheat roots inhibit weed germination when planted as an intercrop (Schonbeck *et al*., 1991), so it is possible that allelopathic root exudates and constant regeneration and decomposition of fine roots could have played more of a role in cucumber inhibition than the breakdown of buckwheat shoots and the release of their allelochemicals. However, roots were only present in the buckwheat-grown soil, so there is no way of knowing if the roots directly caused inhibition of cucumber growth, or if the inhibition was caused by changes in the physical or chemical make-up of the soil due to buckwheat growing in it.

Other studies have found that the shoots of buckwheat plants contain the most allelopathic activity and result in the most inhibition of plant growth (Kalinova, 2008;

Kumar *et al.*, 2009; Xuan and Tsuzuki, 2004). Kumar *et al.* (2009) found that the addition of only 47.6 g of buckwheat shoots to bare soil reduced Powell amaranth (*Amaranthus powellii*) growth by 82% compared to a bare soil control. With more than twice the amount (100 g) of buckwheat shoots added in experiment 1, generally no cucumber inhibition was observed. Perhaps buckwheat allelochemicals have different effects on different target plants. If buckwheat shoots contained allelochemicals effective for inhibiting cucumber, cucumber growth would have been reduced in the shoot amended treatments, regardless of whether the soil had grown buckwheat or not. It is possible that buckwheat roots contain allelochemicals that have a greater inhibitory effect on cucumber than the shoots, or that the roots simply contain higher amounts of allelochemicals in this experiment than what was found by Kumar *et al.* (2009). Regardless, cucumber growers will grow and incorporate both buckwheat shoots and roots into the soil, and the combined effect of these residues is of most concern.

Effect of Buckwheat on Crabgrass Growth

In the replacement series trial, the addition of buckwheat residues caused a reduction in crabgrass growth in treatments containing high densities of crabgrass plants. Buckwheat reduced crabgrass biomass in treatments with crabgrass to cucumber ratios of 3:1 and 4:0, causing a 60% and 47% reduction in dry shoot biomass, respectively (Figure 3). Compared to these treatments with high crabgrass and low cucumber densities, buckwheat was not effective at inhibiting the growth of crabgrass in treatments with lower crabgrass densities. It is possible that since high densities of cucumber were more inhibitive of crabgrass than buckwheat residues, with less interference by cucumbers in the 3:1 and 4:0 ratio treatments, crabgrass was more susceptible to the inhibitive effects of buckwheat residues. It is also possible that the effects of cucumber on crabgrass masked the inhibitive effects of buckwheat. The high densities of cucumber could be more competitive to weeds, one of the reasons that growers direct seed processing cucumber at high densities.

The presence of buckwheat residues and a high density of cucumber plants inhibited both cucumber and crabgrass growth. However, in treatments 1:3 and 2:2, buckwheat did not reduce the growth of crabgrass, and even increased crabgrass biomass in treatments 1:3 compared to the bare soil control. Buckwheat shifted competition between cucumber and crabgrass by being more inhibitive of cucumber than crabgrass, causing a 41% reduction in cucumber dry biomass in treatment 1:3. This possibly lessened the inhibitive effect of cucumber on crabgrass growth, benefiting crabgrass when grown in treatments containing high cucumber densities by reducing cucumbers' competitive advantage and allowing crabgrass to accumulate more biomass.

Effect of Cucumber on Cucumber and Crabgrass Growth

Cucumber plants exhibited strong intra- and interspecific interference, being highly inhibitive of not only themselves, but also of crabgrass. High cucumber plant densities (treatments 0:4 and 1:3) were more inhibitive of cucumber vine length and crabgrass leaf length than were low cucumber densities, regardless of soil amendment (buckwheat or bare) (Tables 17 and 18). Introducing just one additional cucumber plant (treatment 2:2) to treatment 3:1 resulted in a 40% reduction in cucumber dry shoot biomass per plant, and treatments containing four cucumber plants (0:4) had dry shoot biomasses 68% lower than treatments with only one cucumber plant (3:1) (Figure 3). Crabgrass shoot height and biomass were also reduced with higher densities of cucumber plants (Table 18 and Figure 3). Introducing only one cucumber plant reduced crabgrass dry shoot biomass by 56%, and treatment 1:3 with three cucumber plants reduced crabgrass biomass by 81% compared to treatment 4:0 with no cucumber plants.

Thi *et al.* (2008) found that the extracts from only 0.3 g of harvested dry cucumber biomass was enough to cause a 98.8 and 88% reduction in root and shoot growth of crabgrass, respectively. However, Berry *et al.* (2006a,b) found differing results between greenhouse and field conditions. Under controlled conditions, cucumber was able to inhibit amaranth weed species (smooth pigweed and livid amaranth) (Berry *et al.*, 2006a). However, in the field, cucumber was unable to compete and had yield and biomass reductions under amaranth competition at densities of six – eight weeds per m^2 (Berry *et al.*, 2006b). Cucumber possesses allelopathic compounds that reduce the emergence and growth of not only itself, but also common weeds, such as amaranth and crabgrass species, and wild proso millet (Berry *et al.*, 2006a, 2006b; Thi *et al.*, 2008; Lockerman and Putnam, 1979; Putnam and Duke, 1974), so whether the interference of cucumber and crabgrass growth caused by cucumber was due to allelopathic substances or resource competition is unclear.

In this replacement series experiment, a reduction in cucumber plant density (and subsequent increase in crabgrass density) led to increased growth of both species, so it is possible that the fewer the cucumber plants, the lower the concentration of allelochemicals and thus, the lower reduction in growth. Since crabgrass densities were increasing, resource competition was still occurring, though it is possible that cucumber causes greater resource competition through its nutrient and water demands.

Buckwheat residues inhibited crabgrass in treatments with high crabgrass densities, a common weed problem associated with growing a range of vegetable crops. Unfortunately, this benefit of a buckwheat cover crop is outweighed by buckwheat's inhibition of cucumber growth at all densities used in these experiments, as well as buckwheat's improvement of crabgrass growth in treatments with high densities of cucumber plants. Since processing cucumber is often direct seeded at high rates, growing a cover crop that will not only reduce cucumber growth, but also increase weed growth is inefficient and not feasible, despite any additional benefits of buckwheat observed in other studies. Therefore, the assessment from these experiments is that buckwheat grown as a short-cycle cover crop and killed and incorporated one week prior to cucumber seeding will inhibit cucumber growth and does not appear to be a suitable choice for an alternative or additional weed control method.

CONCLUSION

The potential benefits of using buckwheat as a short-cycle cover crop prior to pickling cucumber, such as weed suppression and improvement of the soil and growing conditions of the next crop, are outweighed by the negative effects of buckwheat residues on cucumber. Buckwheat reduced cucumber growth and yield when buckwheat was killed and incorporated one week before cucumber seeding. It was demonstrated in field experiment 4 that the inhibition would be lessened if there was more time between incorporating buckwheat and planting cucumbers; however, because buckwheat did not have lasting inhibitive effects on weeds in this study and waiting longer to plant cucumber is not practical.

Results of the field and greenhouse experiments in St. Charles and Champaign demonstrate that buckwheat is not a suitable choice for a short-cycle cover crop prior to growing processing cucumbers. Even though weed biomass was reduced during buckwheat growth in most cases, adequate weed suppression during cucumber growth was not observed. In addition, the buckwheat cover crop reduced cucumber vegetative growth and yields in a variety of buckwheat cultivation techniques, including different planting and killing times. This work found no evidence of a practical benefit of preceding cucumber with a buckwheat cover crop.

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TABLES AND FIGURES

Table 1. Buckwheat and weed biomass during buckwheat, and the effect of buckwheat kill method and duration on volunteer buckwheat biomass at cucumber harvest in Field Experiment 1 – Buckwheat Kill Method and Duration.

	During Buckwheat		During Cucumbers
Treatment	**Buckwheat dry biomass**	**Weed dry biomass**	**Volunteer Buckwheat dry biomass** [a]
	$g\ m^{-2}$		
Short[b]/Mow	236.48 a[c]	130.24 a	152.30 a
Short/Till	178.90 a	144.77 a	64.91 a
Long/Mow	224.00 a	347.35 a	38.64 a
Long/Till	232.29 a	312.58 a	43.59 a

a – Volunteer buckwheat in buckwheat treatments at end of the cucumber growth period.
b – Short and Long refers to buckwheat stand duration (50 and 56 days, respectively).
c – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 2. Effect of buckwheat kill method and duration on weed biomass and number of cucumber leaves at cucumber harvest in Field Experiment 1 – Buckwheat Kill Method and Duration.

Treatment	**Weed dry biomass**	**No. of Cucumber Leaves**[a]
	$g\ m^{-2}$	
Short[b]/Mow Bare[c]	298.59 a[d]	22 a
Short/Mow BW	414.73 a	17 a
Short/Till Bare	57.26 a	30 a
Short/Till BW	172.11 a	19 a
Long/Mow Bare	185.89 a	13 a
Long/Mow BW	106.56 b	9 a
Long/Till Bare	7.32 c	15 a
Long/Till BW	129.81 b	8 a

a – Number of cucumber leaves per longest vine per plant.
b – Short and Long refers to buckwheat stand duration (50 and 56 days, respectively).
c – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
d – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 3. Effect of buckwheat cover and duration on buckwheat and weed biomass during buckwheat stand in Field Experiment 2 – Buckwheat Duration.

Treatment	Buckwheat dry biomass	Weed dry biomass
	----------------g m^{-2}---------------	
Bare[a]	0.00 a[b]	245.09 a
BW	517.42 b	26.16 b

a – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
b – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 4. Weed counts during buckwheat stand and cucumber stand in Field Experiment 2 – Buckwheat Duration.

Treatment	Grass[ab]	Amaranth sp.	Lambsquarter	Purslane	Nightshade
		During Buckwheat Stand			
Bare[c]	7.1 a[d]	1.5 a	8.1 a	0.8 a	0.0 a
BW	5.0 a	1.0 a	4.1 a	0.8 a	0.0 a
		During Cucumber Stand			
Short[e]/Bare	0.4 a	0.1 a	0.1 a	0.0 a	0.0 a
Short/BW	0.3 a	0.0 a	0.0 a	0.0 a	0.0 a
Long/Bare	0.9 a	0.0 a	0.0 a	0.1 a	0.0 a
Long/BW	0.1 a	0.0 a	0.0 a	0.0 a	0.0 a

a – Weed counts per square foot.
b – Grass = all grass species.
c – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
d – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
e – Short and Long refers to buckwheat stand duration (50 and 55 days, respectively).

Table 5. Effect of buckwheat cover and duration on weed and cucumber biomass, cucumber vine length, and cucumber yield at harvest in Field Experiment 2 – Buckwheat Duration.

Treatment	Weed dry biomass	Cucumber dry biomass [a]	Cucumber vine length	No. of cucumber fruits	Weight of cucumber fruits	Cucumber fruit Grade 1	Cucumber fruit Culls
	$g\ m^{-2}$	$g\ plant^{-1}$	cm		$g\ plant^{-1}$		
Short[b]/Bare[c]	67.27 a[d]	11.34 a	87.7 a	0.9 b	89.29 a	0.7 a	0.7 a
Short/BW	162.54 a	11.33 a	101.3 a	1.5 a	134.63 a	1.0 a	0.7 a
Long/Bare	44.78 a	7.91 a	70.3 a	0.3 a	11.82 a	1.0 a	0.0 a
Long/BW	71.15 a	6.98 a	72.7 a	0.2 a	5.88 a	0.7 a	0.0 a

a – Cucumber data presented as grams, centimeters, or counts per plant, averaged from three representative plants per treatment.
b – Short and Long refers to buckwheat stand duration (50 and 55 days, respectively).
c – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
d – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 6. Effect of buckwheat cover and planting date on buckwheat and weed growth during buckwheat crop in early and late buckwheat plantings in Field Experiment 3 – Buckwheat Planting Date and Duration.

Treatment	Buckwheat dry biomass	Weed dry biomass
	-----------$g\ m^{-2}$----------	
Early[a]/Bare[b]	0.00 a[c]	14.53 a
Early/BW	186.25 b	17.22 a
Late/Bare	0.00 a	0.86 a
Late/BW	56.25 b	209.04 a

a – Early and Late refers to buckwheat planting time (May 30 and June 17, respectively).
b – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
c – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 7. Weed counts during buckwheat stand and cucumber stand in Field Experiment 3 – Buckwheat Planting Date and Duration.

Treatment	Grass[ab]	Amaranth sp.	Lambsquarter	Purslane	Nightshade
			During Buckwheat Stand		
Late/Bare[c]	1.8 a[d]	------------------------------3.0 a[e]----------------------------			
Late/BW	2.4 a	------------------------------13.3 b----------------------------			
			During Cucumber Stand		
Early[f] Long[g]/Bare	0.3 a	0.5 a	0.6 a	0.3 a	0.4 a
Early Long/BW	0.5 a	1.0 a	0.2 a	0.0 a	0.7 a
Late Short/Bare	0.2 a	1.0 a	2.1 a	0.0 a	0.5 a
Late Short/BW	0.3 a	0.5 a	1.5 a	0.0 a	0.5 a
Late Long/Bare	0.4 a	1.1 a	1.5 a	0.0 a	0.4 a
Late Long/BW	1.7 a	0.3 a	0.4 a	0.1 a	0.1 a

a – Weed counts per square foot.
b – Grass = all grass species.
c – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
d – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
e – All broadleaf weeds combined.
f – Early and Late refers to buckwheat planting time (May 30 and June 17, respectively).
g – Short and Long refers to buckwheat stand duration (50 and 55 days, respectively.

Table 8. Effect of buckwheat cover, planting date, and duration on weed and cucumber growth at cucumber harvest in early and late buckwheat plantings, with short or long durations of buckwheat in Field Experiment 3 – Buckwheat Planting Date and Duration.

Treatment	Weed dry biomass	Cucumber dry biomass[a]	Cucumber vine length	Cucumber emergence	Cucumber stand count
	$g\ m^{-2}$	$g\ plant^{-1}$	cm		
Early[b] Long[c]/Bare[d]	378.78 a[e]	22.64 a	167.2a	49.6 a	17.1 a
Early Long/BW	485.88 a	9.55 b	123.5 b	3.5 b	3.3b
Late Short/Bare	478.03 a	16.00 a	128.8 a	13.5 a	8.3a
Late Short/BW	138.10 b	3.68 a	49.0 a	1.5 a	1.3b
Late Long/Bare	428.73 a	18.98 a	133.8 a	12.3 a	12.5 a
Late Long/BW	499.34 a	3.49 a	42.6 b	2.3 a	2.0 b

a – Cucumber data presented as grams, centimeters, or fruit counts per plant, averaged from three representative plants per treatment.
b – Early and Late refers to buckwheat planting time (May 30 and June 17, respectively).
c – Short and Long refers to buckwheat duration (36 and 44 or 41 days, respectively).
d – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
e – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 9. Effect of buckwheat cover on weed and cucumber growth at harvest in early and late buckwheat plantings, with short or long durations of buckwheat in the absence of weeds in Field Experiment 3 – Buckwheat Planting Date and Duration.

Treatment	Weed dry biomass	Cucumber dry biomass[a]	Cucumber vine length	Cucumber emergence	Cucumber stand count
	g m^{-2}	g $plant^{-1}$	cm		
Early[b] Long[c]/Bare[d]	n/a	19.82 a[e]	140.1 a	35.5 a	11.3 a
Early Long/BW	n/a	17.59 a	116.0 a	6.5 b	5.5 a
Late Short/Bare	n/a	14.33 a	97.4 a	13.5 a	10.5 a
Late Short/BW	n/a	9.43 a	66.9 a	3.0 a	4.5 a
Late Long/Bare	n/a	15.43 a	102.4 a	9.5 a	11.5 a
Late Long/BW	n/a	8.02 a	67.3 a	3.5 a	4.5 a

a – Cucumber data presented as grams, centimeters, or fruit counts per plant, averaged from three representative plants per treatment.
b – Early and Late refers to buckwheat planting time (May 30 and June 17, respectively).
c – Short and Long refers to buckwheat duration (36 and 44 or 41 days, respectively).
d – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
e – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 10. Effect of buckwheat cover on cucumber yield at cucumber harvest in early and late buckwheat plantings, with short or long durations of buckwheat in Field Experiment 3 – Buckwheat Planting Date and Duration.

Treatment	No. of cucumber fruits[a]	Weight of cucumber fruits	Cucumber fruit Grade 1	Cucumber fruit Culls
		g		
Early[b] Long[c]/Bare[d]	1.9 a[e]	41.50 a	0.5 a	1.5 a
Early Long/BW	1.0 a	12.25 b	1.0 a	0.5 b
Late Short/Bare	2.3a	444.50 a	0.3 a	1.2 a
Late Short/BW	0.5 a	63.25 a	0.0 a	0.0 a
Late Long/Bare	2.3 a	323.25 a	0.5 a	2.5 a
Late Long/BW	0.3 a	23.75 a	0.5 a	0.3 a

a – Cucumber data presented as grams, centimeters, or fruit counts per plant, averaged from three representative plants per treatment.
b – Early and Late refers to buckwheat planting time (May 30 and June 17, respectively).
c – Short and Long refers to buckwheat duration (36 and 44 or 41 days, respectively).
d – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
e – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 11. Effect of buckwheat cover on cucumber yield at harvest in early and late buckwheat plantings, with short or long durations of buckwheat in the absence of weeds in Field Experiment 3 – Buckwheat Planting Date and Duration.

Treatment	**No. of cucumber fruits**[a]	**Weight of cucumber fruits**	**Cucumber fruit Grade 1**	**Cucumber fruit Culls**
		g		
Early[b] Long[c]/Bare[d]	2.2 a[e]	51.00 a	0.8 a	2.0 a
Early Long/BW	2.1 a	42.25 a	0.0 a	0.5 b
Late Short/Bare	1.6 a	273.08 a	0.4 a	0.6 a
Late Short/BW	1.0 a	130.75 a	0.8 a	0.3 a
Late Long/Bare	2.0 a	232.50 a	1.8 a	1.8 a
Late Long/BW	1.0 b	69.25 a	0.3 a	0.3 a

a – Cucumber data presented as grams, centimeters, or fruit counts per plant, averaged from three representative plants per treatment.
b – Early and Late refers to buckwheat planting time (May 30 and June 17, respectively).
c – Short and Long refers to buckwheat duration (36 and 44 or 41 days, respectively).
d – Bare is bare ground control and BW is the buckwheat cover cropped treatment.
e – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 12. Buckwheat and weed biomass at 26 days after planting buckwheat in Field Experiment 4 – Buckwheat Duration and Delay.

Treatment	Buckwheat dry biomass	Weed dry biomass
	-----------g m^{-2}----------	
LowBW[a]	209.90 a[b]	14.53 a
RegBW	186.54 a	17.22 a

a – LowBW = buckwheat killed 26 DAP; RegBW = buckwheat killed 38 – 44 DAP.
b – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.

Table 13. Effect of length of buckwheat growth and delay between killing buckwheat and direct-seeding cucumbers on weed and cucumber growth at harvest in Field Experiment 4 – Buckwheat Duration and Delay.

Treatment	Weed dry biomass	Cucumber dry biomass [a]	Cucumber vine length	Cucumber emergence	Cucumber stand count
	g m^{-2}	g $plant^{-1}$	cm		
LowBW/Early[b]	742.06 a[c]	31.12 a	163.0 a	12.5 a	7.8 a
RegBW/Early	704.18 a	17.83 b	146.1 a	3.3 b	3.5 b
LowBW/Late[d]	360.38 a	21.22 a	171.0 a	33.8 a	13.8 a
RegBW/Late	485.88 a	9.55 b	123.5 b	3.5 b	3.3 b

a – Cucumber data presented as grams, centimeters, or fruit counts per plant, averaged from three representative plants per treatment.
b – LowBW/Early treatment had 26 days of buckwheat growth and 19 days delay; the RegBW/Early treatment had 38 days of buckwheat growth and 7 days delay. The cucumbers for both of these treatments were planted on July 14.
c – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
d – LowBW/Late treatment had 26 days of buckwheat growth and 25 days delay; the RegBW/Late treatment had 44 days of buckwheat growth and 7 days delay. The cucumbers for both of these treatments were planted on July 20.

Table 14. Weed counts during buckwheat stand and cucumber stand in Field Experiment 4 – Buckwheat Duration and Delay.

Treatment	Grass[ab]	Amaranth sp.	Lambsquarter	Purslane	Nightshade
		During Buckwheat Stand			
LowBW[c]	1.6 a[d]	4.1 a	1.9 a	0.0 a	0.0 a
RegBW	1.8 a	2.9 a	1.8 a	0.3 a	0.0 a
		During Cucumber Stand			
LowBW/Early[e]	0.6 a	2.0 a	1.6 a	0.3 a	1.4 a
RegBW/Early	0.3 a	2.1 a	1.3 a	0.2 a	0.8 a
LowBW/Late[f]	0.0 a	0.8 a	0.4 a	0.2 a	1.2 a
RegBW/Late	0.1 a	1.0 a	0.2 a	0.0 a	0.7 a

a – Weed counts per square foot.
b – Grass = all grass species.
c – LowBW = buckwheat killed 26 DAP; RegBW = buckwheat killed 38 – 44 DAP.
d – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
e – LowBW/Early treatment had 26 days of buckwheat growth and 19 days delay; the RegBW/Early treatment had 38 days of buckwheat growth and 7 days delay. The cucumbers for both of these treatments were planted on July 14.
f – LowBW/Late treatment had 26 days of buckwheat growth and 25 days delay; the RegBW/Late treatment had 44 days of buckwheat growth and 7 days delay. The cucumbers for both of these treatments were planted on July 20.

Table 15. Effect of length of buckwheat growth and delay between killing buckwheat and direct-seeding cucumbers on cucumber yield at harvest in Field Experiment 4 – Buckwheat Duration and Delay.

Treatment	No. of cucumber fruits[a]	Weight of cucumber fruits	Cucumber fruit Grade 1	Cucumber fruit Culls
		g		
LowBW/Early[b]	2.5 a[c]	54.50 a	0.5 a	3.0 a
RegBW/Early	1.5 b	28.25 b	1.0 a	1.8 a
LowBW/Late[d]	1.8 a	43.00 a	0.8 a	1.3 a
RegBW/Late	1.0 a	12.25 b	1.0 a	0.5 a

a – Cucumber data presented as grams, centimeters, or fruit counts per plant, averaged from three representative plants per treatment.
b – LowBW/Early treatment had 26 days of buckwheat growth and 19 days delay; the RegBW/Early treatment had 38 days of buckwheat growth and 7 days delay. The cucumbers for both of these treatments were planted on July 14.
c – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
d – LowBW/Late treatment had 26 days of buckwheat growth and 25 days delay; the RegBW/Late treatment had 44 days of buckwheat growth and 7 days delay. The cucumbers for both of these treatments were planted on July 20.

FIGURES

Figure 1. Average air and soil temperatures during field experiments in St. Charles and Champaign with average temperatures from the previous six years.

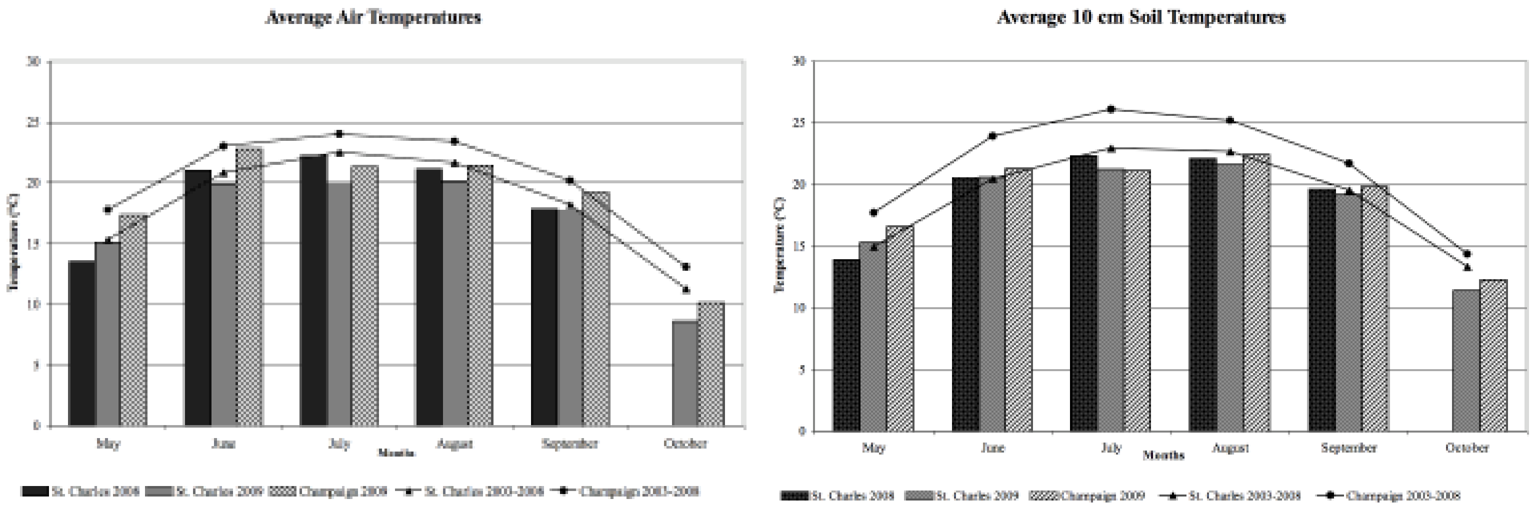


Figure 2. Total monthly precipitation during field experiments in St. Charles and Champaign with average precipitation from the previous six years for each location.

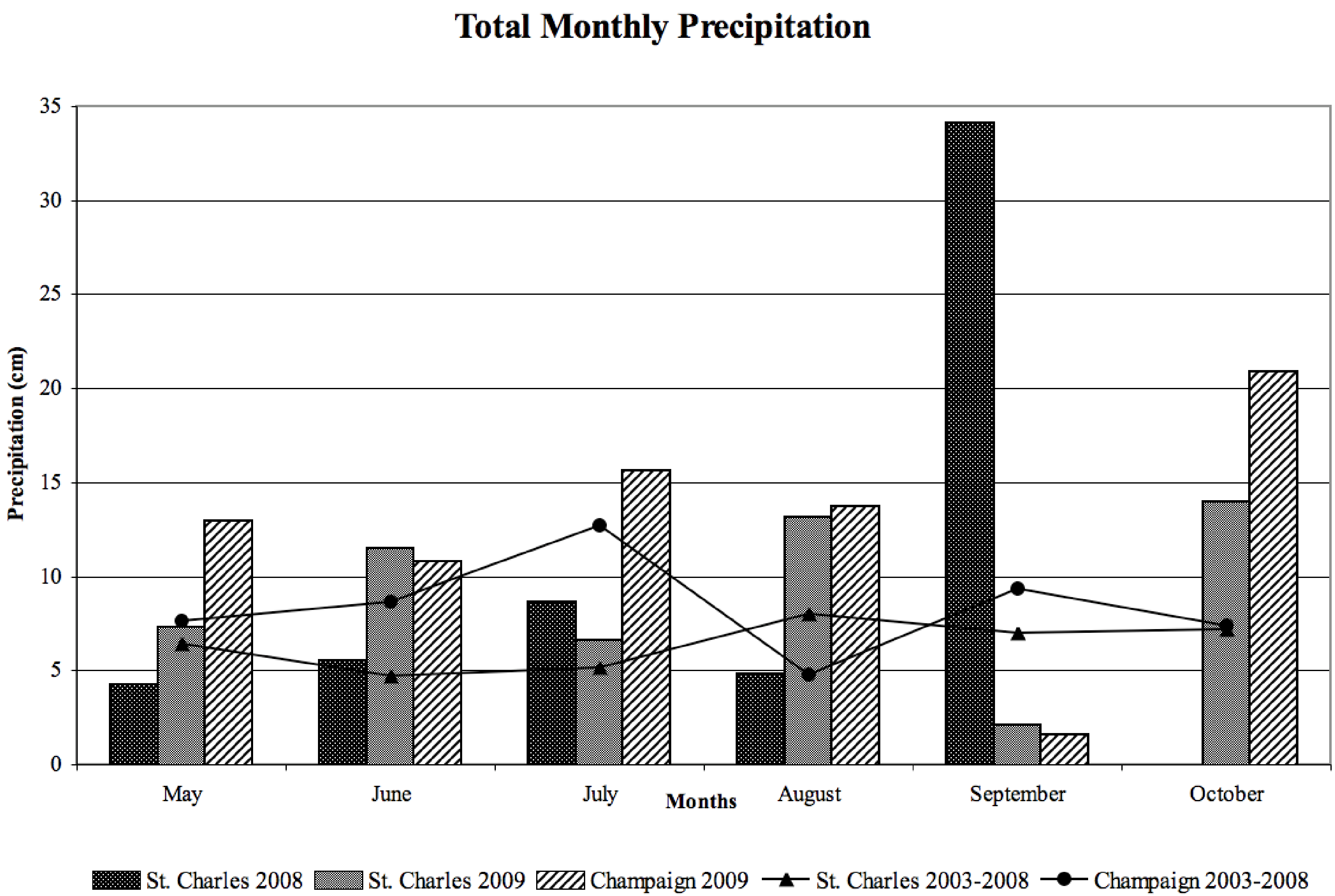


Table 16. Effects of different buckwheat root and shoot tissues on cucumber vine length and shoot biomass in Greenhouse Experiment – Buckwheat Residue Type.

Soil treatments / amendments	**Vine Length (cm)[a]**					**Cucumber dry biomass (g)[b]**
	Weeks After Planting					
	1	**2**	**3**	**4**	**5**	
Bare soil						
None	1.6 a[c]	2.9 ab	10.2 ab	48.6 a	96.9 a	17.20 a
Shoot	1.7 a	3.6 a	11.1 a	48.8 a	100.1 a	16.10 a
Buckwheat-grown soil						
Root	1.5 a	2.9 ab	8.1 b	33.9 b	85.0 b	10.70 b
Root + Shoot	1.5 a	2.6 b	8.9 ab	31.1 b	81.8 b	10.60 b

a – Vine length measured from soil surface to the base of the apical bud on longest vine; average longest vine per plant.
b – Shoot dry weight (DW) per plant 5 weeks after planting.
c – Means within a column followed by same letter are not different at the 0.05 level according to Tukey's HSD test

Table 17. Effects of buckwheat amendments and competition with large crabgrass on cucumber vine length in Greenhouse Experiment – Replacement Series Trial.

Treatment	Weeks After Planting				
	1	2	3	4	5
	Vine Length (cm)				
Bare soil	1.9 a[ab]	4.2 a	11.5 a	51.8 a	91.8 a
Buckwheat-grown soil	1.7 a	3.5 b	9.2 b	38.1 b	78.2 b
3:1[c]	1.9 a	4.0 a	11.8 a	59.6 a	103.0 a
2:2	1.6 a	3.7 a	10.2 ab	47.3 b	90.8 b
1:3	1.9 a	3.7 a	10.0 b	41.7 b	84.0 b
0:4	1.8 a	4.0 a	9.4 b	32.5 c	65.3 c

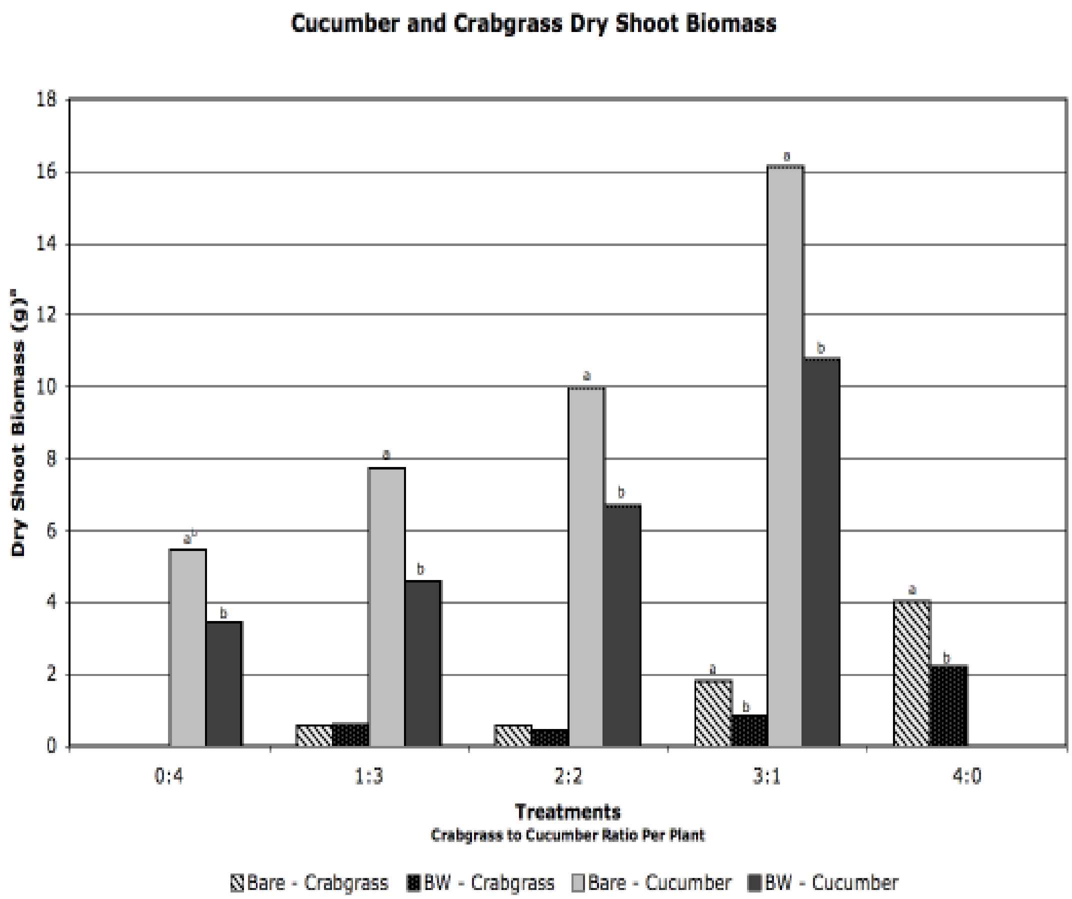
a – Average longest vine per plant.
b – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
c – Ratio of crabgrass to cucumber plants per pot.

Table 18. Effects of buckwheat amendments and competition with large crabgrass on large crabgrass leaf length in Greenhouse Experiment – Replacement Series Trial.

	Weeks After Planting				
Treatment	**1**	**2**	**3**	**4**	**5**
	Leaf Length (cm)				
Bare soil	1.1 a[ab]	7.3 a	26.0 a	38.4 a	43.6 a
Buckwheat-grown soil	0.8 b	5.7 b	23.0 b	35.9 a	39.7 b
4:0[c]	1.0 a	6.4 a	26.6 a	43.5 a	51.8 a
3:1	1.1 a	6.6 a	24.8 a	37.6 ab	42.7 b
2:2	0.9 a	6.2 a	23.8 a	34.5 b	37.0 bc
1:3	1.1 a	6.9 a	22.6 a	32.7 b	34.2 c

a – Average longest crabgrass leaf per plant.
b – Means within a grouped column followed by same letter are not different at the 0.05 level according to Tukey's HSD test.
c – Ratio of crabgrass to cucumber plants per pot.

Figure 3. Effects of buckwheat amendments and competition with large crabgrass on shoot biomass of cucumber and large crabgrass in Greenhouse Experiment – Replacement Series Trial.



a – Dry shoot biomass per plant.
b – Grouped bars with same letter are not different at the 0.05 level according to independent ttest.