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Atrazine and Cyanazine Interception and Retention on Crop Residue

Mark A. Wrucke

ATRAZINE AND CYANAZINE INTERCEPTION AND RETENTION ON CROP RESIDUE

BY
MARK A. WRUCKE

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

W. E. Arnold — Date
Major Adviser

Maurice L. Horton — Date
Head, Plant Science Department

ATRAZINE AND CYANAZINE INTERCEPTION AND RETENTION ON CROP RESIDUE

Abstract

MARK A. WRUCKE

The effect of several variables on herbicide interception and retention by crop residue was investigated. Variables considered include residue type and amount, amount of rain, time of rainfall occurrence, and herbicide formulation. Experiments were conducted in the greenhouse using corn (Zea mays), soybean (glycine max), and wheat (Triticum aestivum) residue. Simulated rainfall was applied using a modified potsprayer. Herbicide concentration in washoff water was determined using the pyridine-alkali colorimeteric technique for chloro-s-triazine herbicides.

As the percent ground cover increased, the amount of herbicide reaching the soil surface at application decreased. With normal residue levels attained in South Dakota, 60% or more of the applied herbicide may be intercepted. Generally, cyanazine {2-[[4-chloro-6-(ethylamino),1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} was more easily removed from residue with rainfall than was atrazine [6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine]. The wettable powder formulation of atrazine and the dry flowable formulation of cyanazine were most easily removed. Of the total applied herbicide, 50% of the atrazine and 75% of the cyanazine was removed with 25 mm of rainfall. With a 25 mm rainfall, atrazine removal decreased by 25% and cyanazine removal decreased by 8% fourteen days after application. Both cyanazine and atrazine were most easily removed from corn residue compared to soybean or wheat residue. A theoretical model was developed for each herbicide and formulation tested. These models can be used to predict the level of herbicide reaching the soil surface under wheat residue with various rainfall conditions.

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INTRODUCTION

In recent years, farmers have made dramatic changes in their tillage practices. The conventional plow-disk-drag system allows farmers to remove crop residue, control weeds, and prepare the soil for planting. However, development of new herbicides and equipment has reduced the need for conventional tillage. While maintaining yields equal to conventional tillage, farmers using tillage systems which leave residue on the soil surface can realize savings of time, labor, and equipment, as well as increased moisture and soil conservation.

As tillage is decreased, several potential problems become apparent. Problems with soil fertility, seedling vigor, crop diseases, and insects have all been noted. However, many researchers (16, 43, 48) feel that weed control may be the major obstacle to expansion of conservation tillage. As tillage practices are reduced, weed problems tend to increase (9, 28, 29, 37, 45).

Increased weed pressure, shifts in weed species, and increased perennial weed numbers are problems associated with reduced tillage. Crop residue on the soil surface can intercept applied herbicides frequently resulting in diminished weed control. Only limited research has been conducted concerning the effect of herbicide interception and removal from residue by rainfall. The objectives this research were: (1) to determine the amount of herbicide intercepted at various residue levels, (2) to determine the amount of herbicide removed by various rainfall levels, (3) to determine if herbicide removal remains the same as time between application and rainfall increases, (4) to compare herbicide retention on different types of crop residue, and (5) to determine the effect of herbicide formulation on retention characteristics.

LITERATURE REVIEW

Concern over soil and moisture loss with conventional tillage has prompted many farmers to adopt conservation tillage techniques. Conservation tillage is generally defined as a tillage system which leaves crop residue on the soil surface to reduce wind and water erosion and increase soil moisture. Terracing and contour farming have been used to reduce erosion, but conservation tillage systems may be more effective. Minimum or no-till production systems can reduce erosion up to 90% compared to 50% reduction with terrace or contour farming. The reduction attained with conservation tillage varies depending on the amount of crop residue left on the soil, soil texture, percent slope and length of slope, and the amount and intensity of wind and rainfall (26, 28, 40, 49, 50).

Reduced evaporative water loss from the soil is another benefit of reduced tillage. Transpiration accounts for only 30 to 50% of the total soil water loss in one year with the remainder due to evaporation (31). Since crop residue insulates the upper soil profile, it reduces evaporative loss during the early stages of crop growth, with rate of evaporation generally decreasing with increased residue rates (4, 39). Water use efficiency of corn (_Zea mays_ L.) grown without tillage can be as much as

100% greater than corn under conventional tillage (22). During periods of drought, depletion of soil water in the upper foot of soil is delayed by 7 to 14 days (39); however, the cumulative evaporation losses under the two tillage systems will eventually be equal (4). Also, crop residue may increase soil water intake by reducing runoff; residue protects by intercepting and absorbing raindrop impact, thus reducing surface sealing.

Increased costs for fuel, labor, and equipment during the 1970's probably sparked the greatest interest in reduced tillage. Depending on the system used, up to one-half the time required for conventional tillage systems can be saved. Fewer trips over the field increase the usable life of tillage equipment and therefore reduce equipment costs (9). Fuel requirements are also greatly reduced due to fewer trips over the field. Fuel savings vary greatly, but it is generally estimated that no-till requires 3 to 4 fewer gallons of diesel fuel per acre than conventional tillage. Savings of 1 to 3 gallons is usually realized with other forms of conservation tillage (9). Total energy savings depends on the tillage systems used, but energy requirements are generally lower with reduced tillage systems.

Although many advantages can be realized with reduced tillage, several potential problems also become apparent. Incorporation of fertilizer becomes more difficult and nitrogen requirements may increase (30). Soil is generally more moist, slower to warm in the spring, and may become more compacted (5, 7, 12, 15). Planting and obtaining uniform stands become more difficult and crop diseases and insects may be more troublesome (19). Weed control becomes more difficult, usually requires greater use of herbicides, and may be a major obstacle to expansion of conservation tillage (16, 19, 43, 48).

Plowing and cultivating is a traditional and most effective method of weed control. With fewer tillage trips, weeds actively growing may not be destroyed, resulting in increased herbicide requirements. In an experiment dealing with weed control in several reduced tillage systems, Kapusta (20) found poorest weed control in no-till plots. Poor control of large weeds with non-selective herbicides at planting time and insufficient rainfall for preemergence herbicide activation were cited as reasons for this lack of control. In South Dakota, significantly higher weed yields were found with no-till than with disk or moldboard plow systems (52). Significantly greater populations of green foxtail [Setaria viridis (L.) P. Beauv.] and foxtail barley (Hordeum jubatum L.) were responsible for the increased weed yield. Fewer spring tillage trips increase the need for nonselective herbicides at planting time, and reduced cultivation may require use of more preemergence and postemergence herbicides.

Wicks and Somerhalder (47) found increased weed pressure with reduced tillage due to concentration of weed seed at the soil surface. Frequently changes in predominant weed species are observed with reduced tillage. Lack of spring tillage allows more of the early germinating broadleaf weeds, such as Pennsylvania smartweed (*Polygonum pennsylvanicum* L.), giant ragweed (*Ambrosia trifida* L.), common ragweed (*Ambrosia artemisiifolia* L.), and common lambsquarter (*Chenopodium album* L.), to survive and form a canopy over smaller grass plants (9, 48). Such a canopy will intercept nonselective herbicides, controlling the broadleaf weeds but releasing the grass weeds to become dominant.

Certain grass weeds have been found to become dominant in continuous reduced tillage systems due to herbicide selectivity. Continuous use of 2,4-D [(2,4-dichlorophenoxy) acetic acid] in direct-drilled cereal crops caused dominance of annual bluegrass (*Poa annua* L.), wild oats (*Avena fatua*), and blackgrass (*Alopecurus myosuroides*) in England (32, 33). Continuous use of atrazine [2-chloro-4-(ethylamino)-6-(isopropyl-amino)-s-triazine] and other triazine herbicides has lead to predominance of fall panicum (*Panicum dichotomiflorum*), field sandbur (*Cenchrus incertus*), and large crabgrass

[*Digitaria sanguinalis* (L.) Scop.] in other studies (42, 48).

Perennial weed problems tend to increase with reduced tillage, especially those systems which eliminate any form of deep tillage. Robertson and associates (36) reported that after three years perennial weeds were more of a problem in no-till plots than conventional till plots. Triplett and Lytle (42) observed that large colonies of perennial weeds developed from individual plants in no-till systems, but not in conventional plots. Frequently observed perennial weed problems include common dandelion (*Taraxacum officinale* Weber), common milkweed (*Asclepias syriaca* L.), Canada thistle [*Circium arvense* (L.) Scop.], groundcherry (*Physalis* spp.), and hemp dogbane (*Apoynum cannabium* L.) (48).

The effect of crop residue on herbicide application and performance has raised some concern among farmers. With no-tillage systems, 80 to 100% of the soil surface may be covered with residue. In other conservation tillage systems, the amount of residue remaining depends on the implements used. Fenster (11) estimated residue reduction with each tillage operation to be 10% for V-sweeps, 25% for chisel plows, and 5 to 10% for rodweeders. Residue reduction with a disk varies from 30 to 70% depending on type of disk (one-way, tandem, or off-set) and depth of operation. Use of a moldboard plow generally results in a 90 to 100% reduction of surface residue. Since the straw to grain ratio of most crops ranges from 1.0 to 2.0, residue levels can vary anywhere from 0 to 10,000 kg/ha or more (23). With higher rates of residue, much of an applied herbicide can be intercepted by residue and prevented from reaching the soil surface. Limited research has been directed at the fate of intercepted herbicide and its effect on weed control.

Corn residue covering 80 to 85% of the soil surface prevented 30% of the applied atrazine from reaching the soil surface in a study by Bauman and Ross (3). Therefore, the actual rate of application to reach the soil was only 70% of the applied rate. Banks and Robinson found that less than 1% of applied metribuzin [4-amino-6-tert-butyl-e-(methylthio)-as-triazin-5(4H)-one] and less than 20% of applied oryzalin (3,5-dinitro-N_4, N_4-propylsulfanilamide) reached the soil surface beneath 9000 kg/ha wheat (*Triticum aestivum* L.) straw residue (1, 2). Even with a residue level of only 2250 kg/ha, 68% of the metribuzin and 53% of the oryzalin was intercepted. Ghadiri et al. (13) found 60% of applied atrazine intercepted by 6400 kg/ha of wheat straw. All of these studies indicate that large portions of applied herbicides can be retained on residue, drastically reducing the actual rate of herbicide reaching the soil.

Wheat straw or ash on the soil surface reduced weed control with five soybean (*Glycine max*) herbicides; however, increasing herbicide rates generally overcame this reduction (41). Moomaw and Burnside (29) found that performance of several soybean herbicides was not affected by crop residue when full label rates were used. When one-half herbicide use rates were applied, weed control was reduced by crop residue and soybean yields decreased. This experiment was conducted during a cycle of dry years in Nebraska resulting in lower than normal residue levels and, overall, poor weed control with all tillage systems. Another study comparing chemical weed control in several tillage systems found poorest control with preemergence herbicides in the no-till plots (51). Interception of herbicides by residue on the soil surface and lack of sufficient rainfall for removal were cited as reasons for the poor control. Wicks et al. (45) had variable results when comparing weed control with several corn herbicide treatments at two residue levels. Generally, poorest grass control was attained on plots containing residue, with broadleaf weed control being more variable. Plots receiving postemergence herbicide treatments had equal control at both residue levels.

In reduced tillage corn and sorghum (*Sorghum bicolcr*), Robison and Wittmus (37) found that herbicides effectively controlled weeds even at residue levels exceeding 5000 kg/ha and covering 73% of the soil surface. When ground cover was reduced from 75% to 47% by one additional disking operation, weed control increased. This increase was attributed to reduced herbicide interception by the residue. In field studies conducted by Erbach and Lovely (10), plant residue levels as high as 6000 kg/ha did not significantly affect performance of alachlor [2-chloro-2′,6′-diethyl-N-(methoxymethyl) acetanilide] and atrazine applied preemergence to no-till corn. A comparison of liquid and granule formulations of each herbicide showed little effect on weed control with alachlor, but control with atrazine granules was less than with the liquid formulation. Greenhouse studies with lower rates of both herbicides found decreased weed control as residue levels increased and better control with liquid formulations than with granules. Simulated rainfall of 1.5 cm improved control nearly eliminating effects of residue and formulation.

Little work has been done to determine if intercepted herbicide becomes adsorbed to plant residue. Grover (17) found that picloram (4-amino-3,5,6-trichloro-picolinic acid) was not adsorbed on wheat straw or cellulose but was highly adsorbed on soil organic matter. Walker and Crawford (44) found little adsorption of atrazine on plant residue, but increased adsorption as plant material decomposed. These studies provide evidence that herbicides are not physically adsorbed to plant residue and may be subject to rainfall or some other form of removal.

Bauman and Ross (3) found 86 to 90% of intercepted atrazine to be removed from corn residue within 30 days of application. Both locations of this experiment received significant rainfall within one week of application, which may account for herbicide removal. Ghaderi et al. (13) found that 90% of the atrazine retained on standing stubble and 63% of that retained on flat stubble were removed by 50 mm of precipitation received during the first three weeks following application. After 6 weeks and 120 mm precipitation, only 4% of the initially applied atrazine remained on the stubble. Greenhouse studies dealing with rainfall amounts found that 25 mm of simulated rainfall immediately and 2 days after application removed significantly more atrazine than did 12.5 mm of rainfall. No difference in removal was detected between 25 and 50 mm of rainfall. These results show that rainfall of at least 25 mm shortly after atrazine application will be most effective for herbicide removal from wheat stubble.

Atrazine retention and removal from corn and three-week old oat (Avena sativa L.) residue as a function of rainfall amount and timing was studied by Lowder and Weber (25). They found that 75 to 87% of applied atrazine was removed with 10 cm of rainfall, with more removed from oat residue than from corn residue. Also, less atrazine was removed 7 days after application than immediately after application. This difference may have been due to volatilization. They concluded that atrazine retention by crop residue is primarily a function of total rainfall received, and is secondarily dependent on type of residue and rainfall pattern.

Banks and Robinson reported that applying simulated rainfall in excess of 0.6 cm did not remove additional metribuzin from straw, with a maximum of 45% of the applied metribuzin reaching the soil at straw levels of 2250 kg/ha or greater (1). Another study (2) found that oryzalin concentration in the soil after 1.3 cm rainfall was reduced by 43% at straw levels of 4500 kg/ha or greater compared to no residue plots. Analysis of the straw for water extractable oryzalin found only 1 to 3% of the applied oryzalin remaining on the straw; thus, approximately 50% of the oryzalin was unaccounted for. The missing oryzalin was either bound to the straw in a form non-extractable by water or had volatilized.

Martin and associates (27) found that corn residue retained little of the herbicides atrazine, cyanazine {2-[[(4-chloro-6-(ethylamino)-s-triazine-2-yl]-amino] -2-methylpropionitrile}, alachlor, and propachlor (2-chloro-N-isopropyl-acetanilide) when simulated rainfall was applied within 12 hours of herbicide application. As with all herbicides, concentration in the washoff water decreased with time as rainfall was applied. The initial 0.5 cm of water removed as much herbicide as the next 3.0 cm of water. Although rainfall was applied within 12 to 14 hours of application, only 61, 76, and 81% of the propachlor, alachlor, and atrazine, respectively, could be accounted for. These losses must be due to either degradation or volatilization. Burt (6) noted increased atrazine volatility from plant material versus soil. Within 48 hours of application, volatility was 18 and 27% from stem and leaf segments, respectively, of dried orchardgrass (Dactylis glomerata). Living Canada thistle leaves showed 63% volatilization in 48 hours; whereas, only 11% volatilized from soil. Thus, herbicide efficacy in reduced tillage systems may be lowered if herbicides decompose or volatilize more readily from residue than from soil.

Much of the research done on herbicide interception has been with the triazine herbicides. Atrazine and cyanazine are two triazine herbicides which are widely used for weed control in corn, sorghum, and fallow. In 1980, atrazine was applied to 32% of the corn acreage in the United States making it the most widely used corn herbicide (18). Cyanazine was applied to 8% of the corn acreage, ranking it fifth among corn herbicides.

Atrazine and cyanazine are selective herbicides for control of both grass and broadleaf weeds which can be applied either preplant, preemergence, or postemergence. Vapor pressure and solubility of each herbicide are shown in the Table 1 (46).

Both herbicides are adsorbed on clay and organic matter and degraded primarily by soil microbes. Generally, there is only minimal loss of either herbicide from photodecomposition or volatilization. Cyanazine has a half-life in soil of approximately two weeks, with atrazine having a half-life of six to seven weeks (14).

The pyridine-alkali colorimetric method was developed by Ragab and modified by Radke et al. in the early 1960′s as a quick and reliable technique for detection of chloro-s-triazine herbicides (34, 35). It involves the reaction of pyridine with the chlorine portion of a triazine molecule. Upon further reaction with sodium hydroxide, a yellow color forms with color intensity indicative of the amount of herbicide present.

The pyridine-alkali reaction with a chloro-s-triazine herbicide is shown in Figure 1 (21, 35). An electrophilic reaction occurs between the unshared electron pair of the nitrogen atom of pyridine and the electron-attracting chlorine of a chloro-s-triazine molecule. This forms a quaternary salt which forms a carbinol base after the addition of a hydroxyl group.

Table 1. Vapor pressure and water solubility of atrazine and cyanazine.*

	Temperature (C)	Vapor Pressure
Atrazine	20	3.0×10^{-7} mmHg
	30	1.4×10^{-6} mmHg
Cyanazine	20	1.6×10^{-9} mmHg
	30	1.0×10^{-8} mmHg
		Solubility in water
Atrazine	27	33 ppm
Cyanazine	25	171 ppm

* From Herbicide Handbook, Fifth Ed., 1983. Weed Science Society of America, Champaign, IL. Pp. 30-35, 119-121.

Treatment with alkali hydrolyzes the carbinol base, opening the pyridine ring and yielding a monoanil of glutaconic aldehyde which is in equilibrium with its tautomeric form. It is at this stage that the yellow color is formed. The latter structure has completely conjugated double bonds, which tend to show strong absorption of visible light.

This test has been shown sensitive to levels as low as 0.033 ppm (35). Reproducibility has been very good when the cooling step was very rapid and temperature maintained constant until the spectrophotometric reading was taken. Saturation of pyridine with glycine results in increased color intensity. Glycine-saturated pyridine has a lower pH than pyridine, which enhances the electrophilic attack at the pyridinium nitrogen that displaces the chlorine (34). Therefore, maximum reproducibility and improved color stability are attained by using glycine-saturated pyridine.

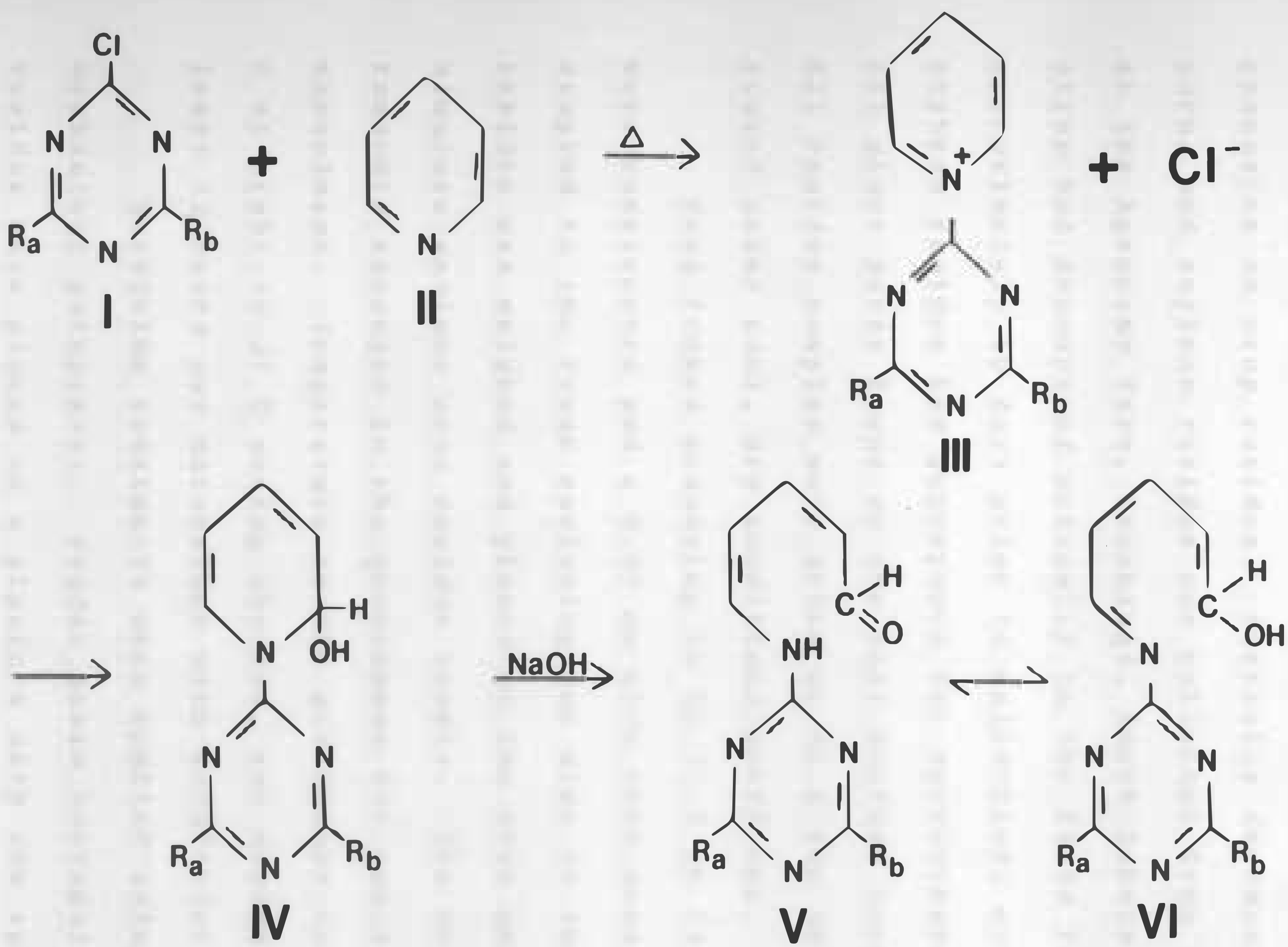

Figure 1. Reaction mechanism for the pyridine-alkali colorimetric technique. The chloro-s-triazine molecule (I) is attacked by pyridine (II) forming a quaternary salt (III). A hydroxyl group is then added to form a carbinol base (IV). Treatment with alkali opens the pyridine ring producing an equilibrium mixture of a monanil of glutaconic aldehyde (V) and its enol form (VI). From Ragab, M.J.H and J.P. McCollum. 1968. J.Agr.Food Chem.16:289.

Materials And Methods

Four experiments were conducted in the greenhouse to determine the retention characteristics of atrazine and cyanazine on crop residue. Partially decomposed wheat, corn, and soybean residue was collected from filler areas at the Agronomy Farm, Brookings, South Dakota. Wheat straw had decomposed naturally in the field for approximately 60 days prior to collection; corn and soybean residue had decomposed for approximately 30 days. All plant parts found on the soil surface were collected. All residue samples were dried at 40 C for 48 hours and stored under cool, dry conditions until use.

Wood frames measuring 24 by 37.5 cm (900 cm^2) were constructed and a 6.35 mm wire mesh screen was stapled to the frame enclosing one side of the box. Crop residue was weighed and placed on the wire mesh to simulate various crop residue levels. The boxes were then randomly arranged in the greenhouse for use in the experiment. Temperature in the greenhouse varied from 16 C at night to 27 C during the day, and daylength of at least 12 hours was maintained with artificial light.

Herbicide treatments were applied using a mechanical potsprayer. Wooden boxes containing crop residue were placed on a platform with the spray nozzle passing over them at a constant speed. The potsprayer, equipped with a TeeJet 730077 flat fan nozzle and a 200 mesh ball-check screen, was calibrated to deliver 187 l/ha spray solution at 173 kPa pressure.

Simulated rainfall treatments were applied with minor modifications of the potsprayer. A Delavan raindrop nozzle was installed and operated at 138 kPa pressure. Simulated rainfall was applied at the rate of approximately 1 mm/min. Brookings city water was the water supply for this study. Runoff water was caught in a stainless steel container as it dripped through the crop residue. After stirring the runoff water, a 50 ml sample was taken and kept in a dark brown glass bottle until analysis.

Runoff samples were analyzed quantitatively using the pyridine-alkali colorimetric technique for chloro-s-triazine herbicides (21, 34, 35). Pyridine (98% v/v. analytical reagent grade) was diluted with distilled water to make 70% pyridine solution (v/v). This solution was saturated with glycine and the excess glycine filtered on medium filter paper. A solution of 9N NaOH was prepared by diluting 10N NaOH (carbonate free) with distilled water. A 5 ml aliquot of the herbicide runoff water solution was pipetted into a 25 ml (16 x 150 mm) borosilicate glass test tubes and 1 ml of 70% pyridine saturated with glycine was added. The solutions were mixed and placed in a boiling water bath for 30 minutes. Large glass marbles, placed on the tubes, served as condensers to prevent excessive evaporation. After boiling, the tubes were cooled to room temperature (20 C) in another water bath. After cooling, 1 ml of 9N NaOH was added to each tube and mixed rapidly with a glass rod. The resulting yellow color was measured one minute after the addition of alkali at 436.5 nm in a B & L Spectronic 20 spectrophotometer fitted with a blue-sensitive phototube. A reagent blank prepared in the same way was used to set 100% transmittance. The percent transmittance was recorded for each sample and parts per million of herbicide in each sample was determined by comparing it to a standard curve.

Stock solutions (10 ppm) of both atrazine and cyanazine in water were prepared. Standard solutions at 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 3.0, 4.0, and 5.0 ppm were prepared from the stock solution by dilution with water. Standard solutions for both herbicides were analyzed using the above procedures and a standard curve calculated for each herbicide. Concentrations of the unknown samples were computed from reference standards made at the same time and under the same conditions as the unknowns.

Residue level effects on herbicide retention

Wheat residue was weighed and evenly distributed on the wire mesh of the wooden boxes to simulate residue levels of 0, 1000, 2000, 3000, 4000, and 5000 kg/ha. Residue levels of 0, 2000, 4000, 6000, 8000, and 10,000 kg/ha were established for corn and soybean residue. To determine percent ground cover, ten holes 2 mm in diameter were drilled through a 50 cm long board. The residue boxes were placed on a sheet of red cardboard, the 50 cm board placed diagonally across the box, and the number of holes through which red could be seen recorded. This procedure was done twice with each box at different diagonals. Percent ground cover was calculated with the following equation: % ground cover = [(20 - no. of red holes counted)/20] x 100. Percent ground cover was calculated for two of the three replications in each experiment.

All boxes were sprayed with either atrazine or cyanazine at a rate of 2.24 kg active ingredient/ha. Each herbicide was applied to each residue type and level. Residue boxes were placed on glass trays of equal dimensions to catch any herbicide which sprayed through the residue during application. After herbicide application, the glass trays were rinsed with 500 ml of water and a 50 ml sample of the rinsate kept for analysis. Samples were analyzed using the pyridine-alkali colorimetric technique previously described with 1 ml of the sample being diluted with 4 ml of water. The concentration of each sample was determined from the standard curve for each herbicide.

Experimental design was a split-split plot where main plots were herbicides, subplots were residue type, and sub-subplots were residue level. All treatments were replicated three times and the experiment was conducted twice.

Rainfall amount effects on herbicide retention

Wheat residue at a level equal to 4000 kg/ha was weighed and evenly distributed on the wire mesh of the wooden boxes. Either the liquid, dry flowable, or wettable powder formulation of atrazine or cyanazine was applied to each box at a rate of 2.24 kg/ha. Simulated rainfall was applied a level of 0.25, 1.0, 2.5, 5.0, 12.5, or 25.0 mm to each box within 12 hours of herbicide application. Washoff water was collected, brought to a total volume of 2300 ml, and a 50 ml sample taken for analysis. For analysis, 2 ml of the sample was further diluted with 3 ml of water and the pyridine-alkali colorimetric technique employed. Concentration of each sample was determined from the standard curve for each herbicide.

Time effects on herbicide retention

Residue boxes were established to simulate 4000 kg/ha wheat straw and either the liquid, dry flowable, or wettable powder formulation of either atrazine or cyanazine was applied to each box at a rate of 2.24 kg/ha. Simulated rainfall at a level of 25.0 mm was applied to each box 0, 1, 3, 7, or 14 days after herbicide application. The 0 day rainfall treatments were applied within 8 hours of herbicide application. A 50 ml sample of the washoff water was saved for analysis in which 2 ml of the sample was diluted with 3 ml water. Herbicide concentration was determined using the previously described technique.

Experimental design was a split-split plot where main plots were herbicides, subplots were herbicide formulations, and sub-subplots were rainfall times. The experiment was repeated twice with treatments replicated three times per experiment.

Herbicide retention on various residue types

Residue boxes containing wheat straw at 4000 kg/ha or corn or soybean residue at 8000 kg/ha were sprayed with atrazine or cyanazine. The liquid, dry flowable, and wettable powder formulations of each herbicide were applied to each residue type. Residue boxes were placed on glass trays of equal dimensions to catch any herbicide which sprayed through the residue. The glass trays were rinsed with 500 ml of water and a 50 ml sample of the rinsate saved for analysis. Within 12 hours of herbicide application, 12.5 mm of simulated rainfall was applied to each box. Washoff water was collected, brought to a total volume of 2300 ml, and 50 ml sample kept for analysis. For analysis, 2 ml of each sample were diluted with 3 ml of water and concentration of each sample determined by the previously described technique.

Experimental design was a split-split plot design with three replications. Main plots were herbicides, subplots were herbicide formulation, and sub-subplots were residue types. The experiment was conducted twice.

All data from all experiments was subjected to an analysis of variance with factors being combined when justified by lack of significance of the appropriate interaction terms (24, 38). Data was further analyzed with regression analysis on all data points and means separated with the Waller-Duncan k-ratio t-test (k=100).

Theoretical simulation model

Data from the rainfall amount experiments and the time of rainfall experiments were combined with the wheat residue level data. Multiple regression analysis was performed using Procedure Stepwise of SAS (38). Additional data points were calculated and added to the data set to improve fit of the model. It was assumed that at a residue level of 0 kg/ha, all applied herbicide would reach the soil surface. Also, the amount of herbicide reaching the soil surface with 5000 kg/ha wheat residue following 25 mm of rain 14 days after application was calculated and added to the data set. The linear term for each variable was forced to occur in each model with the quadratic term for each variable and all possible interaction terms available as optional terms in each model. The best model for each herbicide and formulation was determined by maximum R square and fit of calculated points to data.

RESULTS AND DISCUSSION

Residue level effects on herbicide retention

Different types of residue provide varying degrees of ground cover at equal residue levels. As ground cover increases, the amount of herbicide which is intercepted will increase. Therefore, the objective of this experiment was to determine the relationship between residue level and percent ground cover for corn, soybean, and wheat residue; and, also, to determine the amount of herbicide intercepted at various residue levels.

Percent ground cover was found to increase significantly as the level of each type of residue increased (Figures 2 and 3). At the highest level of residue, wheat straw provided 95% ground cover, corn stalks 80% cover, and soybean residue 90% ground cover. Although wheat straw levels were increased to only one-half of those for corn and soybean by weight, ground cover was slightly higher for wheat. This is probably due to the hollow stems of wheat straw resulting in a low weight per unit of surface area. Percent ground cover was very strongly correlated with residue level for wheat ($r=0.94$, $p=0.0001$), corn ($r=0.91$, $p=0.0001$), and soybeans ($r=0.96$, $p=0.0001$). The strong positive correlations indicate that either ground cover percentage or residue

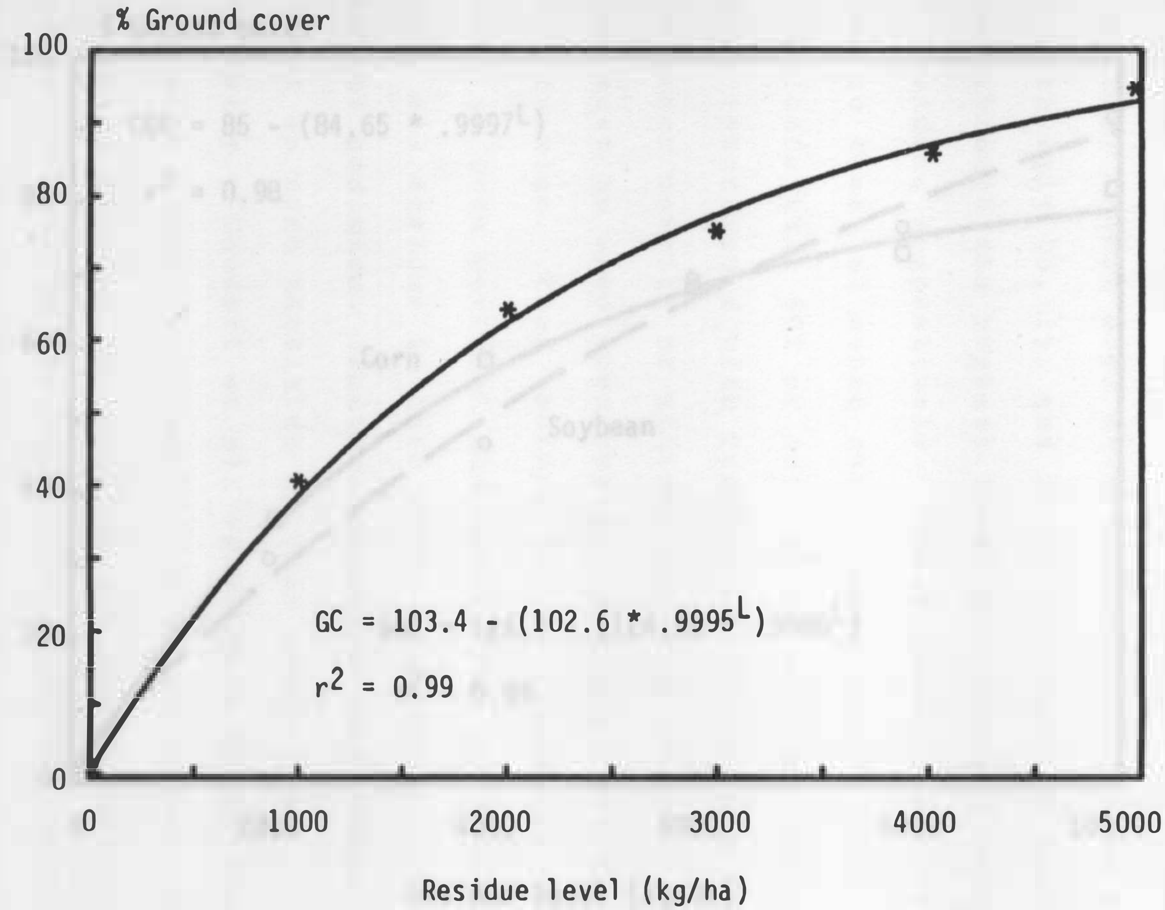

Figure 2. Relationship between level of wheat residue and the percent ground cover. Plotted points are the means of six replications. In the equation, GC = percent ground cover and L = residue level.

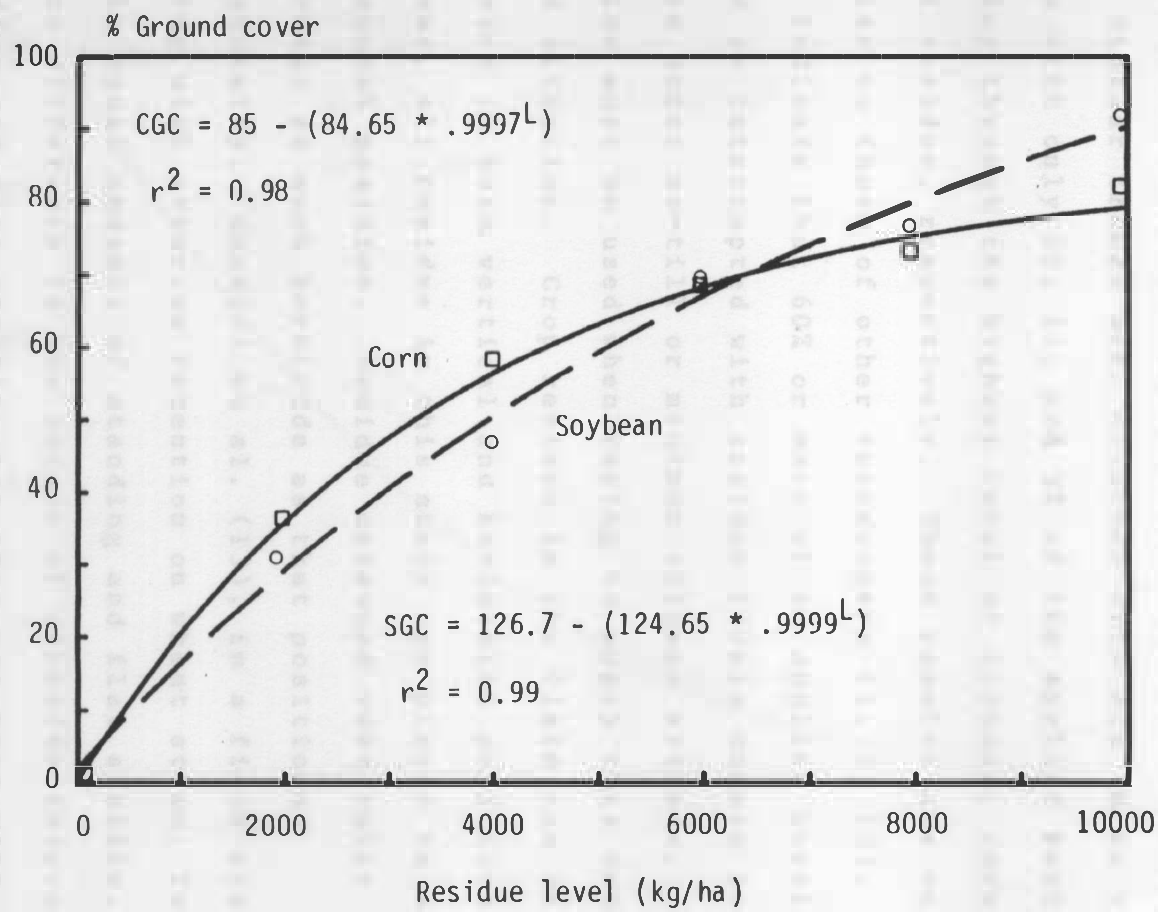

Figure 3. Relationship between level of corn or soybean residue and the percent ground cover. Plotted points are the means of six replications. In the equations, CGC = percent ground cover with corn residue, SGC = percent ground cover with soybean residue, and L = residue level.

weight can be an effective measure of residue level as long as residue type is specified.

As residue level increased, the amount of herbicide which passed through the residue decreased (Figures 4 and 5). Similar trends were observed with all three residue types with only 10, 11, and 5% of the applied herbicide passing through the highest level of soybean, corn, and wheat residue, respectively. These results are very similar to those of other researchers (1, 2, 13). These data indicate that 60% or more of an applied herbicide could be intercepted with residue levels common to South Dakota under no-till or minimum tillage systems. Some caution must be used when trying to apply this data to a field situation. Crop residue in the field can be oriented in both vertical and horizontal positions, whereas, all residue in this study was placed in a horizontal position. Residue oriented vertically may not intercept as much herbicide as that positioned horizontally. Ghadiri et al. (13), in a field study dealing with atrazine retention on wheat straw, found nearly equal amounts of standing and flat stubble. There was no difference in the amount of atrazine intercepted by standing and flat stubble, but this may vary with conditicns and residue type.

Straw to grain ratios for corn, soybeans, and wheat have been established at 1.0, 1.5, and 1.3, respectively

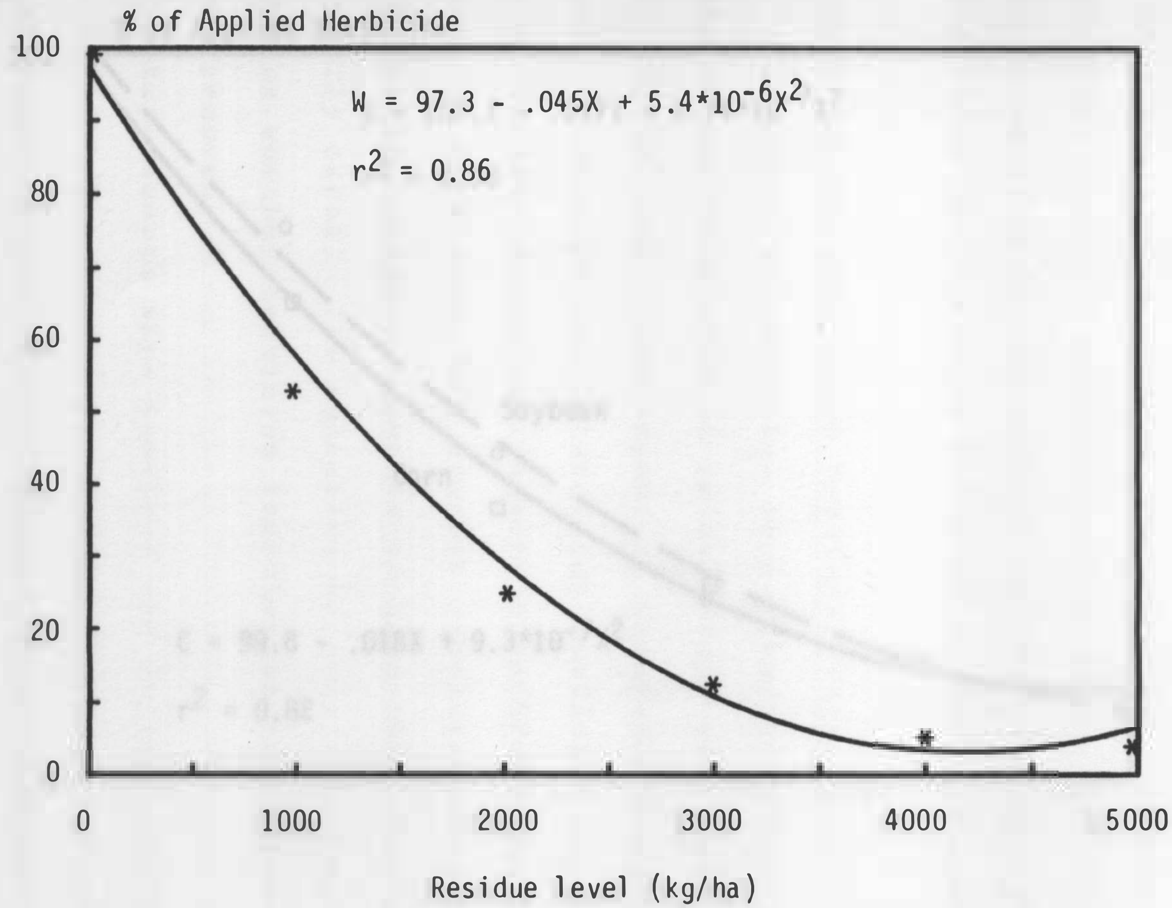

Figure 4. Relationship between wheat residue level and the amount of applied herbicide which passed through the residue during herbicide application averaged across herbicides. Plotted points are the means of six replications of treatments averaged across herbicides. In the equation, W = percent of applied herbicide passing through wheat residue and X = wheat residue level.

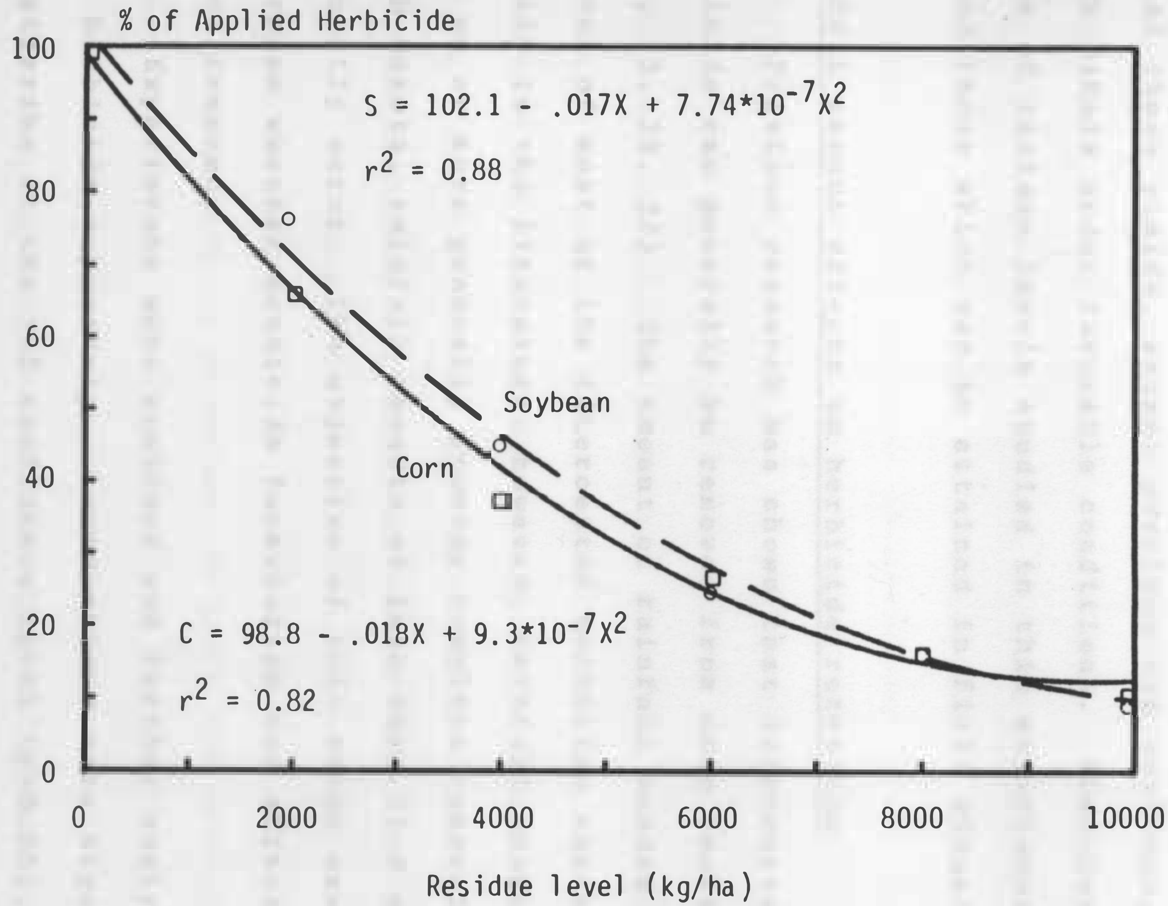

Figure 5. Relationship between soybean or corn residue level and the amount of applied herbicide which passed through the residue during herbicide application averaged across herbicides. Plotted points are the means of six replications of treatments averaged across herbicides. In the equation, S = percent of applied herbicide passing through soybean residue, C = percent of applied herbicide passing through corn residue, and X = residue level.

(23). Based on these ratios, the highest residue levels used in this experiment could be found in fields yielding 160 bushels per acre corn, 90 bushels per acre soybeans, or 60 bushels per acre wheat. It is possible to attain any of these yields, except possibly the soybeans, in South Dakota under favorable conditions. Therefore, the range of residue levels studied in this experiment are not beyond those which may be attained in field situations.

<u>Rainfall amount effects on herbicide retention</u>

Previous research has shown that intercepted herbicide can generally be removed from crop residue (1, 2, 3, 13, 25, 27). The amount of rainfall needed for removal of most of the intercepted herbicide varies greatly in the literature; however, rainfall amounts of 25.0 mm or more generally provide complete removal. In South Dakota, rainfall amounts of less than 25.0 mm frequently occur. The objective of this study was to determine whether herbicide formulation can affect the amount removed.

Experiments were combined and further analyzed for each herbicide separately. Formulations were significant for atrazine at the 94% confidence level (p=0.06). The level of simulated rainfall was very highly significant for each formulation of atrazine with the best fitting regression equation for each formulation shown in Figure 6. The wettable powder formulation was most easily removed by rainfall as indicated by the steep slope of the line at low rainfall amounts. The amount removed starts to level out after 12.5 mm of rainfall. The liquid formulation was most difficult to remove exhibiting a nearly linear response. The dry flowable formulation was intermediate to the other two formulations. Formulation comparisons at each rainfall interval are shown in Table 2. No difference in herbicide removal was detected with the lowest rainfall levels. At the intermediate levels, differences between the wettable powder and liquid formulations were found. The dry flowable formulation was generally intermediate to the other two. No significant differences were detected between formulations at 25 mm rainfall. At this level, removal of both the dry flowable and wettable powder formulations had leveled out and removal of the liquid formulation was approaching that of the other two.

Of the applied atrazine, 58 % of the wettable powder, 48% of the dry flowable, and 46% of the liquid were removed with the highest rainfall level. With 4000 kg/ha of wheat straw, 4-5% of the applied atrazine will spray through directly. Therefore, 40-50% of the applied atrazine was either retained on the straw or lost to volatilization.

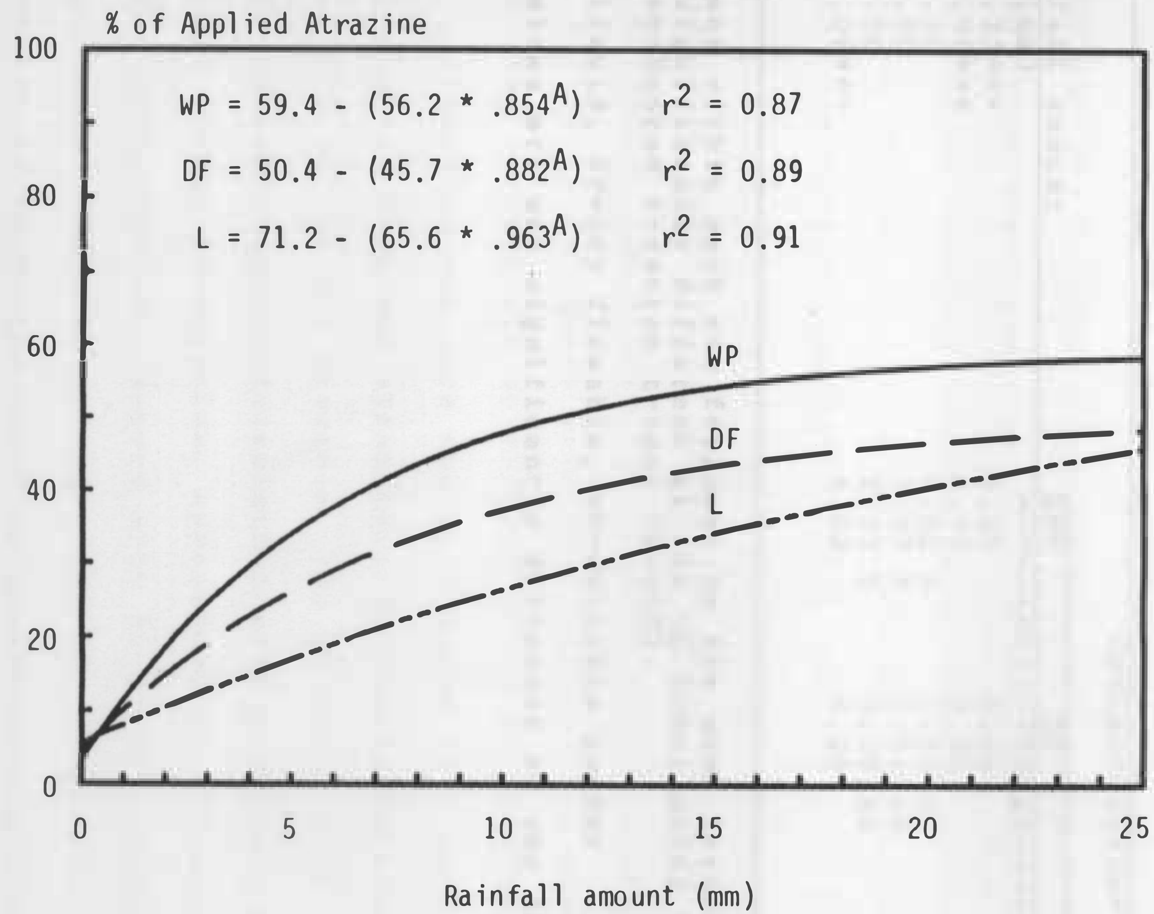

Figure 6. Effect of rainfall amount on atrazine removal from 4000 kg/ha wheat residue for three formulations of atrazine. In the equations, WP = percent of wettable powder atrazine removed, DF = percent of dry flowable atrazine removed, L = percent of liquid atrazine removed, and A = rainfall amount.

Table 2. Concentration of atrazine applied to 4000 kg/ha wheat residue found in washoff water by formulation. All rainfall amounts were brought to 2300 ml total volume before sampling.

	Concentration*		
Rainfall Amount	L**	DF	WP
(mm)		(ppm)	
0.25***	0.47	0.56	0.46
1.00***	0.75	0.76	0.91
2.50	0.91 b	1.53 a	1.91 a
5.00	1.69 b	2.41 ab	3.20 a
12.50	2.53 b	3.39 ab	4.13 a
25.00***	4.03	4.29	5.26

* Means within each row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ration t-test (k-100).

**L=liquid, DF=dry flowable, WP=wettable powder

***Values are not significantly different at the 5% level.

Herbicide formulation and rainfall level were both highly significant for cyanazine. Likewise, the formulation by rainfall amount interaction was highly significant. Regression analysis for each formulation was performed and is presented in Figure 7. The wettable powder and dry flowable formulations were most easily removed from wheat straw at the low rainfall amounts. The first 5 mm of rainfall removed over 50% of the total cyanazine removed in this study. Removal of the wettable powder formulation appears to level out after 12.5 mm of rainfall while removal of the dry flowable formulation continues to increase up through 25 mm of rainfall. As with atrazine, the liquid formulation of cyanazine was most difficult to remove from wheat straw with removal continuing to increase up through 25 mm of rainfall.

Cyanazine was more easily removed from wheat straw with rainfall than was atrazine. At the highest rainfall level, 87% of the dry flowable, 73% of the liquid, and 68% of the wettable powder formulation were removed. When averaged across formulation, approximately 25% more of the applied cyanazine was removed with 25 mm of rainfall than was atrazine. This is probably due to the greater water solubility of cyanazine which is approximately five times more soluble than atrazine (46).

These results are generally in good agreement with other research. Ghadiri et al. (13) found that following

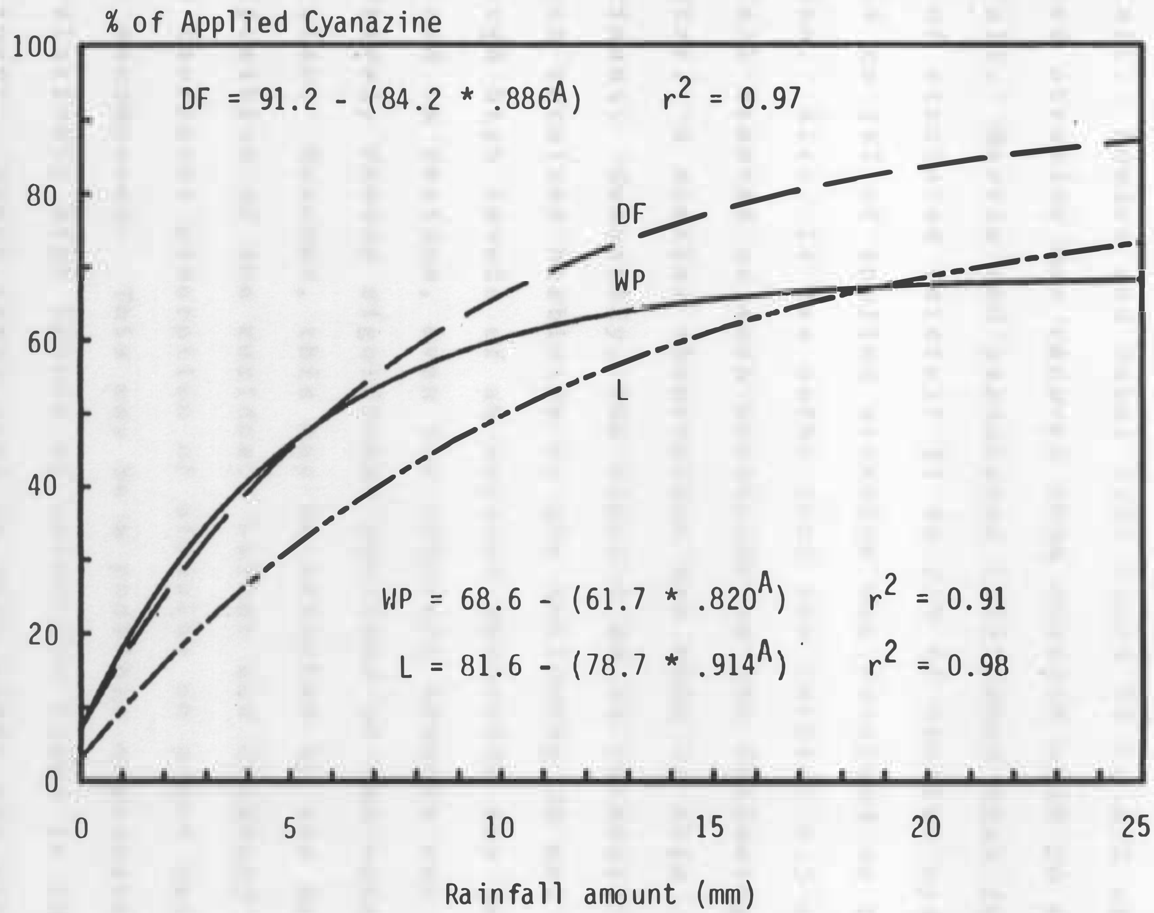

Figure 7. Effect of rainfall amount on cyanazine removal from 4000 kg/ha wheat residue for three formulations of cyanazine. In the equations, WP = percent of wettable powder cyanazine removed, DF = percent of dry flowable cyanazine removed, L = percent of liquid cyanazine removed, and A = rainfall amount.

50 mm of rainfall 23% of applied atrazine was retained on wheat straw in the field and 56 to 61% was retained in a greenhouse study. Also they found no difference in the amount removed with 25 mm of rainfall versus 50 mm of rainfall. Lowder and Weber (25) found 75 to 87% of applied atrazine was removed from residue with 10 cm of rainfall. Martin and associates (27) found that following 4 cm of simulated rainfall 21 to 25% of applied cyanazine and 14 to 16% of applied atrazine was retained on corn residue. Also, it was noted that the initial 0.5 cm of rainfall removed as much herbicide as the following 3.0 cm of water. A similar observation was made in this experiment. Generally, the first 5 mm of rainfall removed as much retained herbicide as the following 20 mm. Although high levels of an applied herbicide may be retained on residue, even low rainfall amounts can effectively remove significant portions of the retained herbicide. However, this may be affected by the degree of decomposition of the residue. Walker and Crawford (44) found increased adsorption of atrazine on plant material as it decomposed. This may be a possible explanation for the relatively high levels of retention found in this experiment. Wheat straw used in this study was allowed to age under field conditions for approximately 60 days before collection. At time of collection, straw surfaces were no longer smooth and shiny, but rough and discolored.

This may provide for a greater surface area for herbicide adsorption to take place.

Time effect on herbicide retention

The amount of intercepted herbicide which can be removed by rainfall tends to decrease with time. Other research has dealt with rainfall which was applied within one day of herbicide application. However, under field conditions several days to weeks may pass before significant rainfall occurs. The objective of this experiment was to determine if as much herbicide could be removed from residue at several time intervals following application as was removed with an immediate rainfall.

Experiments were combined and further analyzed separately by herbicide. Statistical analysis indicated that all three formulations reacted similarly and could be combined. Removal of both herbicides decreased with time but was most dramatic for atrazine (Table 3). Significantly less atrazine was removed with 25 mm of rainfall three days after application than on the day of application. The amount of herbicide removed continued to decrease with time; removal 14 days after application was significantly less than all other rainfall times. Removal on the fourteenth day was 25% less than immediately after application. This difference indicates that atrazine was either bonded to the residue in a form non-extractable with water or was lost through volatilization.

Table 3. The amount of intercepted herbicide removed with 25 mm of rainfall at various time intervals following herbicide application.

Time of Rainfall	Amount removed*	
	Atrazine	Cyanazine
(days)	------(% of maximum)------	
0	100 a	100 a
1	96 ab	99 a
3	92 bc	93 b
7	84 c	91 b
14	75 d	92 b

*Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

Cyanazine produced results similar to those of atrazine. Removal was significantly reduced 3 days after herbicide application. The amount of cyanazine removed was reduced by 7 to 9% when rainfall occurred three days or more after application. Statistical analysis also indicated a significant difference for formulations (p=.0055). However, the formulation by rainfall time interaction was not significant (p=.64) allowing analysis by averaging over formulation or rainfall time. Further analysis to determine the reason for a significant formulation term indicated that when averaged across all rainfall times, significantly less of the wettable powder formulation was removed than the other two formulations (Table 4). Although less of the wettable powder was removed, the pattern of removal with time was similar for all formulations. The wettable powder formulation also had the lowest level of removal with 25 mm of rainfall in the amount of rainfall experiment.

Regression analysis provides a good comparison of the removal pattern for each herbicide (Figure 8). Cyanazine removal appears to be less affected by time than does atrazine removal. Cyanazine removal was reduced by 8% at 14 days compared to 25% for atrazine. This may be related to solubility and volatility differences between the two herbicides. Cyanazine is approximately five times more soluble in water than atrazine (46). Therefore,

Table 4. Concentration of cyanazine found in washoff water following 25 mm of simulated rainfall averaged across rainfall times.

Formulation	Cyanazine concentration* (ppm)
Dry flowable	4.44 a
Liquid	4.36 a
Wettable powder	3.80 b

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

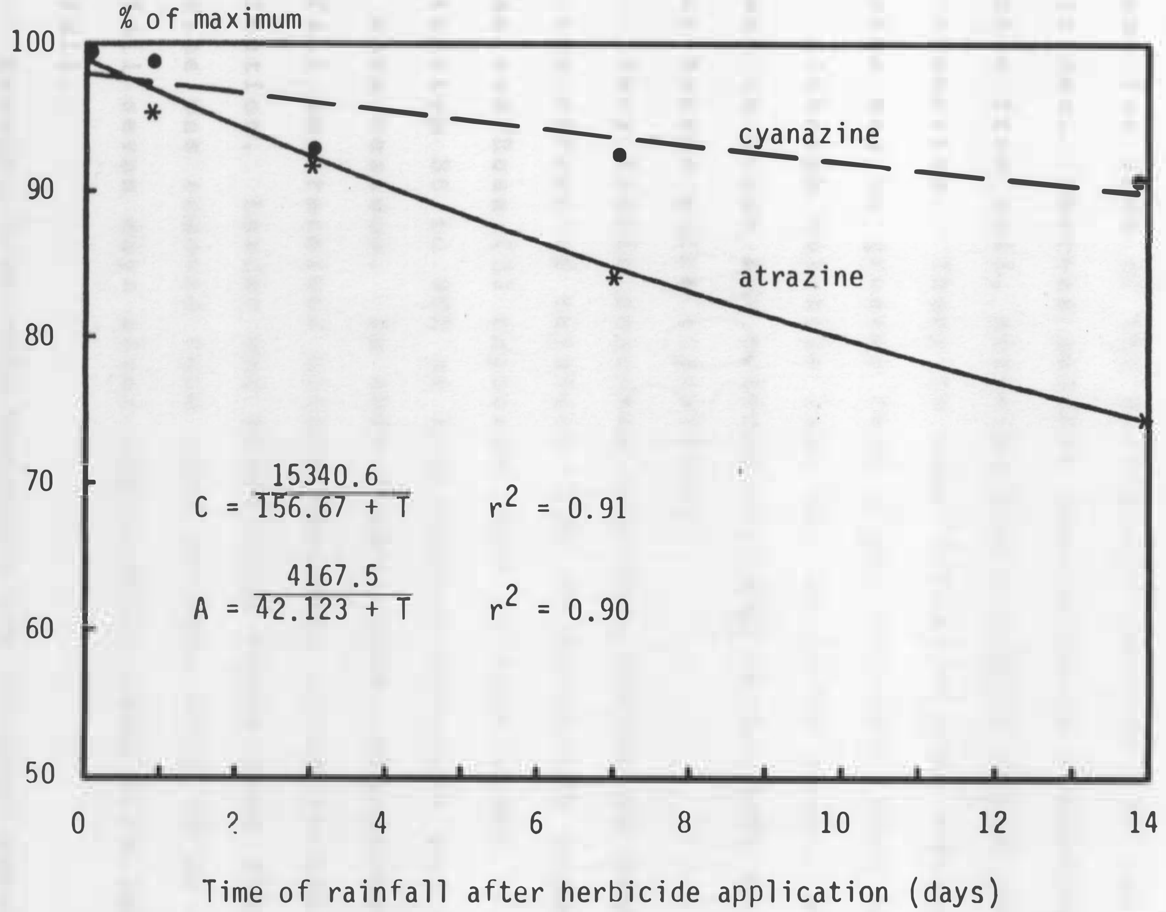

Figure 8. Effect of time of rain on removal of either atrazine or cyanazine from 4000 kg/ha wheat residue averaged across formulations. Plotted points are the means of six replications of treatments averaged across three formulations. In the equations, C = removal of cyanazine as percent of maximum, A = removal of atrazine as percent of maximum, and T = time of rainfall in days.

cyanazine may be more easily removed by rainfall. The 25 mm of rainfall applied in this study provided thorough wetting of all residue allowing for nearly complete removal of cyanazine. Differences in volatility may also account for some of the difference between the two herbicides. Whereas neither herbicide is considered to be volatile from soil, atrazine has a higher vapor pressure than cyanazine. There is some evidence that volatility of atrazine may be greater from plant material than soil (6). Although volatile loss may be quite small, when allowed to occur for periods as long as 14 days or more, it may become quite significant.

Very little research has been conducted dealing with the effect of rainfall time on herbicide removal. Bauman and Ross (3) reported that 30 days after application 86 to 90% of intercepted atrazine was removed from corn residue. In this field study, significant rainfall was received within one week of herbicide application. Lowder and Weber (25) found that 17% less atrazine was removed from corn residue with 10 cm of rainfall seven days after application than with immediate rainfall.

Results from this research are in good agreement with other studies. Significant reductions in removal can occur with time but may vary depending on herbicide. In this study, atrazine was much more affected by rainfall delays than was cyanazine. Formulation had no effect on removal of atrazine and only slight effect on removal of cyanazine.

Herbicide retention on various residue types

Residue type may influence herbicide retention. Residue can vary greatly in surface texture and composition, trichome numbers, surface area, and degree of decomposition. Any or all of these variables can affect herbicide retention. Due to the large diversity of crops grown in South Dakota, retention differences due to residue type becomes increasingly important. The objective of this experiment was to examine herbicide retention on three major residue types and to determine whether herbicide formulation affects retention with each residue type.

Analysis of variance indicated significant interactions involving the herbicide term resulting in separate analysis for each herbicide. Further analysis of atrazine formulations and residue types indicated significant F-tests for both formulation and residue type but no significance for the interaction term. Analysis of atrazine formulations averaged across residue types is shown in Table 5. No difference in the amount of herbicide sprayed through the residue was detected between formulations. However, significantly more of the wettable

Table 5. The effect of atrazine formulation averaged across residue type on the amount of atrazine passing through the residue, the amount removed with 12.5 mm of simulated rainfall, and the recovery total for each formulation.

Formulation	Spray through*	Washoff	Total
	----------% of total applied----------		
DF	30**	50 ab	80**
L	30	41 b	70
WP	29	56 a	85

*Means within a column followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

**Values are not significantly different at the 5% level.

powder was detected in the washoff water than was the liquid formulation. Although only 12.5 mm of simulated rainfall was applied in this experiment, washoff data was similar to that from the amount of rainfall study. No significant difference was detected between atrazine formulations for total amount of herbicide recovered.

Significantly more of the applied herbicide sprayed through the corn residue than through either soybean or wheat straw (Table 6). This is probably due to the slightly lower level of ground cover provided by corn residue compared to the two other residue types. The amount of applied herbicide which was removed by rainfall was similar for all residue types. The lowest level was from soybean residue; however, no difference was detected in the washoff water. The lowest total recovery occurred for soybean residue because of the low level of washoff combined with the lower level of spray-through. Total recovery of applied herbicide was greatest from corn residue. This is primarily due to the larger amount of spray-through with corn residue.

Significant differences were detected for cyanazine formulations averaged across residue types for all parameters measured (Table 7). More of the dry flowable formulation sprayed through the residue than did the liquid formulation. The reason for this difference is not immediately apparent. Significantly more of the dry

Table 6. The effect of residue type averaged across atrazine formulations on the amount of atrazine passing through the residue, the amount removed with 12.5 mm of simulated rainfall, and the recovery total for each residue type.

Residue type	Spray through*	Washoff	Total
	----------% of total applied----------		
Soybean	27 b	46**	73 b
Corn	34 a	51	85 a
Wheat	27 b	49	76 b

*Means within a column followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

**Values are not significantly different at the 5% level.

Table 7. The effect of cyanazine formulation averaged across residue type on the amount of cyanazine passing through the residue, the amount removed with 12.5 mm of simulated rainfall, and the recovery total for each formulation.

Formulation	Spray through*	Washoff	Total
	---------% of total applied----------		
DF	35 a	51 a	86 a
L	28 b	43 b	72 b
WP	34 ab	44 b	78 ab

*Means within a column followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

flowable formulation was removed with the 12.5 mm of rainfall than was the other two formulations. This is to be expected since a previous study indicated that the dry flowable formulation of cyanazine is most easily removed with rainfall. Highest level of recovery likewise occurred with the dry flowable formulation; this was significantly higher than recovery of the liquid formulation.

Analysis of the residue types for cyanazine spray-through found greatest spray-through occurring with corn residue and least with wheat residue (Table 8). This appears to be related to variations in ground cover with the three residue types. Herbicide washoff was also greatest from the corn residue resulting in the highest total recovery rate for the corn residue. Approximately 10% more of the applied herbicide was retained on soybean or wheat straw than was retained on corn stalks.

Lowder and Weber (25) found atrazine to be more easily removed from residue of 3 week old oat plants than from corn stalks. The results from this study also indicate that residue type may affect herbicide retention and removal. Generally greatest removal occurred with corn residue and least with soybean or wheat residue. Although results are somewhat variable between the two herbicides, it becomes apparent that herbicides may react differently on residue types. Therefore, residue type may

Table 8. The effect of residue type averaged across cyanazine formulations on the amount of cyanazine passing through the residue, the amount removed with 12.5 mm of simulated rainfall, and the recovery total for each residue type.

Residue type	Spray through*	Washoff	Total
	----------% of total applied----------		
Soybean	32 ab	43 b	75 b
Corn	36 a	50 a	86 a
Wheat	29 b	46 b	78 b

*Means within a column followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

be a factor along with residue level to consider when choosing a herbicide program to use with conservation tillage.

Of the total atrazine retained on the residue, a significantly larger amount of the wettable powder and dry flowable formulations was removed with the 12.5 mm rainfall (Table 9). Forty-one percent of the intercepted liquid atrazine was not removed compared to 17-24% with the other formulations. With cyanazine, significantly more of the dry flowable formulation was removed with rainfall than either of the other formulations. This is to be expected since formulations were found to react in a similar manner in the amount of rainfall study.

No significant difference was found for atrazine removal from the three residue types (Table 10). Lowest level of removal was from soybean residue with 34% of the atrazine remaining. Significantly more cyanazine was removed from corn residue than from either of the other residue types. Corn stalks have a smooth surface and lower surface area than either soybean or wheat residue. These factors may contribute to greater removal of these herbicides.

Theoretical simulation model

Due to significant differences between herbicides and formulations of each herbicide, a separate model was

Table 9. Effect of herbicide formulation on the amount of herbicide unaccounted for following 12.5 mm of simulated rainfall averaged across residue type.

Formulation	Atrazine	Cyanazine
	----------% lost-----------	
Dry flowable	24 a	19 a
Liquid	41 b	38 b
Wettable powder	17 a	32 b

*Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

Table 10. Effect of residue type on the amount of herbicide unaccounted for following 12.5 mm of simulated rainfall averaged across formulation.

Residue type	Atrazine	Cyanazine
	----------% lost----------	
Soybean	34*	36 b**
Corn	19	17 a
Wheat	29	36 b

*Values are not significantly different at the 5% level.

**Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

developed for each herbicide and formulation (Table 11). All six models are very highly significant and can account for 60 to 70% of the total variability associated with the model. Fit, as indicated by the R squared value, generally increased with the addition of calculated data points. Although this practice may not be statistically sound, it is frequently employed for model development (8). An assumption of this procedure is that all calculated data points must be sensible additions to the data set and based on previously collected data. Calculated data points will frequently aid in reducing error at the extreme limits of each variable.

All models are acceptable only within limited ranges of each variable. Data collection was limited to 0 to 5000 kg/ha of wheat residue with 0 to 25 mm of rainfall occurring within 0 to 14 days of herbicide application. The models are accurate only within these ranges of the variables.

Since three independent variables are involved in each model, it is impossible to graphically illustrate the models. However, the model can be used to determine the expected amount of herbicide present on the soil surface under variable conditions. Table 12 shows the predicted amount of wettable powder atrazine which needs to be applied to obtain 1 kg/ha of active ingredient at the soil surface. Using this model, at the 0 kg/ha residue level

Table 11. Theoretical models for applied atrazine and cyanazine herbicide reaching the soil surface as influenced by wheat residue level, rainfall amounts, and timing of rain

Atrazine - wettable powder

$$\% = 98.35 - .43A + .00724T - .0436L + 5.14E\text{-}6L^2 + .0026AL - 3.7E\text{-}7AL^2 - 1.02E\text{-}6AT^2L \quad r^2=.68$$

Atrazine - dry flowable

$$\% = 94.31 + 1.834A + .5411T - .0401L - .091A^2 - .0332T^2 + 4.63E\text{-}6L2 + .0001044A^2L - 2.0E - 8A^2L^2 - 2.88E - 6AT^2L \quad r^2=.68$$

Atrazine - liquid

$$\% = 94.63 + 1.23A + 1.33T - .0411L - .0687A^2 - .085T^2 + 4.78E\text{-}6L^2 + 1.074E\text{-}4A^2L - 2.0E\text{-}8A^2L^2 - 3.7E\text{-}7AT^2L - 1.55E\text{-}6A^2TL \quad r^2=.69$$

Cyanazine - wettable powder

$$\% = 102.81 - .6567A - .1039T - .0437L + 5.16E\text{-}6L^2 + .00296AL - 4.4E\text{-}7AL^2 - 3.857E\text{-}5ATL \quad r^2=.68$$

Cyanazine -dry flowable

$$\% = 102.66 - .6687A - .038T - .0436L + 5.14E\text{-}6L^2 + .00288AL - 4.1E\text{-}7AL^2 - 7.04E\text{-}5ATL + 2.18E\text{-}6A^2TL \quad r^2=.70$$

Cyanazine - liquid

$$\% = 101.6 + .789A + .139T - .044L - .144At - .058A^2 + 5.15E\text{-}6L^2 + .0052A^2T + .00165AL - 2.4E\text{-}7AL^2 + 4.83E\text{-}5A^2L - 1.0E\text{-}8A^2L^2 \quad r^2=.71$$

*% = percent of applied herbicide reaching the soil surface, A = amount of rainfall in mm, T = time of rainfall in days, and L = wheat residue level.

Table 12. The amount of wettable powder atrazine which would have to be applied at various wheat residue levels, rainfall times, and rainfall amounts to provide 1.0 kg/ha active ingredient at the soil surface.

Residue level (kg/ha)	Time of Rainfall (days)	Amount of Rain (mm) 0	5	10	15	20	25
		(kg a.i./ha)					
	0	1.02	1.04	1.06	1.09	1.11	1.14
0	7	1.02	1.04	1.06	1.09	1.11	1.14
	14	1.02	1.04	1.06	1.09	1.11	1.14
	0	3.15	2.08	1.55	1.24	1.03	1.00
2000	7	3.15	1.95	1.41	1.11	1.00	1.00
	14	3.14	2.16	1.65	1.33	1.12	1.00
	0	16.16	3.80	2.15	1.50	1.15	1.00
4000	7	16.03	3.08	1.70	1.18	1.00	1.00
	14	15.90	4.45	2.59	1.83	1.41	1.15

nearly all the applied atrazine was found on the soil surface. At 2000 kg/ha, over 3 kg/ha of atrazine needs to be applied to have 1 kg/ha at the soil surface when no rainfall occurs; however, 25 mm of rainfall provided nearly complete removal. At 4000 kg/ha residue, 16 kg/ha of atrazine needs to be applied to obtain 1 kg/ha at the soil surface with no rainfall. This agrees very closely with previous data which found that only approximately 5% of the applied herbicide passed through 4000 kg/ha of wheat straw (Figure 4). When 5 mm of rainfall occurs, the amount of herbicide required is reduced to approximately 4 kg/ha with slightly more required when rainfall occurs 14 days after application. Again, when 25 mm of rainfall occurs, nearly complete removal occurs.

Similar results are obtained with the model for the dry flowable cyanazine (Table 13). Nearly all applied herbicide is present on the soil surface at the 0 residue level. Nearly 3 kg/ha of cyanazine needs to be applied with 2000 kg/ha of wheat residue present to obtain 1 kg/ha at the soil surface. With 4000 kg/ha wheat residue, approximately 10 kg/ha cyanazine needs to be applied. Greater amounts need to be applied when rainfall is delayed to 14 days after application. However, when 25 mm of rainfall occurs nearly complete removal can be expected.

Table 13. The amount of dry flowable cyanazine which would have to be applied at various wheat residue levels, rainfall times, and rainfall amounts to provide 1.0 kg/ha active ingredient at the soil surface.

Residue level	Time of Rainfall	Amount of Rain (mm)					
		0	5	10	15	20	25
(kg/ha)	(days)	------------(kg a.i./ha)------------					
0	0	1.0	1.01	1.04	1.08	1.12	1.16
	7	1.0	1.01	1.04	1.08	1.12	1.17
	14	1.0	1.01	1.05	1.09	1.13	1.17
2000	0	2.78	1.88	1.42	1.14	1.00	1.00
	7	2.80	2.05	1.58	1.26	1.03	1.00
	14	2.82	2.25	1.77	1.40	1.12	1.00
4000	0	9.53	3.13	1.88	1.34	1.04	1.00
	7	9.78	4.28	2.53	1.70	1.23	1.00
	14	10.04	6.79	3.91	2.35	1.52	1.05

The theoretical models shown in Table 11 are based on data generated in the laboratory under controlled conditions. Estimates of the amount of applied herbicide on the soil surface determined with these models fit quite well with the laboratory data. The next obvious step is to determine how well these models relate to field conditions. Correlation of these models with field data is beyond the scope and purpose of this thesis. Further work of this type is encouraged to determine the practical applications of these models to aid farmers in making herbicide decisions in high residue situations.

SUMMARY

The purpose of this experiment was to determine the effect of several variables on herbicide interception and retention by crop residue. Variables such as residue type and amount, time and amount of rainfall, and herbicide formulation were considered.

Percent ground cover increased as residue weight increased with all residue types. Ground cover with wheat straw increased nearly twice as fast as with corn or soybean residue. At the highest levels tested for soybean, corn, and wheat residue only 10, 11, and 5%, respectively, of the applied herbicide penetrated the residue and reached the soil surface. Therefore, a significant portion of the applied herbicide may be intercepted by crop residue.

Wettable powder atrazine and dry flowable cyanazine were the formulations most easily removed with simulated rainfall. The liquid formulation of both atrazine and cyanazine was most difficult to remove from wheat residue. The initial 0.5 mm of rainfall removed as much intercepted atrazine or cyanazine as the following 10 mm. Of the total applied herbicide, approximately 50% of the atrazine and 75% of the cyanazine could be removed with 25 mm of rainfall.

Removal of intercepted herbicide decreased as the time between herbicide application and simulated rainfall increased. Atrazine removal was significantly decreased at three days after application and was reduced by 25% at 14 days. Herbicide formulation did not affect atrazine removal. Cyanazine removal was significantly reduced at three days following application. Removal was reduced by 8% at 14 days. Cyanazine formulation did have an effect with the wettable powder being the most difficult to remove.

Residue type can affect interception and retention of both atrazine and cyanazine. Highest levels of spray through and washoff occurred with corn residue resulting in the greatest total recovery from corn residue. In this study, corn residue at the level tested provided less ground cover than either wheat or soybean residue. This may explain the increased level of recovery from corn residue.

A theoretical model was developed for each herbicide by formulation combination tested. These models can be used to predict the level of herbicide reaching the soil surface under various residue and rainfall conditions. These models are based purely on laboratory data and need to be used with caution in field situations.

From this study, it appears that crop residue can have a significant effect on the actual rate of herbicide reaching the soil surface. Rainfall amounts of 12.5 mm received within three days of herbicide application can generally remove most of the intercepted herbicide. Herbicide formulation can also affect removal with rainfall. However, it must be remembered that this work was conducted under controlled conditions of the greenhouse. Further work is encouraged to correlate these results with those obtained under field conditions. Such information could be extremely valuable to farm managers making herbicide decisions in high residue situations.

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APPENDIX

LIST OF APPENDIX TABLES

Table 1. Raw data from each replication used to determine the percent ground cover at each residue level tested.

Key

Exp = Experiment number
Res = Residue type
Rep = Replication number
Holes = Number of holes through which red was seen
Grdcover = Percent ground cover

EXP	RES	LEVEL	REP	HOLES	GRDCOVER
1	BEAN	0	1	20	0
1	BEAN	0	2	20	0
1	BEAN	2000	1	13	35
1	BEAN	2000	2	12	40
1	BEAN	4000	1	12	40
1	BEAN	4000	2	9	55
1	BEAN	6000	1	5	75
1	BEAN	6000	2	6	70
1	BEAN	8000	1	3	85
1	BEAN	8000	2	5	75
1	BEAN	10000	1	3	85
1	BEAN	10000	2	2	90
1	CORN	0	1	20	0
1	CORN	0	2	20	0
1	CORN	2000	1	14	30
1	CORN	2000	2	14	30
1	CORN	4000	1	11	45
1	CORN	4000	2	11	45
1	CORN	6000	1	6	70
1	CORN	6000	2	7	65
1	CORN	8000	1	4	80
1	CORN	8000	2	6	70
1	CORN	10000	1	4	80
1	CORN	10000	2	4	80
1	WHEAT	0	1	20	0
1	WHEAT	0	2	20	0
1	WHEAT	1000	1	12	40
1	WHEAT	1000	2	10	50
1	WHEAT	2000	1	8	60
1	WHEAT	2000	2	8	60
1	WHEAT	3000	1	6	70
1	WHEAT	3000	2	5	75
1	WHEAT	4000	1	1	95
1	WHEAT	4000	2	4	80
1	WHEAT	5000	1	1	95
1	WHEAT	5000	2	1	95
2	BEAN	0	3	20	0
2	BEAN	0	4	20	0
2	BEAN	2000	3	13	35
2	BEAN	2000	4	14	30
2	BEAN	4000	3	12	40
2	BEAN	4000	4	10	50
2	BEAN	6000	3	9	55
2	BEAN	6000	4	5	75
2	BEAN	8000	3	7	65
2	BEAN	8000	4	3	85
2	BEAN	10000	3	1	95
2	BEAN	10000	4	0	100
2	CORN	0	3	20	0
2	CORN	0	4	20	0
2	CORN	2000	3	12	40
2	CORN	2000	4	11	45
2	CORN	4000	3	5	75
2	CORN	4000	4	6	70

EXP	RES	LEVEL	REP	HOLES	GRDCOVER
2	CORN	6000	3	8	60
2	CORN	6000	4	6	70
2	CORN	8000	3	7	65
2	CORN	8000	4	5	75
2	CORN	10000	3	2	90
2	CORN	10000	4	4	80
2	WHEAT	0	3	20	0
2	WHEAT	0	4	20	0
2	WHEAT	1000	3	12	40
2	WHEAT	1000	4	14	30
2	WHEAT	2000	3	5	75
2	WHEAT	2000	4	8	60
2	WHEAT	3000	3	5	75
2	WHEAT	3000	4	5	75
2	WHEAT	4000	3	3	85
2	WHEAT	4000	4	3	85
2	WHEAT	5000	3	1	95
2	WHEAT	5000	4	1	95

Table 2. Raw data from each replication used to determine the amount of herbicide intercepted by crop residue at various levels.

Key

Exp = Experiment number
Trt = Treatment number
Herb = Herbicide
Res = Residue type
Level = Residue level in kg/ha
Rep = Replication number
Pcttran = Percent transmittance
Conc = Concentration of herbicide in sample
Pctappl = Percent of applied herbicide passing through the residue

EXP	TRT	HERB	RES	LEVEL	REP	PCTTRAN	CONC	PCTAPPL
1	13	ATRA	BEANS	0	1	16.0	4.60276	88.5977
1	13	ATRA	BEANS	0	2	23.0	4.60804	88.6992
1	13	ATRA	BEANS	0	3	10.0	5.11773	98.5102
1	14	ATRA	BEANS	2000	1	20.0	4.21031	81.0434
1	14	ATRA	BEANS	2000	2	35.0	3.34973	64.4783
1	14	ATRA	BEANS	2000	3	20.0	3.84894	74.0875
1	15	ATRA	BEANS	4000	1	31.0	3.22281	62.0353
1	15	ATRA	BEANS	4000	2	50.0	2.06438	39.7369
1	15	ATRA	BEANS	4000	3	40.0	1.85779	35.7602
1	16	ATRA	BEANS	6000	1	49.0	1.89714	36.5176
1	16	ATRA	BEANS	6000	2	62.0	1.26613	24.3714
1	16	ATRA	BEANS	6000	3	46.0	1.40252	26.9967
1	17	ATRA	BEANS	8000	1	64.0	1.06763	20.5507
1	17	ATRA	BEANS	8000	2	71.0	0.80162	15.4302
1	17	ATRA	BEANS	8000	3	60.0	0.59521	11.4570
1	18	ATRA	BEANS	10000	1	82.0	0.40250	7.7476
1	18	ATRA	BEANS	10000	2	83.0	0.36118	6.9522
1	18	ATRA	BEANS	10000	3	72.0	0.18737	3.6066
1	7	ATRA	CORN	0	1	15.0	4.70366	92.9867
1	7	ATRA	CORN	0	2	24.0	4.49537	88.8691
1	7	ATRA	CORN	0	3	16.0	4.33460	85.6908
1	8	ATRA	CORN	2000	1	21.5	4.06773	80.4151
1	8	ATRA	CORN	2000	2	35.0	3.34973	66.2210
1	8	ATRA	CORN	2000	3	40.0	1.85779	36.7267
1	9	ATRA	CORN	4000	1	41.0	2.44185	48.2729
1	9	ATRA	CORN	4000	2	53.0	1.84565	36.4867
1	9	ATRA	CORN	4000	3	73.0	0.16522	3.2662
1	10	ATRA	CORN	6000	1	67.0	0.93176	18.4199
1	10	ATRA	CORN	6000	2	72.0	0.75710	14.9672
1	10	ATRA	CORN	6000	3	56.0	0.78944	15.6064
1	11	ATRA	CORN	8000	1	62.5	1.13933	22.5234
1	11	ATRA	CORN	8000	2	73.0	0.71401	14.1153
1	11	ATRA	CORN	8000	3	51.0	1.07321	21.2163
1	12	ATRA	CORN	10000	1	57.0	1.42360	28.1432
1	12	ATRA	CORN	10000	2	69.0	0.89490	17.6913
1	12	ATRA	CORN	10000	3	78.0	0.08180	1.6171
1	1	ATRA	WHEAT	0	1	16.0	4.60276	90.0555
1	1	ATRA	WHEAT	0	2	26.0	4.27429	83.6288
1	1	ATRA	WHEAT	0	3	18.0	4.08813	79.9864
1	2	ATRA	WHEAT	1000	1	50.0	1.83405	35.8842
1	2	ATRA	WHEAT	1000	2	57.0	1.57389	30.7939
1	2	ATRA	WHEAT	1000	3	37.0	2.11002	41.2836
1	3	ATRA	WHEAT	2000	1	74.5	0.63585	12.4408
1	3	ATRA	WHEAT	2000	2	76.0	0.59325	11.6073
1	3	ATRA	WHEAT	2000	3	54.0	0.89748	17.5597
1	4	ATRA	WHEAT	3000	1	92.0	0.18866	3.6912
1	4	ATRA	WHEAT	3000	2	87.0	0.25980	5.0832
1	4	ATRA	WHEAT	3000	3	65.0	0.39340	7.6970
1	5	ATRA	WHEAT	4000	1	92.0	0.18866	3.6912
1	5	ATRA	WHEAT	4000	2	92.0	0.16503	3.2289
1	5	ATRA	WHEAT	4000	3	74.0	0.14489	2.8349
1	6	ATRA	WHEAT	5000	1	97.0	0.12344	2.4151
1	6	ATRA	WHEAT	5000	2	94.0	0.13706	2.6817
1	6	ATRA	WHEAT	5000	3	85.0	0.04152	0.8123

EXP	TRT	HERB	RES	LEVEL	REP	PCTTRAN	CONC	PCTAPPL
1	19	CYAN	BEANS	0	1	11.5	5.06554	97.506
1	19	CYAN	BEANS	0	2	16.0	4.28358	82.454
1	19	CYAN	BEANS	0	3	21.0	5.86921	112.975
1	20	CYAN	BEANS	2000	1	28.0	3.47879	66.962
1	20	CYAN	BEANS	2000	2	25.0	3.40041	65.454
1	20	CYAN	BEANS	2000	3	30.0	4.42377	85.152
1	21	CYAN	BEANS	4000	1	48.0	1.96134	37.753
1	21	CYAN	BEANS	4000	2	50.0	1.50898	29.046
1	21	CYAN	BEANS	4000	3	50.0	1.93570	37.260
1	22	CYAN	BEANS	6000	1	63.0	1.11515	21.465
1	22	CYAN	BEANS	6000	2	61.0	0.93851	18.065
1	22	CYAN	BEANS	6000	3	67.0	0.60601	11.665
1	23	CYAN	BEANS	8000	1	68.0	0.88869	17.106
1	23	CYAN	BEANS	8000	2	76.0	0.41838	8.053
1	23	CYAN	BEANS	8000	3	76.0	0.19415	3.737
1	24	CYAN	BEANS	10000	1	81.0	0.43000	8.277
1	24	CYAN	BEANS	10000	2	82.0	0.29362	5.652
1	24	CYAN	BEANS	10000	3	80.0	0.07601	1.463
1	25	CYAN	CORN	0	1	14.0	4.80566	95.003
1	25	CYAN	CORN	0	2	17.0	4.18017	82.638
1	25	CYAN	CORN	0	3	14.0	7.13324	141.017
1	26	CYAN	CORN	2000	1	27.0	3.56634	70.503
1	26	CYAN	CORN	2000	2	22.0	3.68290	72.807
1	26	CYAN	CORN	2000	3	41.0	2.93175	57.958
1	27	CYAN	CORN	4000	1	38.0	2.66446	52.674
1	27	CYAN	CORN	4000	2	36.0	2.46638	48.758
1	27	CYAN	CORN	4000	3	60.0	1.06615	21.077
1	28	CYAN	CORN	6000	1	45.0	2.16060	42.713
1	28	CYAN	CORN	6000	2	49.0	1.56877	31.013
1	28	CYAN	CORN	6000	3	74.0	0.26820	5.302
1	29	CYAN	CORN	8000	1	73.0	0.69003	13.641
1	29	CYAN	CORN	8000	2	74.0	0.47055	9.302
1	29	CYAN	CORN	8000	3	87.0	-0.03461	-0.684
1	30	CYAN	CORN	10000	1	85.0	0.32667	6.458
1	30	CYAN	CORN	10000	2	82.0	0.29362	5.805
1	30	CYAN	CORN	10000	3	81.0	0.05272	1.042
1	31	CYAN	WHEAT	0	1	12.0	5.01301	98.082
1	31	CYAN	WHEAT	0	2	12.0	4.71048	92.163
1	31	CYAN	WHEAT	0	3	21.0	5.86921	114.834
1	32	CYAN	WHEAT	1000	1	44.0	2.22924	43.616
1	32	CYAN	WHEAT	1000	2	52.0	1.39336	27.262
1	32	CYAN	WHEAT	1000	3	39.0	3.18056	62.229
1	33	CYAN	WHEAT	2000	1	74.0	0.65363	12.789
1	33	CYAN	WHEAT	2000	2	73.0	0.49861	9.756
1	33	CYAN	WHEAT	2000	3	61.0	0.99292	19.427
1	34	CYAN	WHEAT	3000	1	88.0	0.26085	5.104
1	34	CYAN	WHEAT	3000	2	91.0	0.19571	3.829
1	34	CYAN	WHEAT	3000	3	82.0	0.03192	0.625
1	35	CYAN	WHEAT	4000	1	93.0	0.17339	3.392
1	35	CYAN	WHEAT	4000	2	95.0	0.18656	3.650
1	35	CYAN	WHEAT	4000	3	93.0	-0.03206	-0.627
1	36	CYAN	WHEAT	5000	1	94.0	0.15923	3.115
1	36	CYAN	WHEAT	5000	2	92.0	0.19144	3.746
1	36	CYAN	WHEAT	5000	3	98.0	0.03871	0.757

EXP	TRT	HERB	RES	LEVEL	REP	PCTTRAN	CONC	PCTAPPL
2	13	ATRA	BEANS	0	4	20	5.93990	114.336
2	13	ATRA	BEANS	0	5	27	4.72585	90.967
2	13	ATRA	BEANS	0	6	14	6.23244	119.967
2	14	ATRA	BEANS	2000	4	28	4.86068	93.562
2	14	ATRA	BEANS	2000	5	40	3.32989	64.096
2	14	ATRA	BEANS	2000	6	24	5.08394	97.860
2	15	ATRA	BEANS	4000	4	45	2.92135	56.232
2	15	ATRA	BEANS	4000	5	56	1.93973	37.337
2	15	ATRA	BEANS	4000	6	37	3.76095	72.394
2	16	ATRA	BEANS	6000	4	56	1.92304	37.016
2	16	ATRA	BEANS	6000	5	76	0.71090	13.684
2	16	ATRA	BEANS	6000	6	60	1.89121	36.403
2	17	ATRA	BEANS	8000	4	62	1.46348	28.170
2	17	ATRA	BEANS	8000	5	75	0.75892	14.608
2	17	ATRA	BEANS	8000	6	56	2.17315	41.831
2	18	ATRA	BEANS	10000	4	68	1.06388	20.478
2	18	ATRA	BEANS	10000	5	73	0.85918	16.538
2	18	ATRA	BEANS	10000	6	65	1.56437	30.112
2	7	ATRA	CORN	0	4	23	5.52270	109.178
2	7	ATRA	CORN	0	5	33	4.05188	80.102
2	7	ATRA	CORN	0	6	21	5.41655	107.080
2	8	ATRA	CORN	2000	4	49	2.53501	50.115
2	8	ATRA	CORN	2000	5	41	3.23241	63.902
2	8	ATRA	CORN	2000	6	28	4.65639	92.052
2	9	ATRA	CORN	4000	4	76	0.62438	12.343
2	9	ATRA	CORN	4000	5	60	1.64873	32.594
2	9	ATRA	CORN	4000	6	46	2.95765	58.470
2	10	ATRA	CORN	6000	4	64	1.32362	26.167
2	10	ATRA	CORN	6000	5	57	1.86486	36.866
2	10	ATRA	CORN	6000	6	52	2.47330	48.895
2	11	ATRA	CORN	8000	4	64	1.32362	26.167
2	11	ATRA	CORN	8000	5	86	0.30852	6.099
2	11	ATRA	CORN	8000	6	72	1.15457	22.825
2	12	ATRA	CORN	10000	4	89	0.13760	2.720
2	12	ATRA	CORN	10000	5	84	0.37769	7.467
2	12	ATRA	CORN	10000	6	76	0.94542	18.690
2	1	ATRA	WHEAT	0	4	26	5.12049	100.185
2	1	ATRA	WHEAT	0	5	29	4.49554	87.958
2	1	ATRA	WHEAT	0	6	20	5.52969	108.191
2	2	ATRA	WHEAT	1000	4	38	3.66159	71.641
2	2	ATRA	WHEAT	1000	5	48	2.58958	50.666
2	2	ATRA	WHEAT	1000	6	35	3.95198	77.322
2	3	ATRA	WHEAT	2000	4	60	1.61000	31.501
2	3	ATRA	WHEAT	2000	5	64	1.38035	27.007
2	3	ATRA	WHEAT	2000	6	56	2.17315	42.519
2	4	ATRA	WHEAT	3000	4	63	1.39271	27.249
2	4	ATRA	WHEAT	3000	5	78	0.61912	12.113
2	4	ATRA	WHEAT	3000	6	66	1.50241	29.395
2	5	ATRA	WHEAT	4000	4	79	0.48706	9.530
2	5	ATRA	WHEAT	4000	5	89	0.21537	4.214
2	5	ATRA	WHEAT	4000	6	85	0.54139	10.593
2	6	ATRA	WHEAT	5000	4	86	0.22495	4.401
2	6	ATRA	WHEAT	5000	5	91	0.16034	3.137
2	6	ATRA	WHEAT	5000	6	89	0.39139	7.658

EXP	TRT	HERB	RES	LEVEL	REP	PCTTRAN	CONC	PCTAPPL
2	19	CYAN	BEANS	0	4	20	5.10238	98.215
2	19	CYAN	BEANS	0	5	14	5.12812	98.710
2	19	CYAN	BEANS	0	6	11	5.66601	109.064
2	20	CYAN	BEANS	2000	4	42	3.04480	58.609
2	20	CYAN	BEANS	2000	5	27	3.26910	62.926
2	20	CYAN	BEANS	2000	6	17	5.00952	96.427
2	21	CYAN	BEANS	4000	4	53	2.21053	42.550
2	21	CYAN	BEANS	4000	5	44	1.42766	27.481
2	21	CYAN	BEANS	4000	6	36	3.20201	61.635
2	22	CYAN	BEANS	6000	4	61	1.68525	32.439
2	22	CYAN	BEANS	6000	5	58	0.41290	7.948
2	22	CYAN	BEANS	6000	6	48	2.27296	43.752
2	23	CYAN	BEANS	8000	4	78	0.79677	15.337
2	23	CYAN	BEANS	8000	5	69	-0.06650	-1.280
2	23	CYAN	BEANS	8000	6	60	1.50846	29.036
2	24	CYAN	BEANS	10000	4	81	0.67213	12.938
2	24	CYAN	BEANS	10000	5	82	-0.27239	-5.243
2	24	CYAN	BEANS	10000	6	82	0.53424	10.284
2	25	CYAN	CORN	0	4	16	5.53222	109.367
2	25	CYAN	CORN	0	5	15	4.97124	98.277
2	25	CYAN	CORN	0	6	12	5.55374	109.792
2	26	CYAN	CORN	2000	4	47	2.64951	52.378
2	26	CYAN	CORN	2000	5	26	3.39823	67.180
2	26	CYAN	CORN	2000	6	23	4.39416	86.868
2	27	CYAN	CORN	4000	4	62	1.62441	32.113
2	27	CYAN	CORN	4000	5	38	2.00128	39.563
2	27	CYAN	CORN	4000	6	38	3.03574	60.014
2	28	CYAN	CORN	6000	4	83	0.59439	11.751
2	28	CYAN	CORN	6000	5	43	1.51748	29.999
2	28	CYAN	CORN	6000	6	40	2.87404	56.817
2	29	CYAN	CORN	8000	4	79	0.75415	14.909
2	29	CYAN	CORN	8000	5	54	0.65659	12.980
2	29	CYAN	CORN	8000	6	52	1.99985	39.535
2	30	CYAN	CORN	10000	4	78	0.79677	15.751
2	30	CYAN	CORN	10000	5	65	0.07545	1.492
2	30	CYAN	CORN	10000	6	69	1.04307	20.621
2	31	CYAN	WHEAT	0	4	7	6.56205	128.390
2	31	CYAN	WHEAT	0	5	13	5.28730	103.449
2	31	CYAN	WHEAT	0	6	10	5.77942	113.077
2	32	CYAN	WHEAT	1000	4	27	4.39143	85.921
2	32	CYAN	WHEAT	1000	5	35	2.31930	45.378
2	32	CYAN	WHEAT	1000	6	26	4.10191	80.256
2	33	CYAN	WHEAT	2000	4	46	2.72643	53.344
2	33	CYAN	WHEAT	2000	5	50	0.93727	18.338
2	33	CYAN	WHEAT	2000	6	45	2.48980	48.714
2	34	CYAN	WHEAT	3000	4	60	1.74716	34.184
2	34	CYAN	WHEAT	3000	5	60	0.30492	5.966
2	34	CYAN	WHEAT	3000	6	56	1.74501	34.142
2	35	CYAN	WHEAT	4000	4	70	1.17629	23.015
2	35	CYAN	WHEAT	4000	5	69	-0.06650	-1.301
2	35	CYAN	WHEAT	4000	6	69	1.04307	20.408
2	36	CYAN	WHEAT	5000	4	88	0.41882	8.194
2	36	CYAN	WHEAT	5000	5	83	-0.27204	-5.323
2	36	CYAN	WHEAT	5000	6	75	0.78423	15.344

Table 3. Raw data from each replication used to determine the effect of rainfall amount on removal of herbicide intercepted by wheat residue.

Key

Exp = Experiment number
Trt = Treatment number
Herb = Herbicide
Form - Formulation
Rep = Replication number
Amt = Amount of simulated rain applied in mm
Time = Time of rainfall application in days
Pcttran = Percent transmittance
Conc = Concentration of herbicide in sample
Pctappl = Percent of applied herbicide removed with rainfall

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTAPPL
1	7	ATRA	DF	1	0.25	0	80	0.48339	13.8906
1	7	ATRA	DF	2	0.25	0	90	0.22310	6.4110
1	7	ATRA	DF	3	0.25	0	96	0.13766	3.9557
1	8	ATRA	DF	1	1.00	0	77	0.58592	16.8367
1	8	ATRA	DF	2	1.00	0	89	0.24349	6.9969
1	8	ATRA	DF	3	1.00	0	94	0.15306	4.3983
1	9	ATRA	DF	1	2.50	0	70	0.86901	24.9715
1	9	ATRA	DF	2	2.50	0	74	0.69972	20.1070
1	9	ATRA	DF	3	2.50	0	85	0.29801	8.5636
1	10	ATRA	DF	1	5.00	0	60	1.37995	39.6537
1	10	ATRA	DF	2	5.00	0	68	0.96117	27.6198
1	10	ATRA	DF	3	5.00	0	72	0.72590	20.8591
1	11	ATRA	DF	1	12.50	0	52	1.87894	53.9924
1	11	ATRA	DF	2	12.50	0	62	1.26773	36.4291
1	11	ATRA	DF	3	12.50	0	76	0.56674	16.2855
1	12	ATRA	DF	1	25.00	0	47	2.23153	64.1245
1	12	ATRA	DF	2	25.00	0	61	1.32321	38.0234
1	12	ATRA	DF	3	25.00	0	73	0.68381	19.6499
1	1	ATRA	L	1	0.25	0	91	0.20397	5.8611
1	1	ATRA	L	2	0.25	0	97	0.11547	3.3181
1	1	ATRA	L	3	0.25	0	81	0.40216	11.5564
1	2	ATRA	L	1	1.00	0	85	0.33758	9.7006
1	2	ATRA	L	2	1.00	0	73	0.74016	21.2691
1	2	ATRA	L	3	1.00	0	89	0.21831	6.2732
1	3	ATRA	L	1	2.50	0	76	0.62260	17.8908
1	3	ATRA	L	2	2.50	0	83	0.39215	11.2686
1	3	ATRA	L	3	2.50	0	89	0.21831	6.2732
1	4	ATRA	L	1	5.00	0	64	1.16053	33.3486
1	4	ATRA	L	2	5.00	0	77	0.58592	16.8367
1	4	ATRA	L	3	5.00	0	72	0.72590	20.8591
1	5	ATRA	L	1	12.50	0	59	1.43794	41.3200
1	5	ATRA	L	2	12.50	0	62	1.26773	36.4291
1	5	ATRA	L	3	12.50	0	70	0.81465	23.4094
1	6	ATRA	L	1	25.00	0	48	2.15851	62.0261
1	6	ATRA	L	2	25.00	0	63	1.21351	34.8709
1	6	ATRA	L	3	25.00	0	46	2.35640	67.7125
1	13	ATRA	WP	1	0.25	0	90	0.22310	6.4110
1	13	ATRA	WP	2	0.25	0	90	0.22310	6.4110
1	13	ATRA	WP	3	0.25	0	89	0.21831	6.2732
1	14	ATRA	WP	1	1.00	0	75	0.66053	18.9809
1	14	ATRA	WP	2	1.00	0	86	0.31218	8.9707
1	14	ATRA	WP	3	1.00	0	94	0.15306	4.3983
1	15	ATRA	WP	1	2.50	0	61	1.32321	38.0234
1	15	ATRA	WP	2	2.50	0	76	0.62260	17.8908
1	15	ATRA	WP	3	2.50	0	88	0.23594	6.7800
1	16	ATRA	WP	1	5.00	0	53	1.81218	52.0740
1	16	ATRA	WP	2	5.00	0	69	0.91446	26.2776
1	16	ATRA	WP	3	5.00	0	70	0.81465	23.4094
1	17	ATRA	WP	1	12.50	0	46	2.30581	66.2590
1	17	ATRA	WP	2	12.50	0	59	1.43794	41.3200
1	17	ATRA	WP	3	12.50	0	77	0.53076	15.2519
1	18	ATRA	WP	1	25.00	0	35	3.20560	92.1150
1	18	ATRA	WP	2	25.00	0	55	1.68242	48.3453
1	18	ATRA	WP	3	25.00	0	72	0.72590	20.8591

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTAPPL
1	25	CYAN	DF	1	0.25	0	95	0.13677	3.930
1	25	CYAN	DF	2	0.25	0	93	0.17691	5.083
1	25	CYAN	DF	3	0.25	0	94	0.22957	6.597
1	26	CYAN	DF	1	1.00	0	77	0.65558	18.838
1	26	CYAN	DF	2	1.00	0	77	0.65558	18.838
1	26	CYAN	DF	3	1.00	0	74	0.64144	18.432
1	27	CYAN	DF	1	2.50	0	62	1.35877	39.045
1	27	CYAN	DF	2	2.50	0	61	1.41440	40.644
1	27	CYAN	DF	3	2.50	0	61	1.19310	34.284
1	28	CYAN	DF	1	5.00	0	51	2.03093	58.360
1	28	CYAN	DF	2	5.00	0	48	2.23723	64.288
1	28	CYAN	DF	3	5.00	0	55	1.52316	43.769
1	29	CYAN	DF	1	12.50	0	42	2.67938	76.994
1	29	CYAN	DF	2	12.50	0	38	2.99603	86.093
1	29	CYAN	DF	3	12.50	0	46	2.10760	60.563
1	30	CYAN	DF	1	25.00	0	32	3.50383	100.685
1	30	CYAN	DF	2	25.00	0	35	3.24500	93.247
1	30	CYAN	DF	3	25.00	0	37	2.79926	80.439
1	19	CYAN	L	1	0.25	0	91	0.22142	6.363
1	19	CYAN	L	2	0.25	0	94	0.15629	4.491
1	19	CYAN	L	3	0.25	0	92	0.24693	7.096
1	20	CYAN	L	1	1.00	0	83	0.44325	12.737
1	20	CYAN	L	2	1.00	0	89	0.27031	7.768
1	20	CYAN	L	3	1.00	0	88	0.29754	8.550
1	21	CYAN	L	1	2.50	0	72	0.86262	24.788
1	21	CYAN	L	2	2.50	0	76	0.69480	19.965
1	21	CYAN	L	3	2.50	0	76	0.57643	16.564
1	22	CYAN	L	1	5.00	0	61	1.41440	40.644
1	22	CYAN	L	2	5.00	0	63	1.30423	37.478
1	22	CYAN	L	3	5.00	0	68	0.86825	24.950
1	23	CYAN	L	1	12.50	0	50	2.09861	60.305
1	23	CYAN	L	2	12.50	0	44	2.52762	72.633
1	23	CYAN	L	3	12.50	0	50	1.83461	52.719
1	24	CYAN	L	1	25.00	0	38	2.99603	86.093
1	24	CYAN	L	2	25.00	0	40	2.83551	81.480
1	24	CYAN	L	3	25.00	0	42	2.40177	69.016
1	31	CYAN	WP	1	0.25	0	88	0.29640	8.517
1	31	CYAN	WP	2	0.25	0	91	0.22142	6.363
1	31	CYAN	WP	3	0.25	0	78	0.51671	14.848
1	32	CYAN	WP	1	1.00	0	62	1.35877	39.045
1	32	CYAN	WP	2	1.00	0	76	0.69480	19.965
1	32	CYAN	WP	3	1.00	0	68	0.86825	24.950
1	33	CYAN	WP	1	2.50	0	61	1.41440	40.644
1	33	CYAN	WP	2	2.50	0	59	1.52895	43.935
1	33	CYAN	WP	3	2.50	0	57	1.40784	40.455
1	34	CYAN	WP	1	5.00	0	48	2.23723	64.288
1	34	CYAN	WP	2	5.00	0	52	1.96436	56.447
1	34	CYAN	WP	3	5.00	0	70	0.78735	22.625
1	35	CYAN	WP	1	12.50	0	41	2.75690	79.221
1	35	CYAN	WP	2	12.50	0	39	2.91522	83.771
1	35	CYAN	WP	3	12.50	0	54	1.58280	45.483
1	36	CYAN	WP	1	25.00	0	34	3.33018	95.695
1	36	CYAN	WP	2	25.00	0	38	2.99603	86.093
1	36	CYAN	WP	3	25.00	0	51	1.76967	50.853

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTAPPL
2	7	ATRA	DF	4	0.25	0	94	0.15306	4.3983
2	7	ATRA	DF	5	0.25	0	92	0.17458	5.0165
2	7	ATRA	DF	6	0.25	0	92	0.17458	5.0165
2	8	ATRA	DF	4	1.00	0	93	0.16305	4.6855
2	8	ATRA	DF	5	1.00	0	78	0.49632	14.2621
2	8	ATRA	DF	6	1.00	0	91	0.18763	5.3915
2	9	ATRA	DF	4	2.50	0	85	0.29801	8.5636
2	9	ATRA	DF	5	2.50	0	70	0.81465	23.4094
2	9	ATRA	DF	6	2.50	0	73	0.68381	19.6499
2	10	ATRA	DF	4	5.00	0	80	0.43202	12.4144
2	10	ATRA	DF	5	5.00	0	59	1.41203	40.5754
2	10	ATRA	DF	6	5.00	0	69	0.86131	24.7504
2	11	ATRA	DF	4	12.50	0	63	1.17340	33.7185
2	11	ATRA	DF	5	12.50	0	52	1.88844	54.2656
2	11	ATRA	DF	6	12.50	0	60	1.35008	38.7953
2	12	ATRA	DF	4	25.00	0	53	1.81580	52.1781
2	12	ATRA	DF	5	25.00	0	48	2.19430	63.0546
2	12	ATRA	DF	6	25.00	0	50	2.03832	58.5723
2	1	ATRA	L	4	0.25	0	95	0.14460	4.1551
2	1	ATRA	L	5	0.25	0	96	0.13766	3.9557
2	1	ATRA	L	6	0.25	0	97	0.13225	3.8003
2	2	ATRA	L	4	1.00	0	94	0.15306	4.3983
2	2	ATRA	L	5	1.00	0	95	0.14460	4.1551
2	2	ATRA	L	6	1.00	0	90	0.20220	5.8104
2	3	ATRA	L	4	2.50	0	83	0.34703	9.9722
2	3	ATRA	L	5	2.50	0	85	0.29801	8.5636
2	3	ATRA	L	6	2.50	0	85	0.29801	8.5636
2	4	ATRA	L	4	5.00	0	75	0.60423	17.3630
2	4	ATRA	L	5	5.00	0	82	0.37383	10.7423
2	4	ATRA	L	6	5.00	0	75	0.60423	17.3630
2	5	ATRA	L	4	12.50	0	66	1.01048	29.0369
2	5	ATRA	L	5	12.50	0	72	0.72590	20.8591
2	5	ATRA	L	6	12.50	0	70	0.81465	23.4094
2	6	ATRA	L	4	25.00	0	61	1.28966	37.0592
2	6	ATRA	L	5	25.00	0	63	1.17340	33.7185
2	6	ATRA	L	6	25.00	0	58	1.47550	42.3995
2	13	ATRA	WP	4	0.25	0	98	0.12837	3.6887
2	13	ATRA	WP	5	0.25	0	92	0.17458	5.0165
2	13	ATRA	WP	6	0.25	0	98	0.12837	3.6887
2	14	ATRA	WP	4	1.00	0	87	0.25510	7.3306
2	14	ATRA	WP	5	1.00	0	77	0.53076	15.2519
2	14	ATRA	WP	6	1.00	0	86	0.27579	7.9251
2	15	ATRA	WP	4	2.50	0	70	0.81465	23.4094
2	15	ATRA	WP	5	2.50	0	68	0.90951	26.1353
2	15	ATRA	WP	6	2.50	0	73	0.68381	19.6499
2	16	ATRA	WP	4	5.00	0	64	1.11757	32.1140
2	16	ATRA	WP	5	5.00	0	55	1.67510	48.1349
2	16	ATRA	WP	6	5.00	0	60	1.35008	38.7953
2	17	ATRA	WP	4	12.50	0	59	1.41203	40.5754
2	17	ATRA	WP	5	12.50	0	48	2.19430	63.0546
2	17	ATRA	WP	6	12.50	0	50	2.03832	58.5723
2	18	ATRA	WP	4	25.00	0	56	1.60704	46.1792
2	18	ATRA	WP	5	25.00	0	44	2.52460	72.5461
2	18	ATRA	WP	6	25.00	0	40	2.87936	82.7402

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTAPPL
2	25	CYAN	DF	4	0.25	0	96	0.21751	6.250
2	25	CYAN	DF	5	0.25	0	95	0.22288	6.404
2	25	CYAN	DF	6	0.25	0	80	0.46228	13.284
2	26	CYAN	DF	4	1.00	0	85	0.34939	10.040
2	26	CYAN	DF	5	1.00	0	79	0.48883	14.047
2	26	CYAN	DF	6	1.00	0	80	0.46228	13.284
2	27	CYAN	DF	4	2.50	0	67	0.91069	26.169
2	27	CYAN	DF	5	2.50	0	62	1.14272	32.837
2	27	CYAN	DF	6	2.50	0	67	0.91069	26.169
2	28	CYAN	DF	4	5.00	0	57	1.40784	40.455
2	28	CYAN	DF	5	5.00	0	53	1.64377	47.235
2	28	CYAN	DF	6	5.00	0	60	1.24480	35.770
2	29	CYAN	DF	4	12.50	0	50	1.83461	52.719
2	29	CYAN	DF	5	12.50	0	45	2.17916	62.619
2	29	CYAN	DF	6	12.50	0	48	1.96846	56.565
2	30	CYAN	DF	4	25.00	0	29	3.50409	100.692
2	30	CYAN	DF	5	25.00	0	37	2.79926	80.439
2	30	CYAN	DF	6	25.00	0	35	2.96753	85.274
2	19	CYAN	L	4	0.25	0	94	0.22957	6.597
2	19	CYAN	L	5	0.25	0	96	0.21751	6.250
2	19	CYAN	L	6	0.25	0	99	0.20934	6.015
2	20	CYAN	L	4	1.00	0	89	0.28290	8.129
2	20	CYAN	L	5	1.00	0	89	0.28290	8.129
2	20	CYAN	L	6	1.00	0	93	0.23759	6.827
2	21	CYAN	L	4	2.50	0	77	0.54591	15.687
2	21	CYAN	L	5	2.50	0	79	0.48883	14.047
2	21	CYAN	L	6	2.50	0	78	0.51671	14.848
2	22	CYAN	L	4	5.00	0	65	0.99953	28.722
2	22	CYAN	L	5	5.00	0	64	1.04593	30.056
2	22	CYAN	L	6	5.00	0	65	0.99953	28.722
2	23	CYAN	L	4	12.50	0	50	1.83461	52.719
2	23	CYAN	L	5	12.50	0	51	1.76967	50.853
2	23	CYAN	L	6	12.50	0	51	1.76967	50.853
2	24	CYAN	L	4	25.00	0	49	1.90087	54.623
2	24	CYAN	L	5	25.00	0	39	2.63630	75.756
2	24	CYAN	L	6	25.00	0	41	2.47862	71.225
2	31	CYAN	WP	4	0.25	0	96	0.21751	6.250
2	31	CYAN	WP	5	0.25	0	93	0.23759	6.827
2	31	CYAN	WP	6	0.25	0	99	0.20934	6.015
2	32	CYAN	WP	4	1.00	0	81	0.43706	12.559
2	32	CYAN	WP	5	1.00	0	79	0.48883	14.047
2	32	CYAN	WP	6	1.00	0	88	0.29754	8.550
2	33	CYAN	WP	4	2.50	0	67	0.91069	26.169
2	33	CYAN	WP	5	2.50	0	65	0.99953	28.722
2	33	CYAN	WP	6	2.50	0	71	0.74889	21.520
2	34	CYAN	WP	4	5.00	0	60	1.24480	35.770
2	34	CYAN	WP	5	5.00	0	56	1.46484	42.093
2	34	CYAN	WP	6	5.00	0	67	0.91069	26.169
2	35	CYAN	WP	4	12.50	0	56	1.46484	42.093
2	35	CYAN	WP	5	12.50	0	47	2.03737	58.545
2	35	CYAN	WP	6	12.50	0	32	3.22985	92.812
2	36	CYAN	WP	4	25.00	0	45	2.17916	62.619
2	36	CYAN	WP	5	25.00	0	48	1.96846	56.565
2	36	CYAN	WP	6	25.00	0	53	1.64377	47.235

Table 4. Raw data from each replication used to determine the effect of time of rainfall after application on removal of intercepted herbicide from wheat residue.

Key

Exp = Experiment number
Trt = Treatment number
Herb = Herbicide
Form = Formulation
Rep = Replication number
Amt = Amount of simulated rain applied in mm
Time = Time of rainfall application in days
PctTran = Percent transmittance
Conc = Concentration of herbicide in sample
Pctmax = Percent of removal at zero day

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTMAX
3	6	ATRA	DF	1	25	0	10	6.50369	156.825
3	6	ATRA	DF	2	25	0	22	5.03601	121.434
3	6	ATRA	DF	3	25	0	27	4.13701	99.756
3	7	ATRA	DF	1	25	1	9	6.63452	159.979
3	7	ATRA	DF	2	25	1	22	5.03601	121.434
3	7	ATRA	DF	3	25	1	27	4.13701	99.756
3	8	ATRA	DF	1	25	3	20	5.26751	127.016
3	8	ATRA	DF	2	25	3	34	3.75726	90.600
3	8	ATRA	DF	3	25	3	28	4.03477	97.291
3	9	ATRA	DF	1	25	7	15	5.86920	141.525
3	9	ATRA	DF	2	25	7	41	3.09857	74.716
3	9	ATRA	DF	3	25	7	33	3.54343	85.443
3	10	ATRA	DF	1	25	14	19	5.38522	129.855
3	10	ATRA	DF	2	25	14	38	3.37300	81.334
3	10	ATRA	DF	3	25	14	44	2.57889	62.185
3	1	ATRA	EC	1	25	0	11	6.37417	149.786
3	1	ATRA	EC	2	25	0	9	6.63452	155.904
3	1	ATRA	EC	3	25	0	29	3.93386	92.441
3	2	ATRA	EC	1	25	1	14	5.99347	140.840
3	2	ATRA	EC	2	25	1	11	6.37417	149.786
3	2	ATRA	EC	3	25	1	28	4.03477	94.813
3	3	ATRA	EC	1	25	3	15	5.86920	137.920
3	3	ATRA	EC	2	25	3	10	6.50369	152.830
3	3	ATRA	EC	3	25	3	28	4.03477	94.813
3	4	ATRA	EC	1	25	7	20	5.26751	123.781
3	4	ATRA	EC	2	25	7	23	4.92223	115.667
3	4	ATRA	EC	3	25	7	31	3.73600	87.792
3	5	ATRA	EC	1	25	14	33	3.85661	90.626
3	5	ATRA	EC	2	25	14	24	4.80977	113.024
3	5	ATRA	EC	3	25	14	44	2.57889	60.601
3	11	ATRA	WP	1	25	0	10	6.50369	141.350
3	11	ATRA	WP	2	25	0	26	4.58877	99.731
3	11	ATRA	WP	3	25	0	22	4.66803	101.454
3	12	ATRA	WP	1	25	1	11	6.37417	138.535
3	12	ATRA	WP	2	25	1	22	5.03601	109.452
3	12	ATRA	WP	3	25	1	20	4.88971	106.272
3	13	ATRA	WP	1	25	3	15	5.86920	127.560
3	13	ATRA	WP	2	25	3	43	2.92218	63.510
3	13	ATRA	WP	3	25	3	9	6.20348	134.825
3	14	ATRA	WP	1	25	7	14	5.99347	130.261
3	14	ATRA	WP	2	25	7	35	3.65923	79.529
3	14	ATRA	WP	3	25	7	30	3.83427	83.333
3	15	ATRA	WP	1	25	14	10	6.50369	141.350
3	15	ATRA	WP	2	25	14	35	3.65923	79.529
3	15	ATRA	WP	3	25	14	35	3.35615	72.942
3	21	CYAN	DF	1	25	0	5	6.61993	142.606
3	21	CYAN	DF	2	25	0	7	6.37123	137.248
3	21	CYAN	DF	3	25	0	24	4.53799	97.757
3	22	CYAN	DF	1	25	1	8	6.24867	134.608
3	22	CYAN	DF	2	25	1	7	6.37123	137.248
3	22	CYAN	DF	3	25	1	20	4.96795	107.019
3	23	CYAN	DF	1	25	3	10	6.00712	129.405
3	23	CYAN	DF	2	25	3	15	5.42416	116.847
3	23	CYAN	DF	3	25	3	22	4.75050	102.335

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTMAX
3	24	CYAN	DF	1	25	7	10	6.00712	129.405
3	24	CYAN	DF	2	25	7	9	6.12730	131.993
3	24	CYAN	DF	3	25	7	27	4.22849	91.090
3	25	CYAN	DF	1	25	14	4	6.74608	145.323
3	25	CYAN	DF	2	25	14	14	5.53837	119.307
3	25	CYAN	DF	3	25	14	34	3.54960	76.465
3	16	CYAN	EC	1	25	0	8	6.24867	136.738
3	16	CYAN	EC	2	25	0	8	6.24867	136.738
3	16	CYAN	EC	3	25	0	26	4.33042	94.761
3	17	CYAN	EC	1	25	1	9	6.12730	134.082
3	17	CYAN	EC	2	25	1	11	5.88814	128.848
3	17	CYAN	EC	3	25	1	21	4.85860	106.319
3	18	CYAN	EC	1	25	3	10	6.00712	131.452
3	18	CYAN	EC	2	25	3	10	6.00712	131.452
3	18	CYAN	EC	3	25	3	23	4.64362	101.615
3	19	CYAN	EC	1	25	7	7	6.37123	139.420
3	19	CYAN	EC	2	25	7	14	5.53837	121.194
3	19	CYAN	EC	3	25	7	23	4.64362	101.615
3	20	CYAN	EC	1	25	14	6	6.49498	142.128
3	20	CYAN	EC	2	25	14	15	5.42416	118.695
3	20	CYAN	EC	3	25	14	29	4.02834	88.151
3	26	CYAN	WP	1	25	0	5	6.61993	163.932
3	26	CYAN	WP	2	25	0	16	5.31115	131.522
3	26	CYAN	WP	3	25	0	28	4.12780	102.218
3	27	CYAN	WP	1	25	1	5	6.61993	163.932
3	27	CYAN	WP	2	25	1	20	4.87105	120.624
3	27	CYAN	WP	3	25	1	24	4.53799	112.376
3	28	CYAN	WP	1	25	3	14	5.53837	137.149
3	28	CYAN	WP	2	25	3	25	4.34778	107.666
3	28	CYAN	WP	3	25	3	26	4.33042	107.236
3	29	CYAN	WP	1	25	7	22	4.65816	115.352
3	29	CYAN	WP	2	25	7	39	3.04143	75.316
3	29	CYAN	WP	3	25	7	28	4.12780	102.218
3	30	CYAN	WP	1	25	14	14	5.53837	137.149
3	30	CYAN	WP	2	25	14	24	4.45005	110.198
3	30	CYAN	WP	3	25	14	26	4.33042	107.236
4	6	ATRA	DF	4	25	0	32	3.63905	87.749
4	6	ATRA	DF	5	25	0	37	3.03072	73.080
4	6	ATRA	DF	6	25	0	43	2.53617	61.155
4	7	ATRA	DF	4	25	1	36	3.26450	78.717
4	7	ATRA	DF	5	25	1	44	2.45813	59.273
4	7	ATRA	DF	6	25	1	44	2.45813	59.273
4	8	ATRA	DF	4	25	3	34	3.44913	83.170
4	8	ATRA	DF	5	25	3	43	2.53617	61.155
4	8	ATRA	DF	6	25	3	45	2.38135	57.422
4	9	ATRA	DF	4	25	7	35	3.35615	80.928
4	9	ATRA	DF	5	25	7	47	2.23153	53.809
4	9	ATRA	DF	6	25	7	43	2.53617	61.155
4	10	ATRA	DF	4	25	14	40	2.91111	70.196
4	10	ATRA	DF	5	25	14	43	2.53617	61.155
4	10	ATRA	DF	6	25	14	49	2.08673	50.318
4	1	ATRA	EC	4	25	0	31	3.73600	87.792
4	1	ATRA	EC	5	25	0	41	2.69601	63.353
4	1	ATRA	EC	6	25	0	48	2.15851	50.723

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTMAX
4	2	ATRA	EC	4	25	1	31	3.73600	87.792
4	2	ATRA	EC	5	25	1	53	1.81218	42.584
4	2	ATRA	EC	6	25	1	49	2.08673	49.036
4	3	ATRA	EC	4	25	3	35	3.35615	78.866
4	3	ATRA	EC	5	25	3	27	3.95524	92.944
4	3	ATRA	EC	6	25	3	48	2.15851	50.723
4	4	ATRA	EC	4	25	7	40	2.91111	68.408
4	4	ATRA	EC	5	25	7	31	3.57040	83.901
4	4	ATRA	EC	6	25	7	44	2.45813	57.764
4	5	ATRA	EC	4	25	14	46	2.42072	56.884
4	5	ATRA	EC	5	25	14	54	1.74667	41.045
4	5	ATRA	EC	6	25	14	49	2.08673	49.036
4	11	ATRA	WP	4	25	0	30	3.83427	83.333
4	11	ATRA	WP	5	25	0	18	4.89446	106.375
4	11	ATRA	WP	6	25	0	36	3.11754	67.756
4	12	ATRA	WP	4	25	1	31	3.73600	81.197
4	12	ATRA	WP	5	25	1	21	4.57011	99.326
4	12	ATRA	WP	6	25	1	44	2.45813	53.425
4	13	ATRA	WP	4	25	3	32	3.63905	79.090
4	13	ATRA	WP	5	25	3	40	2.77781	60.372
4	13	ATRA	WP	6	25	3	40	2.77781	60.372
4	14	ATRA	WP	4	25	7	34	3.44913	74.963
4	14	ATRA	WP	5	25	7	43	2.53617	55.121
4	14	ATRA	WP	6	25	7	41	2.69601	58.595
4	15	ATRA	WP	4	25	14	36	3.26450	70.950
4	15	ATRA	WP	5	25	14	39	2.86086	62.177
4	15	ATRA	WP	6	25	14	43	2.53617	55.121
4	21	CYAN	DF	4	25	0	26	4.33042	93.285
4	21	CYAN	DF	5	25	0	37	3.07794	66.305
4	21	CYAN	DF	6	25	0	39	2.91524	62.800
4	22	CYAN	DF	4	25	1	29	4.02834	86.778
4	22	CYAN	DF	5	25	1	40	2.83553	61.083
4	22	CYAN	DF	6	25	1	39	2.91524	62.800
4	23	CYAN	DF	4	25	3	27	4.22849	91.090
4	23	CYAN	DF	5	25	3	40	2.83553	61.083
4	23	CYAN	DF	6	25	3	37	3.07794	66.305
4	24	CYAN	DF	4	25	7	35	3.45756	74.482
4	24	CYAN	DF	5	25	7	38	2.99604	64.540
4	24	CYAN	DF	6	25	7	39	2.91524	62.800
4	25	CYAN	DF	4	25	14	31	3.83314	82.573
4	25	CYAN	DF	5	25	14	34	3.33020	71.739
4	25	CYAN	DF	6	25	14	40	2.83553	61.083
4	16	CYAN	EC	4	25	0	26	4.33042	94.761
4	16	CYAN	EC	5	25	0	32	3.50384	76.673
4	16	CYAN	EC	6	25	0	41	2.75691	60.329
4	17	CYAN	EC	4	25	1	26	4.33042	94.761
4	17	CYAN	EC	5	25	1	39	2.91524	63.793
4	17	CYAN	EC	6	25	1	41	2.75691	60.329
4	18	CYAN	EC	4	25	3	36	3.36675	73.674
4	18	CYAN	EC	5	25	3	39	2.91524	63.793
4	18	CYAN	EC	6	25	3	42	2.67939	58.632
4	19	CYAN	EC	4	25	7	31	3.83314	83.879
4	19	CYAN	EC	5	25	7	38	2.99604	65.561
4	19	CYAN	EC	6	25	7	42	2.67939	58.632

EXP	TRT	HERB	FORM	REP	AMT	TIME	PCTTRAN	CONC	PCTMAX
4	20	CYAN	EC	4	25	14	35	3.45756	75.6607
4	20	CYAN	EC	5	25	14	43	2.60297	56.9599
4	20	CYAN	EC	6	25	14	42	2.67939	58.6323
4	26	CYAN	WP	4	25	0	34	3.54960	87.9002
4	26	CYAN	WP	5	25	0	45	2.45340	60.7546
4	26	CYAN	WP	6	25	0	49	2.16740	53.6721
4	27	CYAN	WP	4	25	1	31	3.83314	94.9216
4	27	CYAN	WP	5	25	1	40	2.83553	70.2174
4	27	CYAN	WP	6	25	1	51	2.03096	50.2935
4	28	CYAN	WP	4	25	3	34	3.54960	87.9002
4	28	CYAN	WP	5	25	3	50	2.09863	51.9693
4	28	CYAN	WP	6	25	3	52	1.96438	48.6448
4	29	CYAN	WP	4	25	7	30	3.93012	97.3233
4	29	CYAN	WP	5	25	7	47	2.30821	57.1592
4	29	CYAN	WP	6	25	7	47	2.30821	57.1592
4	30	CYAN	WP	4	25	14	33	3.64288	90.2101
4	30	CYAN	WP	5	25	14	44	2.52764	62.5929
4	30	CYAN	WP	6	25	14	47	2.30821	57.1592

Table 5. Raw data from each replication used to compare herbicide interception and retention on various residue types.

Key

Exp = Experiment number
Trt = Treatment number
Herb = Herbicide
Form = Formulation
Type = Residue type
Rep = Replication number
Pctspray = Percent transmittance from the spray through sample
Pctwash = Percent transmittance from the washoff water sample
ConcX = Concentration of herbicide in spray through sample
ConcY = Concentration of herbicide in washoff water sample
ConcT = Concentration of herbicide accounted for
PctconcX = Percent of applied herbicide found in spray through sample
PctconcY = Percent of applied herbicide found in washoff water sample
PctconcT = Percent of applied herbicide accounted for

EXP	TRT	HERB	FORM	TYPE	REP	PCTSPRAY	PCTWASH	CONCX	CONCY	CONCT	PCTCONCX	PCTCONCY	PCTCONCT
1	6	ATRA	DF	BEANS	1	61	47	1.57689	2.61084	4.18774	32.3050	53.4870	85.792
1	6	ATRA	DF	BEANS	2	57	40	1.84422	3.23104	5.07526	37.7816	66.1926	103.974
1	6	ATRA	DF	BEANS	3	53	37	2.13402	3.51790	5.65192	43.7185	72.0693	115.788
1	5	ATRA	DF	CORN	1	69	41	1.10965	3.13823	4.24787	22.7327	64.2912	87.024
1	5	ATRA	DF	CORN	2	50	42	2.36611	3.04682	5.41293	48.4733	62.4186	110.892
1	5	ATRA	DF	CORN	3	53	38	2.13402	3.42087	5.55489	43.7185	70.0816	113.800
1	4	ATRA	DF	WHEAT	1	72	45	0.95760	2.78102	3.73862	19.6178	56.9733	76.591
1	4	ATRA	DF	WHEAT	2	50	42	2.36611	3.04682	5.41293	48.4733	62.4186	110.892
1	4	ATRA	DF	WHEAT	3	52	38	2.20998	3.42087	5.63085	45.2747	70.0816	115.356
1	3	ATRA	L	BEANS	1	61	52	1.57689	2.20998	3.78687	32.3050	45.2747	77.580
1	3	ATRA	L	BEANS	2	67	52	1.21803	2.20998	3.42801	24.9532	45.2747	70.228
1	3	ATRA	L	BEANS	3	63	57	1.45166	1.84422	3.29588	29.7393	37.7816	67.521
1	2	ATRA	L	CORN	1	63	42	1.45166	3.04682	4.49847	29.7393	62.4186	92.158
1	2	ATRA	L	CORN	2	63	50	1.45166	2.36611	3.81777	29.7393	48.4733	78.213
1	2	ATRA	L	CORN	3	57	42	1.84422	3.04682	4.89104	37.7816	62.4186	100.200
1	1	ATRA	L	WHEAT	1	71	39	1.00688	3.32525	4.33213	20.6273	68.1227	88.750
1	1	ATRA	L	WHEAT	2	60	53	1.64162	2.13402	3.77564	33.6310	43.7185	77.350
1	1	ATRA	L	WHEAT	3	54	51	2.05946	2.28734	4.34681	42.1911	46.8596	89.051
1	9	ATRA	WP	BEANS	1	75	43	0.81819	2.95681	3.77501	16.7618	60.5747	77.337
1	9	ATRA	WP	BEANS	2	56	36	1.91456	3.61633	5.53089	39.2227	74.0858	113.308
1	9	ATRA	WP	BEANS	3	54	40	2.05946	3.23104	5.29050	42.1911	66.1926	108.384
1	8	ATRA	WP	CORN	1	68	38	1.16314	3.42087	4.58401	23.8286	70.0816	93.910
1	8	ATRA	WP	CORN	2	48	34	2.52786	3.81740	6.34526	51.7870	78.2051	129.992
1	8	ATRA	WP	CORN	3	55	42	1.98631	3.04682	5.03313	40.6925	62.4186	103.111
1	7	ATRA	WP	WHEAT	1	79	32	0.65197	4.02409	4.67606	13.3566	82.4394	95.796
1	7	ATRA	WP	WHEAT	2	57	37	1.84422	3.51790	5.36212	37.7816	72.0693	109.851
1	7	ATRA	WP	WHEAT	3	61	41	1.57689	3.13823	4.71512	32.3050	64.2912	96.596
1	15	CYAN	DF	BEANS	1	53	37	1.58002	2.79954	4.37956	29.4682	52.2127	81.681
1	15	CYAN	DF	BEANS	2	51	40	1.71195	2.54231	4.25426	31.9287	47.4152	79.344
1	15	CYAN	DF	BEANS	3	51	33	1.71195	3.16302	4.87498	31.9287	58.9918	90.921
1	14	CYAN	DF	CORN	1	50	35	1.78011	2.97835	4.75846	33.1999	55.5476	88.748
1	14	CYAN	DF	CORN	2	39	31	2.62659	3.35356	5.98015	48.9870	62.5454	111.532
1	14	CYAN	DF	CORN	3	30	35	3.45102	2.97835	6.42938	64.3632	55.5476	119.911
1	13	CYAN	DF	WHEAT	1	50	35	1.78011	2.97835	4.75846	33.1999	55.5476	88.748
1	13	CYAN	DF	WHEAT	2	55	32	1.45396	3.25756	4.71152	27.1170	60.7550	87.872
1	13	CYAN	DF	WHEAT	3	55	35	1.45396	2.97835	4.43231	27.1170	55.5476	82.665
1	12	CYAN	L	BEANS	1	55	45	1.45396	2.14290	3.59685	27.1170	39.9660	67.083
1	12	CYAN	L	BEANS	2	47	48	1.99339	1.92083	3.91422	37.1776	35.8244	73.002
1	12	CYAN	L	BEANS	3	44	41	2.21985	2.45950	4.67934	41.4012	45.8707	87.272
1	11	CYAN	L	CORN	1	69	36	0.73560	2.88821	3.62381	13.7192	53.8665	67.586
1	11	CYAN	L	CORN	2	40	39	2.54231	2.62659	5.16890	47.4152	48.9870	96.402
1	11	CYAN	L	CORN	3	59	36	1.21941	2.88821	4.10762	22.7425	53.8665	76.609
1	10	CYAN	L	WHEAT	1	68	30	0.77739	3.45102	4.22841	14.4986	64.3632	78.862
1	10	CYAN	L	WHEAT	2	64	44	0.95919	2.21985	3.17904	17.8893	41.4012	59.290
1	10	CYAN	L	WHEAT	3	53	47	1.58002	1.99339	3.57341	29.4682	37.1776	66.646
1	18	CYAN	WP	BEANS	1	48	45	1.92083	2.14290	4.06373	35.8244	39.9660	75.790
1	18	CYAN	WP	BEANS	2	45	45	2.14290	2.14290	4.28579	39.9660	39.9660	79.932
1	18	CYAN	WP	BEANS	3	52	42	1.64526	2.37815	4.02340	30.6848	44.3535	75.038
1	17	CYAN	WP	CORN	1	50	34	1.78011	3.06996	4.85007	33.1999	57.2561	90.456
1	17	CYAN	WP	CORN	2	52	39	1.64526	2.62659	4.27184	30.6848	48.9870	79.672
1	17	CYAN	WP	CORN	3	57	44	1.33375	2.21985	3.55360	24.8751	41.4012	66.276
1	16	CYAN	WP	WHEAT	1	55	43	1.45396	2.29827	3.75222	27.1170	42.8637	69.981
1	16	CYAN	WP	WHEAT	2	55	44	1.45396	2.21985	3.67381	27.1170	41.4012	68.518
1	16	CYAN	WP	WHEAT	3	44	48	2.21985	1.92083	4.14068	41.4012	35.8244	77.226

EXP	TRT	HERB	FORM	TYPE	REP	PCTSPRAY	PCTWASH	CONCX	CONCY	CONCT	PCTCONCX	PCTCONCY	PCTCONCT
2	6	ATRA	DF	BEANS	4	60	62	1.31237	1.17564	2.48801	26.8857	24.0847	50.970
2	6	ATRA	DF	BEANS	5	74	55	0.54072	1.69281	2.23352	11.0774	34.6797	45.757
2	6	ATRA	DF	BEANS	6	58	59	1.45792	1.38404	2.84196	29.8676	28.3541	58.222
2	5	ATRA	DF	CORN	4	56	57	1.61230	1.53401	3.14631	33.0304	31.4264	64.457
2	5	ATRA	DF	CORN	5	77	53	0.43165	1.86044	2.29209	8.8430	38.1138	46.957
2	5	ATRA	DF	CORN	6	60	48	1.31237	2.31814	3.63050	26.8857	47.4905	74.376
2	4	ATRA	DF	WHEAT	4	72	51	0.62446	2.03689	2.66136	12.7930	41.7288	54.522
2	4	ATRA	DF	WHEAT	5	74	56	0.54072	1.61230	2.15302	11.0774	33.0304	44.108
2	4	ATRA	DF	WHEAT	6	57	51	1.53401	2.03689	3.57090	31.4264	41.7288	73.155
2	3	ATRA	L	BEANS	4	68	45	0.81845	2.61925	3.43769	16.7671	53.6591	70.426
2	3	ATRA	L	BEANS	5	64	61	1.04775	1.24290	2.29065	21.4646	25.4626	46.927
2	3	ATRA	L	BEANS	6	62	66	1.17564	0.92868	2.10432	24.0847	19.0254	43.110
2	2	ATRA	L	CORN	4	50	52	2.12844	1.94756	4.07600	43.6041	39.8987	83.503
2	2	ATRA	L	CORN	5	49	61	2.22218	1.24290	3.46508	45.5247	25.4626	70.987
2	2	ATRA	L	CORN	6	60	62	1.31237	1.17564	2.48801	26.8857	24.0847	50.970
2	1	ATRA	L	WHEAT	4	71	53	0.66965	1.86044	2.53008	13.7187	38.1138	51.832
2	1	ATRA	L	WHEAT	5	57	60	1.53401	1.31237	2.84637	31.4264	26.8857	58.312
2	1	ATRA	L	WHEAT	6	58	66	1.45792	0.92868	2.38660	29.8676	19.0254	48.893
2	9	ATRA	WP	BEANS	4	72	54	0.62446	1.77552	2.39998	12.7930	36.3741	49.167
2	9	ATRA	WP	BEANS	5	60	45	1.31237	2.61925	3.93161	26.8857	53.6591	80.545
2	9	ATRA	WP	BEANS	6	63	56	1.11059	1.61230	2.72289	22.7521	33.0304	55.783
2	8	ATRA	WP	CORN	4	49	53	2.22218	1.86044	4.08262	45.5247	38.1138	83.638
2	8	ATRA	WP	CORN	5	53	49	1.86044	2.22218	4.08262	38.1138	45.5247	83.638
2	8	ATRA	WP	CORN	6	64	48	1.04775	2.31814	3.36588	21.4646	47.4905	68.955
2	7	ATRA	WP	WHEAT	4	70	56	0.71704	1.61230	2.32934	14.6896	33.0304	47.720
2	7	ATRA	WP	WHEAT	5	65	45	0.98711	2.61925	3.60636	20.2224	53.6591	73.882
2	7	ATRA	WP	WHEAT	6	61	54	1.24290	1.77552	3.01842	25.4626	36.3741	61.837
2	15	CYAN	DF	BEANS	4	53	34	1.26076	2.65164	3.91241	23.5138	49.4544	72.968
2	15	CYAN	DF	BEANS	5	47	39	1.63827	2.23024	3.86851	30.5546	41.5950	72.150
2	15	CYAN	DF	BEANS	6	42	38	1.99638	2.31136	4.30774	37.2335	43.1078	80.341
2	14	CYAN	DF	CORN	4	42	31	1.99638	2.92348	4.91986	37.2335	54.5242	91.758
2	14	CYAN	DF	CORN	5	35	35	2.56420	2.56420	5.12840	47.8235	47.8235	95.647
2	14	CYAN	DF	CORN	6	41	39	2.07275	2.23024	4.30299	38.6578	41.5950	80.253
2	13	CYAN	DF	WHEAT	4	50	37	1.44240	2.39405	3.83645	26.9014	44.6502	71.552
2	13	CYAN	DF	WHEAT	5	44	37	1.84839	2.39405	4.24245	34.4734	44.6502	79.124
2	13	CYAN	DF	WHEAT	6	47	38	1.63827	2.31136	3.94963	30.5546	43.1078	73.662
2	12	CYAN	L	BEANS	4	62	38	0.80131	2.31136	3.11266	14.9447	43.1078	58.053
2	12	CYAN	L	BEANS	5	48	45	1.57140	1.77677	3.34817	29.3073	33.1376	62.445
2	12	CYAN	L	BEANS	6	42	44	1.99638	1.84839	3.84478	37.2335	34.4734	71.707
2	11	CYAN	L	CORN	4	32	37	2.83128	2.39405	5.22534	52.8047	44.6502	97.455
2	11	CYAN	L	CORN	5	52	36	1.31972	2.47834	3.79806	24.6135	46.2221	70.836
2	11	CYAN	L	CORN	6	55	41	1.14758	2.07275	3.22034	21.4030	38.6578	60.061
2	10	CYAN	L	WHEAT	4	55	39	1.14758	2.23024	3.37782	21.4030	41.5950	62.998
2	10	CYAN	L	WHEAT	5	51	40	1.38027	2.15070	3.53097	25.7427	40.1116	65.854
2	10	CYAN	L	WHEAT	6	50	41	1.44240	2.07275	3.51515	26.9014	38.6578	65.559
2	18	CYAN	WP	BEANS	4	47	37	1.63827	2.39405	4.03233	30.5546	44.6502	75.205
2	18	CYAN	WP	BEANS	5	55	47	1.14758	1.63827	2.78586	21.4030	30.5546	51.958
2	18	CYAN	WP	BEANS	6	32	38	2.83128	2.31136	5.14264	52.8047	43.1078	95.913
2	17	CYAN	WP	CORN	4	51	31	1.38027	2.92348	4.30375	25.7427	54.5242	80.267
2	17	CYAN	WP	CORN	5	42	39	1.99638	2.23024	4.22662	37.2335	41.5950	78.828
2	17	CYAN	WP	CORN	6	34	33	2.65164	2.74067	5.39232	49.4544	51.1148	100.569
2	16	CYAN	WP	WHEAT	4	50	34	1.44240	2.65164	4.09404	26.9014	49.4544	76.356
2	16	CYAN	WP	WHEAT	5	43	41	1.92160	2.07275	3.99435	35.8387	38.6578	74.496
2	16	CYAN	WP	WHEAT	6	40	36	2.15070	2.47834	4.62904	40.1116	46.2221	86.334