

CHAPTER 1. Literature Review

1.1. Conventional and No-Tillage Production Systems

1.1.1. Conventional tillage: Conventional tillage is defined as the use of a moldboard plow for primary tillage followed by other tillage implements, such as disks and harrows, for seedbed preparation. Conventional tillage leaves less than fifteen percent residue cover after planting (Anderson, 1996). In Virginia in 1996, 37% of corn, 78% of small grains and 4% of double-crop soybeans were grown under conventional tillage. (Bull, 1996).

1.1.2. No-tillage: No-tillage is the practice of leaving the soil undisturbed subsequent to the previous harvest. Planting or drilling is accomplished in a narrow seedbed with coulters, row cleaners, disk openers, or in-row chisels (Anderson, 1996). Keisling (1998) describes the no-tillage practice as no tillage other than cutting a narrow seed furrow through undisturbed soil, plant residue, and any vegetation present at planting. In Virginia in 1996, 48% of corn, 8% of small grains and 94% of double-crop soybeans were grown under no-tillage conditions (Bull, 1996).

1.2. Typical Growing Seasons, Yields and Traditional Herbicide Programs in Virginia for Full Season Corn, Barley and Double-Crop Soybeans

1.2.1. Full Season Corn: In 1999, almost 32 million hectares of corn were planted in the United States, with approximately 210,500 hectares in Virginia. Planting dates for full-season

corn range from early to mid April in the eastern part of Virginia to late April or early May in the western part of the state. After a 5 to 6 month growing season corn is harvested in late August, September or October. The average yield of corn grain for the last 5 years in Virginia is 6184kg/ha (Virginia agricultural statistics,1999).

There are many herbicidal options in no-till corn production systems. However, in most locations and years depending on weed infestations a no-till program consists of three distinct herbicidal inputs including a non-selective burndown herbicide in combination with one or more residual preemergence herbicides at planting as well as a selective postemergence herbicide during the growing season. The selective postemergence application is used to control species unaffected by the preemergence herbicide and to control regrowth of perennial species from underground rootstocks. Davis (1986) stressed that the success or failure of no-till corn depends upon control of the vegetation existing at planting as well as residual control of weeds during the growing season.

Presently, non-selective burndown herbicides such as paraquat (1,1'-dimethyl-4,4'-bipyridinium ion), glufosinate [ammonium-(3-amino-3-carboxypropyl)-methylphosphinate] and glyphosate [N-(phosphonomethyl)-glycine] have been used to control existing vegetation at planting (Wilson et al, 1985; Davis, 1986; Wilson et al, 1988). The majority of residual preemergence herbicides are triazine or chloroacetamide based. The triazine herbicide family and specifically atrazine [2-chloro-4-(ethylamino)-6-(isopropyl-amino)-s-triazine] is used primarily for season-long control of annual broadleaf weeds and some grass weeds (Weed Control Manual, 1996; WSSA, 1994). Chloroacetamides such as metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] control many annual grass

weeds and certain small-seeded annual broadleaf weeds (Weed Control Manual, 1996; WSSA, 1994). Triazolopyrimidines such as the herbicide flumetsulam [N-(2,6-difluorophenyl)-5-methyl[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide] have recently been introduced as an alternative to atrazine. This compound is commonly used where triazine resistant species are present or where regulatory restrictions regarding proximity to water prohibit atrazine application. Selective postemergence herbicides are used to control weeds not controlled by preemergence herbicides and regrowth of perennial species. Many postemergence herbicides are available for selective control of emerged weeds in corn. The efficacy and selection of specific compounds depends on the type of weed species present (Virginia Cooperative Extension, 2000). Commonly used products include sulfonyl urea, triazine, benzothiadiazole, benzonitrile, phenoxy acid, benzoic acid, pyridinecarboxylic acid, and pyridate herbicides.

1.2.2. Barley: In 1999, Virginia producers planted 32,400 hectares of barley to be harvested for grain. In Virginia, barley is typically planted in late September through October and harvested in late May or early June. The average yield of barley grain for the last five years in Virginia is 4032 kg/ha (Virginia Agricultural Statistics, 1999).

In Virginia, 78 percent of the barley hectareage is planted into conventionally tilled soil (Bull, 1996). In this production system a nonselective burndown herbicide is not necessary. Herbicide applications consist of postemergence applications of a limited number of compounds. These compounds include certain members of the benzonitrile, sulfonyl urea, phenoxy acid, and benzoic acid families for broadleaf weed control and the compound diclofop (+/-)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid in the aryloxyphenoxy propionate

family for the control of annual grasses (Virginia Cooperative Extension, 2000). The remainder of the hectareage that is planted in a no-till program typically receives one of the non-selective burndown herbicides used in no-till corn production.

1.2.3. Double-Crop Soybeans: In 1999, Virginia producers planted 194,300 hectares of double-crop soybeans (Virginia Agricultural Statistics, 1999). Double-crop production systems refer to the practice of planting and harvesting two crops in one year's time on the same land. Double-cropping provides a method of diversifying the rotation, maximizing production, and increasing the profit potential of a cropping system (Pullins et al, 1998). Soybeans are planted after the harvest of a small grain crop, typically wheat or barley. The average yield of double-crop soybeans for the last five years in Virginia is 1794 kg/ha (Virginia Agricultural Statistics, 1999).

In Virginia 94 percent of double-crop soybeans are planted in a no-tillage production system (Bull, 1996). The weed control program for no-till double-crop soybeans has three potential inputs, which include a nonselective burndown herbicide, residual preemergence herbicides, and selective postemergence herbicides depending on the type and level of weed infestation. The nonselective burndown herbicides consist of the same compounds used in no-till corn production for the control of vegetation existing at planting (Virginia Cooperative Extension, 2000). Residual preemergence options include selected members of the chloroacetamide, urea, triazolopyrimidine, triazine, dinitroaniline, sulfonyl urea, and imidazolinone herbicide families for season-long weed control.

Many herbicidal options are available for selective postemergence applications in soybeans for weed species unaffected by the preemergence herbicide and perennial species regrowth. Selection of specific herbicides depends on the type of weed infestation. Commonly used compounds include members of the imidazolinone, sulfonyl urea, diphenylether, benzothiadiazole, urea, phenoxy acid, cyclohexanedione, and aryloxyphenoxy propionate herbicide families.

1.3. Rationale for Double-Crop Corn Production

Late crop production of corn (*Zea mays* L.) for grain following the harvest of a small grain is not currently practiced in Virginia. Historical precipitation and evapotranspiration data indicate that delayed corn planting could result in a high probability of available moisture during critical periods of crop development (Brann, 1997), (Figure 1). Traditional full-season corn when planted in early April through early May will reach the critical growth periods of silking, tasseling and grain fill in the month of July. Examination of Figure 1 reveals that although July is the month with the highest amount of precipitation, in most of the State, it is also coupled with the highest evapotranspiration level, which leads to a net deficit in available moisture for crop utilization. The ability to delay corn planting to late May or early June may facilitate corn development during a period with a higher level of available moisture in late August through mid-September.

Double-crop corn may also reduce economic risk as two crops would be harvested in the same year. Statistics from the Virginia Agricultural Statistics Service (1998) indicate corn prices for the last five years have averaged \$0.11/kg and Virginia averaged 6184 kg/ha, therefore

gross economic income averages for Virginia corn production has been \$680.30 per hectare. Barley prices have averaged \$0.09/kg in the last five years and Virginia averages 4032 kg per hectare. Therefore, gross income averages for Virginia barley production has been \$362.88 per hectare. Soybean prices have averaged \$0.23/kg and Virginia averages 1794 kg/ha of double-crop soybeans. Gross income averages for Virginia double-crop soybean production has been \$412.66 per hectare. Two crops are grown in the double-crop soybean production system, both barley and soybeans, therefore the addition of these two gross income averages equals \$775.54 per hectare. The average gross income differential between double-crop soybeans following barley compared to full-season corn is \$95.24 per hectare. Double-crop corn production following barley would have to yield approximately 3763 kg/ha to equal the gross returns of double-crop soybeans following barley. Double-crop corn production following barley would have to yield approximately 2791 kg/ha to equal the gross returns of full season corn.

Virginia livestock production could also benefit from the adoption of a double-crop corn system as Virginia farmers produce only 1.7 billion kilograms of corn grain per year while livestock consume 4.2 billion kilograms a year. The resulting deficit of 2.5 billion kilograms is imported to Virginia annually (Kenyon, 1998).

Effective herbicide programs are critical if the adoption of this cropping system is to occur. Minimizing inputs while retaining effective weed control will greatly enhance the probability of adoption. Mosely and Hagood (1990) demonstrated the ability to reduce herbicide inputs while retaining yield in the production of double-crop soybeans. These reductions in herbicide inputs

were possible primarily to the weed suppression afforded by the mulch remaining after small grain harvest.

1.4. Herbicide Chemistry and Activity for Compounds Applied in Experiments

1.4.1. Paraquat: Reduced-tillage or no-till methods of crop production did not develop until the mid-1960's, when herbicides such as paraquat offered alternatives to mechanical weed control (Gebhardt et al, 1985). Paraquat is a nonselective contact herbicide for use in no-till prior to planting or crop emergence to control existing vegetation and has no residual activity. (WSSA, 1996). Paraquat is a uncoupling agent in photosynthetic electron transport that leads to reduction of molecular oxygen yielding superoxide radicals (Hatzios, 1997). Paraquat is rapidly absorbed by green plant tissue, and the superoxides which are produced rapidly destroy plant cells (Anderson, 1996). The dicationic paraquat forms ionic bonds with negatively charged clays and the activity of the molecule is immediately eliminated when contact with the soil occurs (WSSA, 1994). Paraquat is a registered compound of Zeneca corporation under the trade name Gramoxone Extra[®] and use rates range from 0.5 to 1.1 kg ai/ha. This herbicide is often tank mixed with preemergence residual herbicides and efficacy is dependant upon the use of a non-ionic surfactant to increase vegetation coverage (Virginia Cooperative Extension, 2000). Paraquat has the chemical composition of 1,1'-dimethyl-4,4'-bipyridylium ion and is formulated as the dichloride salt.

1.4.2. Atrazine: Atrazine is one of the oldest synthetically manufactured herbicides and is produced by many companies in a variety of formulations. Atrazine was first released for experiment station evaluation in 1957, and became commercially available for use in corn in 1958 (Gysin and Knusli, 1957). Atrazine has the chemical composition 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine and is registered for use in corn, grain sorghum, sugarcane, and certain other crops (Crop protection reference, 2000). Atrazine was estimated by the environmental protection agency to have been the most heavily used pesticide in the United States in 1991, and was used at the rate of 36 million kilograms, primarily on corn (Ware, 1994). Atrazine is absorbed by the roots when applied to soil and translocated throughout the plant through the apoplast (WSSA, 1994). Atrazine applied postemergence is quickly absorbed by foliage and little translocation from the treated leaves occurs (WSSA). Atrazine is generally considered as a photosynthetic inhibitor. The mode of action of atrazine is to inhibit photosynthesis by binding to the Q_B-binding region of the D1 protein in the chloroplast thylakoid membranes and blocking electron transport (WSSA, 1994; Hatzios, 1997; Devine, 1993). The blocking of electron flow causes energy spillover to oxygen and other nearby molecules, photooxidation, and eventually phytotoxicity at the organelle, cell, and tissue level (Devine, 1993). Atrazine is effectively metabolized in tolerant species such as corn or sorghum to non-toxic forms through glutathione conjugation (WSSA, 1994; Devine, 1993; Hatzios, 1997).

Atrazine can be applied as early preplant, preplant incorporated, preemergence and postemergence treatments in corn and sorghum with rates ranging from 1.1-2.2 kg ai/ha. (Virginia Cooperative Extension, 2000; WSSA, 1994). Postemergence efficacy is increased

with surfactants to increase the rate and amount of atrazine absorbed by the foliage (WSSA, 1994; Virginia Cooperative Extension, 2000; Crop protection reference, 2000; Anderson, 1996). Registration or environmental protection agency restrictions limit the total amount of atrazine to not exceed 2.8 kilograms of active ingredient per hectare per calendar year due to detection of this herbicide in ground water (Virginia cooperative extension, 2000). Atrazine effectively controls many annual broadleaf species including pigweed (*Amaranthus spp*), morningglory (*Ipomoea spp*), jimsonweed (*Datura stramonium L.*), velvetleaf (*Abutilon theophrasti Medicus*), smartweed (*Polygonum spp*), lambsquarters (*Chenopodium album L.*), and has limited efficacy on some grass species including foxtail (*Setaria spp.*), barnyardgrass (*Echinochola crus-galli (L.) Beauv.*), and goosegrass (*Elusine indica (L.) Gaertn.*) (Virginia Cooperative Extension, 2000; WSSA, 1994; Crop protection reference, 2000). Atrazine is often tank mixed with other chemicals for species not readily controlled by atrazine alone.

1.4.3. Metolachlor: Metolachlor is a widely used preemergence herbicide in the chloroacetamide chemical family and is sold under the trade name Dual II Magnum[®] by Novartis. It is registered for weed control in corn, cotton, peanuts, pod crops, potatoes, grain and forage sorghum and soybeans (Crop protection reference, 2000) and has the chemical composition 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide (Crop protection reference; WSSA, 1994). Common application rates in corn range from 1.4 to 4.5 kg ai/ha depending on soil texture and organic matter content (Crop protection reference, 2000). Metolachlor has excellent activity on many annual grass species including foxtail species

(*Setaria spp.*), barnyardgrass, goosegrass, fall panicum (*Panicum dichotomiflorum* Michx.), and generally acceptable control of yellow nutsedge (*Cyperus esculentus* L.) (Virginia Cooperative Extension, 2000; Crop protection reference, 2000). A limited number of broadleaf species may also be controlled by metolachlor including pigweed species, (*Amaranthus spp.*) Eastern black nightshade (*Solanum ptycanthum* Dun.) and carpetweed (*Mollugo verticillata* L.) (Virginia cooperative extension, 2000; Crop protection reference, 2000).

Metolachlor is absorbed primarily by emerging shoots of grasses and broadleaves with limited absorption through the roots (WSSA, 1994). Metolachlor is only effective in controlling plants after germination and before emergence (WSSA, 1994). Plants past the seedling stage can still absorb metolachlor, however no control will occur because metolachlor is phytotoxic only to emerging seedlings (WSSA, 1994). The exact mechanism of action is not fully understood, however inhibition of fatty acid, lipid, protein, isoprenoid and flavonoid biosynthesis are common characteristics of the chloroacetamide herbicides (WSSA, 1994). Metabolism is performed in tolerant species by cleavage of the methyl ether followed by conjugation with glucose (WSSA, 1994). Conjugation with glutathione is also a detoxification process (WSSA, 1994; Hatzios, 1997).

1.4.4. Nicosulfuron, Prosulfuron, Primisulfuron, and Halosulfuron: Nicosulfuron 2-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide, prosulfuron 1-(4-methoxy-6-methyl-triazine-2-yl)-3-[3,3,3-trifluoropropyl]-phenylsulfonyl]-urea, primisulfuron methyl 2-[[[[[4,6-bis(difluoromethoxy)-2-

pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoate and halosulfuron methyl-5- {[4,6-dimethoxy-2-pyrimidinyl)amino] carbonylamino-sulfonyl}-3-chloro-1-H-pyrazole-4-carboxylate are all members of the sulfonylurea herbicide family that are registered for use in corn (Crop protection reference, 2000). These sulfonylurea herbicides are applied postemergence and are effective at very low use rates (WSSA, 1994). Efficacy of these sulfonylureas is dependent on the use of a surfactant to increase plant absorption (Crop protection reference; WSSA, 1994).

Sulfonylureas are a relatively new form of chemistry with the first becoming available for commercial use in 1982 (Ware, 1994). New compounds in this family have been regularly introduced since this initial registration. Sulfonylurea herbicides are composed of three moieties, an aryl group, a heterocycle portion and a sulfonylurea bridge that links the other two moieties (Devine, 1993). Differential selectivity is due to small substitution differences in each part of the molecule (Devine, 1993). Each chemical has strengths and weaknesses in the control of certain weed species and are used in accordance with the weed spectrum present. For example, nicosulfuron controls rhizome johnsongrass (*Sorghum halepense* (L.) Pers.) but is not effective against yellow nutsedge, whereas halosulfuron is poor in the control of rhizome johnsongrass and excellent in the control of yellow nutsedge (Virginia Cooperative Extension, 2000; Crop protection reference, 2000).

The mode of action of sulfonylurea herbicides is to inhibit acetolactate synthase, which is a key enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine (WSSA, 1994; Anderson, 1996; Devine, 1993; Hatzios, 1997). Plant death then occurs due to the lack of these essential amino acids (WSSA, 1994). Selectivity of the sulfonylurea

herbicides occurs because the tolerant plants rapidly detoxify the herbicides into non-toxic metabolites (Anderson, 1996). To date, seven different metabolic transformations of sulfonylureas have been reported, include aryl hydroxylation of the phenyl group, aliphatic hydroxylation, urea hydrolysis, sulfonamide cleavage, *O*-dealkylation, aryl hydroxylation of the pyrimidine ring and de-esterification (Hatzios, 1997). Over the last decade resistance has been reported in certain weed biotypes to specific sulfonylureas due to an altered binding site in the acetolactate synthase target enzyme (Hatzios, 1997; WSSA, 1994).

1.4.5. Dicamba: Dicamba, 3,6-dichloro-2-methoxybenzoic acid, a benzoic acid herbicide controls many annual broadleaf species and suppresses certain perennial broadleaf weeds. It is produced by several chemical companies in several different formulations and registered for use in corn, grain and forage sorghum, pasture, rangeland, small grains and turf (Crop protection reference, 2000). Dicamba application rates can range from 0.07 kg ae/ha in small grains to 2.2 kg ae/ha in pasture and rangeland (Crop protection reference, 2000; WSSA, 1994). Dicamba is primarily used postemergence, but does have preemergence activity (Crop protection reference, 2000; WSSA, 1994). Dicamba readily penetrates plant leaves, roots, and stems and is translocated by both the symplast and apoplast (WSSA, 1994; Ware, 1994; Anderson, 1996). Symptoms associated with dicamba application develop quickly and include twisting or epinasty, stem swelling and leaf cupping (Anderson, 1996; WSSA, 1994).

The mechanism of action of dicamba is not well understood, but appears to involve cell wall plasticity and nucleic acid metabolism (WSSA, 1994). Evidence provided by Devine (1993) indicates that inhibition of RNA and protein synthesis occurs in soybean due to the application

of dicamba. Tolerant species are able to rapidly detoxify dicamba to non-toxic metabolites through several processes including hydroxylation, demethylation, conjugation with glucose and decarboxylation (WSSA, 1994).

1.4.6. Glyphosate: Glyphosate N-(phosphonomethyl)glycine has traditionally been used as a nonselective, postemergence herbicide applied preplant or before emergence of over 150 crops for the control of annual and perennial grass and broadleaf weeds (Anderson, 1996; WSSA, 1994). Glyphosate can also be applied as a directed postemergence treatment or through the use of a wiper applicator to control weeds between rows or to control weeds exceeding the height of the crop canopy (Anderson, 1996; WSSA, 1994). Glyphosate is currently manufactured by Monsanto and is marketed under several trade names including Accord®, Rodeo®, Ranger®, but is most commonly associated with the trade name Roundup® or Roundup Ultra®.

Glyphosate is absorbed across the cuticle and translocated in the symplast with accumulation in underground tissues, immature leaves, and meristems (WSSA, 1994). The primary mechanism of action of glyphosate is to inhibit 5-enolpyruvylshikimate-3-phosphate synthase which produces 5-enolpyruvylshikimate-3-phosphate from shikimate-3-phosphate and phosphoenolpyruvate in the shikimic acid pathway (WSSA, 1994; Anderson, 1996). The essential aromatic amino acids phenylalanine, tyrosine, and tryptophan are products of the shikimate pathway (Devine, 1993). It has been estimated that as much as twenty percent of the carbon fixed by photosynthetic plants flows through the shikimate pathway (Conn, 1986). Blocking the shikimate pathway essentially starves the plants, because the aromatic amino acids

are needed for protein synthesis or for biosynthetic pathways leading to growth (WSSA, 1994). Symptoms of glyphosate phytotoxicity occur six to ten days after application, where tissue chlorosis is followed by necrosis and eventual plant death. There is evidence that blocking the production of 5-enolpyruvylshikimate-3-phosphate is not the only mechanism of action of glyphosate. Exogenous addition of aromatic amino acids to treated plants does not eliminate the phytotoxic effects of glyphosate, therefore an additional site of action is suspected (WSSA, 1994).

1.5. Agricultural Biotechnology: Herbicide and Insect Resistance

1.5.1. Herbicide Resistance: In the past decade, advances in biotechnology have provided the means to impart herbicide resistance to normally herbicide-susceptible crops to produce herbicide-resistant crops (Duke, 1996). Crops currently on the market that have genetically embedded resistance to a specific herbicide include glyphosate resistant soybeans, corn, and cotton, glufosinate resistant soybeans, glufosinate resistant corn, and bromoxynil resistant cotton. Herbicide resistance is advantageous because it facilitates a postemergence application of a non-selective herbicide that can control or suppress a wider range of weed species than a typical selective herbicide would allow. The potential impact of integration of these technologies is substantial. Benefits that could be realized include reduced cost of production and the ability to increase control of perennial weeds and other difficult to control species. Environmental impacts could be reduced through the use of compounds with little persistence in the environment and low toxicity. Additional environmental benefits include the potential ability to

implement reduced tillage crop production procedures with an associated reduction in soil erosion and introduction of herbicides into surface water.

1.5.2. Insect Resistance: A primary concern regarding insect control in corn is that insecticide costs may exceed the value of loss in yield and grain quality incurred by the insect (Lenhart, 1996). Therefore, agriculture has turned to genetic engineering to search for an alternative control strategy. The primary insect that has been targeted is the European corn borer (*Ostrinia nubilalis*) because it is generally acknowledged as the number one insect problem of corn in the Northeastern United States (Keller, 1986). European corn borer infestations may lead to decreases in corn yield by reducing grain weight, by increasing the incidence of lodging and ear drop, and by providing entry sites for stalk and ear pathogens (Keller, 1986). The severity of yield loss from European corn borer ranges from two to twelve percent per borer per plant (Anonymous, 1994). Recently, the incorporation of genetic material from *Bacillus thuringensis* has demonstrated significant potential for control of the European corn borer. *Bacillus thuringensis* is a bacterium that occurs naturally in the soil, and produces proteins that will kill certain lepidoptera insects as well as others with alkaline digestive tracts when ingested (Anonymous, 1994). Corn that produces the proteins toxic to the lepidoptera insects was created by inserting selected DNA from *Bacillus thuringensis* into the genome of corn (Ostlie et al, 1997). Corn that produces proteins of *Bacillus thuringensis* is commonly referred to as Bt corn. A primary advantage of this technology is the selectivity of Bt proteins, which are effective against the European corn borer, corn earworm (*Helicoverpa zea*) cotton bollworm (*Anthonomus grandis*) and Colorado potato beetle (*Leptinotarsa decemlineata*),

while being benign to humans, birds, fish and beneficial insects (Anonymous, 1994; Rice and Pilcher, 1998). Reduced insecticide use, cost and lower mortality of beneficial insects due to incorporation of the genes from *Bacillus thuringiensis* are other major advantages of Bt use (Rice and Pilcher, 1998). The Bt gene has been tested in toxicological studies and it was discovered that all other insecticides registered for control of the European corn borer are significantly more toxic than Bt (Anonymous, 1994). The Bt gene does not increase yield in a hybrid; it protects the hybrids genetic yield potential by reducing the amount of leaf injury and stalk tunneling caused by European corn borer. Bt protection can also be expressed in the grain to reduce feeding by corn earworms. Maximum yield protection attributed to Bt hybrids has ranged from 2250 to 5048 kg/ha in Kansas (Rice and Pilcher, 1998).

1.5.3. Safety: Concern over genetically engineered food is growing in both Europe and in the United States (Jemison, 2000). Fears include hypotheses that genetically modified foods may be less nutritious, may lead to genetic contamination of the environment, and that genetically modified foods could be a health hazard. Experiments by Hammond et al. (1996) determined that the feeding value of soybeans is not altered relative to the value of unmodified parental lines by genetic incorporation of glyphosate tolerance. Results also indicated the safety of the introduced 5-enolpyruvyl-shikimate-3-phosphate synthase protein (Hammond et al, 1996). Padgett et al (1996) determined that glyphosate resistant soybeans contain equivalent amounts of protein, fat, fiber, ash and carbohydrates as the parental, conventional soybean cultivar. In cotton, it was found that glyphosate-tolerant cotton lines were compositionally equivalent and as safe and nutritious as the parental and conventional cotton varieties commercially available for

livestock feed (Nida et al, 1996). Presently, research is being conducted to evaluate the potential of pollen transport from genetically modified corn to non-modified corn (Jemison and Vayda, 2000).

1.5.4. Glyphosate Resistant Corn: Glyphosate resistant corn was created through the same genetic transformation procedure as glyphosate resistant soybeans. Glyphosate resistant soybeans and corn were created through the incorporation of a naturally occurring 5-enolpyruvylshikimate-3-phosphate synthase gene from an *Agrobacterium* species that is insensitive to the herbicide glyphosate (Padgett et al., 1995). During the past five years, university weed scientists have cooperated with scientists from the private sector in evaluating these and other genetically modified crops. Bhowmik et al (1998) determined that glyphosate tolerant corn was completely tolerant to postemergence treatments of glyphosate, while Johnson et al. (2000) observed corn injury levels below ten percent when glyphosate was applied either alone or in combination with other herbicides.

Weed control advantages due to the implementation of glyphosate resistance are currently under evaluation. In recent studies, a single postemergence application of glyphosate does not allow sufficient season-long weed control (Hagood 1998, 1999; Johnson et al., 2000; Lingenfelter et al., 2000). A residual herbicide applied preemergence followed by a early post application of glyphosate or sequential glyphosate applications provide more efficacious weed control (Hagood 1998, 1999; Johnson et al. 2000; Lingenfelter et al, 2000). Reduced corn yields due to early competition by weeds are also associated with a single postemergence application of glyphosate (Stachowski, 1998). A major advantage of glyphosate resistance is

the ability to control or suppress perennial species. Glenn et al. (2000) observed 83 to 97 percent control of hemp dogbane (*Apocynum cannabinum* L.), and 97 to 100 percent control of pokeweed (*Phytolacca americana* L.) with a single postemergence application of 1.1-1.7 kg/ha glyphosate. The difficult to control perennial species trumpet creeper (*Campsis radicans* (L.) Seem. Ex Bureau) was controlled at levels exceeding 70 percent with a 4.5 kg/ha glyphosate rate (Bradley et al., 2000).

1.6. Research Objectives

The development of an economical weed control program in the production of double-crop corn could add an additional option to grower's management strategies. The general objective of this research is to elucidate the effect of corn planting subsequent to small grain harvest on the herbicidal and cultural inputs required to preclude economic losses due to weeds, as compared to those inputs required for traditional full-season corn establishment. This research contains four specific objectives. The first objective was to evaluate the cost/benefit characteristics of use of residual herbicides for annual broadleaf and annual grass control in double-crop vs. full-season plantings. The second objective was to determine if low amounts of herbicides would provide season-long control in double-crop corn due to the shorter growing season and the natural mulch resulting from small grain harvest. The third objective was to determine the potential for use of glyphosate resistant corn in both full-season and double-crop corn

production. The final objective was to evaluate the economic return of double-crop corn in comparison to full-season corn.