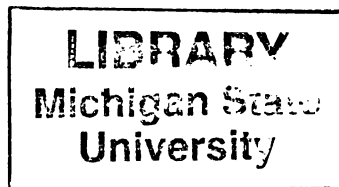


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DRY EDIBLE BEAN RESPONSE TO
DIMETHENAMID AND METOLACHLOR

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Kyle William Poling

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M. S. degree in Crop and Soil Sciences

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**DRY EDIBLE BEAN RESPONSE TO
DIMETHENAMID AND METOLACHLOR**

By

Kyle William Poling

A THESIS

**Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of**

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ABSTRACT

DRY EDIBLE BEAN RESPONSE TO APPLICATIONS OF DIMETHENAMID OR METOLACHLOR

By

Kyle William Poling

Dimethenamid and metolachlor are chloroacetamide herbicides that are applied in dry edible beans (*Phaseolus vulgaris*) to control annual grasses, small-seeded broadleaf weeds, and yellow nutsedge (*Cyperus esculentus* L.). Metolachlor has become the standard herbicide treatment for preemergence grass control in dry beans since registration in 1983. Dimethenamid was registered for use in dry beans in 1996. During that year some dry bean fields in Michigan that received an application of dimethenamid were injured. Research was conducted (1) to determine if dry bean classes and/or varieties differed in their susceptibility to applications of dimethenamid or metolachlor, (2) to determine if placement or application timing of dimethenamid influenced dry bean tolerance to dimethenamid, and (3) to determine whether environmental conditions at the time of planting and emergence influenced dry bean tolerance to applications of dimethenamid or metolachlor.

In a greenhouse study navy and black beans were more susceptible to dimethenamid than pinto, kidney, small red, and cranberry classes of dry beans. Cultivars within the same class of dry beans differed in their tolerance to applications of dimethenamid and metolachlor in both the greenhouse and the field. Dimethenamid was usually more injurious to dry beans compared to metolachlor.

In our greenhouse research, injury to 'Vista' navy beans was greatest when dimethenamid or metolachlor was absorbed by the hypocotyl rather than the roots. Dry bean injury from dimethenamid or metolachlor resulted in a reduction of leaf area early in the growing season. Visual injury and leaf area reduction also resulted in delayed maturity and yield loss in some instances. In the field dimethenamid and metolachlor were each applied preplant incorporated (PPI), preemergence (PRE), and at the early crook stage, unifoliolate, 1st trifoliolate, and 2nd trifoliolate growth stages to 'Vista' navy bean. When dimethenamid and metolachlor were applied at the crook and unifoliolate stages the leaf area was reduced from 21 to 34% when measured at the 3rd trifoliolate growth stage. To minimize the chance of severe injury, these herbicides should not be applied at the crook or unifoliolate stages.

Environmental conditions following application of dimethenamid or metolachlor affected dry bean tolerance to these herbicides. The quantity of precipitation that a dry bean field received at the time of emergence following a preemergence application of dimethenamid or metolachlor was important. Rain at the time of emergence appears to increase the amount of herbicide absorbed by the dry bean hypocotyl which resulted in crop injury. Moderate temperature (22 to 31 C) did not appear to play a significant role in dry bean injury from dimethenamid or metolachlor in our research.

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Chapter 1

LITERATURE REVIEW

Weed Control Strategies

Dry bean farmers use a combination of mechanical, cultural, and chemical practices in their weed management systems (Burnside et al., 1994). A survey conducted in 1989 showed that the major production problem for Minnesota and North Dakota dry bean growers was the control of weeds (Lamey et al., 1991). Dry bean farmers use various methods to control weeds in their fields. Today an integrated weed management strategy could include any combination of the following practices: class and cultivar selection, narrow row spacing, and increased seeding density (Malik et al., 1993), as well as planting date, herbicides and cultivation (Leep et al., 1982).

Market Classes

A dry edible bean (*Phaseolus vulgaris*) market class is a category that classifies a dry edible bean according to size and color of seed. Navy beans are white in color and are considered small in size (17-22 g/100 seeds) relative to other classes of dry beans. Black (or black turtle) beans, which genetically are closely related to navy beans, are of similar size to navy beans with a black seed coat. The pinto class of dry beans is tan with dark brown mottling and has a medium seed size (38-42 g/100 seeds). Pinto beans are distantly related

to both navy and black beans. Great northern and pink beans are similar in size and shape to the pinto class but with a brilliant white and pink seed coat, respectively. The small red or red Mexican market class is a red bean and is slightly smaller than a pinto bean. The pinto, great northern, pink and small red market classes are all closely related genetically (Voysest and Dessert, 1991). Cranberry dry beans have a white-red mottled seed coat and are medium-large in size (45-55 g/100 seeds). Light red and dark red kidney beans are the largest seed of all the market classes (50-60 g/100 seeds). The two kidney bean classes and cranberry market class are closely related.

The total number of acres of each class of dry beans grown can vary dramatically from year to year. This fluctuation is a direct effect of the price a grower can receive for a bag (100 lbs) of dry beans in the months preceding planting. Since navy beans and black beans are well suited for the climate in Michigan, these market classes account for the majority of dry beans grown. In 1997 Michigan farmers produced 5,033,000 cwt of dry beans ranking the state as the second largest producer in the country. Almost one-half (48%) of the total acres planted in Michigan in 1997 were of the navy bean class and 25% were black beans. The following year the acres planted in the state declined from 315,000 to 300,000. Navy bean accounted for 28% of the total dry beans grown in 1998 while black bean acreage increased greatly to nearly 42% (Varner, 1999 personal communication).

Cultivar Selection

One of the first weed control decisions that confronts a grower is related to the seed selection process. Cultivars of common beans differ in their competitive ability with weeds

(Malik et al., 1993). These differences, attributed to inherent genetic variation (Monks and Oliver, 1988), can include seedling establishment and canopy development (Field and Nkumbula, 1986). It is important to select a bean cultivar that emerges evenly and vigorously from the soil and has a high percent germination to enable the crop to become well established before weeds begin to germinate (Robertson and Frazier, 1978). Fields with reduced plant populations suffer most by the presence of weeds (Burnside, 1979; Goulden, 1976). However, research has shown that white beans have some ability to compensate for reduced plant stands (Field and Nkumbula, 1986).

Dry edible beans have two basic plant types, determinate (bush) or indeterminate (vining or trailing). Cultivars of a particular market class may be classified according to plant type. In the determinate type, main stem elongation ceases when the terminal flower racemes of the main stem or lateral branches have developed. The indeterminate type will continue to flower and fill pods either simultaneously or alternately as long as temperature and moisture permit growth to occur.

In addition to being classified as either determinate or indeterminate plant types, four plant growth habits have been identified. Type I plants, the only one of the four growth habits that possesses the determinate flowering pattern, have a bush style plant architecture. Plants of Type II growth habit are indeterminate with short, upright vines, a narrow profile, and have three to four stems. Dry beans of Type III and Type IV growth habits also have an indeterminate flowering pattern. The architectural tendency of Type III plants are prostrate and viney while Type IV plants have strong climbing tendencies (Singh, 1982).

Malik et al. (1993) studied three navy bean cultivars in Ontario. They reported that the indeterminate cultivars OAC Laser and OAC Gryphon (Type II and Type III growth habit, respectively) reduced overall weed biomass compared to OAC Sprint (Type I growth habit). The OAC Sprint cultivar ceased vegetative growth at flowering when weeds were still actively growing. The later maturing Type II and III cultivars that continued to grow after flowering were more competitive with weeds than the early maturing Type I cultivar. The major weed species that were present included redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), and green foxtail (*Setaria viridis* L.). The continued growth of the indeterminate cultivars reduced total weed biomass 11 to 35% compared with the determinate cultivar.

In a study conducted in western Nebraska, differences in weed control in determinate and indeterminate great northern varieties were evident. In plots treated with EPTC the densities of redroot pigweed, black nightshade (*Solanum nigrum* L.), and bristly foxtail (*Setaria verticillata* L. Beauv.) at harvest were significantly higher in the determinate variety Great Northern 1140 compared to the indeterminate variety Tara. When these varieties received a preplant application of alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide], black nightshade densities were higher in plots seeded with 'Great Northern 1140' as compared to plots seeded with 'Tara'. Yields of 'Tara' were significantly higher than 'Great Northern 1140' after treatment with either EPTC or alachlor and, under weed free conditions and a long growing season 'Tara' yielded more than 'Great Northern 1140' (Wilson et al., 1980).

Date of Planting

Dry beans should be planted into warm (>55 F), moist soil to obtain a good plant stand. If the soil at planting depth is dry, farmers should wait for a rain rather than planting into dry soil (Erdmann and Adams, 1982). Planting dry beans in May is generally not desirable because the potential for root rot, green regrowth, and erratic yields is increased. Planting after June 30 raises the chance of white mold infection or reduced bean quality from frost damage (Varner, 1999 personal communication).

Date-of-planting trials were conducted in Michigan from 1986 to 1990 (Varner, 1999). Optimum planting dates were found to be June 1 to 10 for full-season beans (>98 days), June 5 to 20 for mid-season beans (91-98 days), and June 10 to 25 for early maturing beans (≤ 90 days). Temperature and rainfall during the critical periods of flowering and pod fill have a direct effect on yield potential. Spacing out planting dates and/or planting varieties with varying maturity dates will stagger the blossom and harvest dates, which in turn spreads out the risk of raising dry beans.

Weed Competition

Dry beans, being a short duration and slow growing crop, suffer more from weed competition than most other row crops (Verma and Bhardwaj, 1963). Weeds that emerge above the bean canopy are the most competitive (Dawson, 1964). Uncontrolled populations of weeds can reduce white bean yields by as much as 70% (Woolley et al., 1993). A number of different factors influence the extent to which weeds affect crop yields. These include weed-related factors such as time of emergence and density, as well as environmental factors

and management practices that affect both crop and weed development (Chikoye et al., 1996.).

The critical period of weed control represents the time interval between two different components (Hall et al., 1992). The first component is the maximum length of time weeds can remain in a crop before losses in yield occur. The second component is the length of time a weed free environment must be maintained to prevent yield reduction (Weaver and Tan, 1983). The critical period for weed control in dry beans is between 3 and 6 weeks after planting (Burnside et al., 1998).

Weeds compete with dry beans for light, nutrients, and water thereby reducing crop yield and economic return (Blackshaw, 1991). Even when weeds are removed with a cultivator from between the rows, weeds remaining in the rows may reduce yields substantially. Noticeable yield differences were seen when cultivation alone was compared to cultivation plus rotary hoeing. In a field trial, the additional weed control gained from the rotary hoeing increased bean yields by 384 pounds per acre one year and 732 pounds the next year (Leep et al., 1982).

Growers in the state of Minnesota identified foxtails (*Setaria* spp.), redroot pigweed, common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters, nightshades (*Solanum* spp.), common cocklebur (*Xanthium strumarium* L.), and wild mustard (*Brassica kaber* (DC.) L.C. Wheeler) as their most competitive weeds (Lamey et al., 1991). Most grasses can be effectively controlled with the graminicides labeled for use in dry beans. Unfortunately, similar success in controlling broadleaf weeds has not been reached (Blackshaw and Esau, 1991).

The problem of nightshades in agriculture has increased greatly over the last 25 years (Ogg and Rogers, 1989). Nightshade species begin germinating two to three weeks after dry beans are planted and continue to germinate through the middle of August (Leep et al., 1982). In a two year study conducted by Blackshaw (1991), as few as 2 hairy nightshade (*Solanum sarrachoides* Sendtner) plants per meter of row reduced yield by an average of 13%. As the density of hairy nightshade increased, plant biomass and seed yield of dry bean was reduced. Dry bean yields in Alberta were reduced by over 80% by hairy nightshade (Basset and Munro, 1985). In addition to causing lower crop yields, nightshade causes harvesting problems, a reduction in crop quality, and the risk of toxicity in a food crop (Ogg and Rogers, 1989).

Common ragweed is a major weed escape in white bean fields throughout Ontario. Chikoye et al. (1996) found that the time of emergence and density of ragweed influenced crop yield. When a population of 1.5 ragweed plants per meter of row emerged with the dry bean crop, 10 to 22% yield loss occurred. When the same density of ragweed seedlings (1.5 plants m⁻¹ of row) emerged at the V3 crop stage, yield reduction was only 4 to 9%. In snap bean (*Phaseolus vulgaris* L.), ragweed that competed with the crop for the first 30 days of crop growth reduced total yield by 30%. When 120 ragweed plants m⁻¹ competed with snap bean for 90 days, yield losses reached 75% (Lamey et al., 1991). Common ragweed decreased snap bean yields more when interference occurred between flower initiation and harvest compared with interference during the period before flowering (Evanylo and Wilson, 1988).

Neary and Majek (1990) determined the maximum amount of time common cocklebur could remain in snap bean and not cause a significant yield loss. Similar to common ragweed, the time in which cocklebur was most competitive with snap beans was between full bloom and harvest. From the time between full bloom and harvest of snap bean, common cocklebur attained 38 and 67% of its total height and weight, respectively. During this same time period the snap beans attained approximately 16% of their total height and 18% of their total weight. Weeds were shorter than snap beans until full bloom at which time they were approximately the same height. Yields were reduced 2 to 55% by weed densities of 0.5 to 8 m⁻² that remained in the crop all season long. If snap beans were kept weed free until the unifoliate stage, up to 4 common cocklebur seedlings per m⁻² could remain in the crop until harvest and not reduce snap bean yield.

Cultivation

Although dry bean herbicide technology continues to progress, the cultivator is still an important part of a weed control program. One cultivation, performed 3 weeks after planting, controlled 68% of broadleaf species. If dry beans were rotary hoed 1 and 2 weeks after planting and then cultivated at 3 and 6 weeks after planting, broadleaf weed control increased to 76%. Mechanical weed control treatments alone controlled only 65% of annual grasses (Burnside et al., 1994). According to a study conducted among Minnesota dry bean growers, grassy weeds are more difficult to control than broadleaf weeds (Lamey et al., 1991). However, growers do have more than a dozen mechanical plus chemical weed

management systems that control grasses in dry bean production fields (Burnside et al., 1994).

It is common practice for farmers to apply preemergence herbicides in a 7 to 10 inch band over each row. Weeds between the rows are then controlled mechanically (i.e. cultivation and rotary hoeing). This practice cuts the cost of chemical weed control by nearly one-third (Leep et al., 1982).

Aside from weed control, cultivation serves a number of other important functions. Most growers cultivate at least once to hill beans sufficiently for pulling at the end of the harvest season. Also, cultivation opens up the soil enabling both water and oxygen to flow more freely to the developing root system (Leep et al., 1982).

Many of the obvious effects of cultivation on a dry bean production system are positive ones. However, the timing of this operation is critical. Once the dry bean plants begin to flower, cultivation should no longer be performed because a large portion of the secondary root system has developed. The majority of these roots are located just below the soil surface. Cultivating after this time will cause the secondary roots to be pruned which reduces the plants' ability to take up water and nutrients. Also, cultivating after this time can cause flower buds to be knocked off by equipment travelling between the rows. In addition, fields should not be cultivated when plants and/or soil are wet to minimize compaction and reduce the chance of spreading disease (Leep et al., 1982).

Chemical Control

In 1979 there were eight herbicides available for use in dry bean production. Herbicide programs used by dry bean farmers today have changed very little since 1979. Of the herbicides applied 20 years ago (Meggitt, 1979), four are still being used today. Currently there are a total of twelve herbicides registered to control weeds in dry beans (Table 1) (Renner and Kells, 1999).

Herbicide application in dry beans became more common in the mid-1960's when it was discovered that dry edible beans were tolerant to EPTC (Eptam) and that EPTC provided good weed control. EPTC controls annual grasses and some annual broadleaf weeds. EPTC must be incorporated immediately after application to avoid volatilization. Trifluralin (Treflan) was introduced a few years after EPTC. Trifluralin controls early season grasses and common lambsquarters (Leep et al., 1982). By the early 1970's the standard chemical weed control practice in dry beans was a tank mixture of these two products. Today over 60% of all the dry bean acres in Michigan receive a preplant incorporated (PPI) application of EPTC + trifluralin (Renner, 1999 personal communication).

There are only a limited number of postemergence (POST) herbicides registered for use in dry beans. This forces growers to rely heavily on preplant incorporated and preemergence (PRE) herbicides for weed control. Herbicides applied PRE may provide inconsistent weed control under less than ideal moisture conditions (Leep et al., 1982). Three of the herbicides that are commonly applied PPI in dry beans include trifluralin, ethalfluralin (Sonalan), and pendimethalin (Prowl). These herbicides are all dinitroanilines and control annual grasses and common lambsquarters. Trifluralin and ethalfluralin also

control redroot pigweed and pendimethalin suppresses velvetleaf (Renner and Kells, 1986 to 1999). The chloroacetamide herbicides applied PPI that are registered for use in dry beans are alachlor (Lasso), metolachlor (Dual), and dimethenamid (Frontier). Metolachlor controls annual grass species and redroot pigweed. Alachlor and dimethenamid control the same weeds as metolachlor plus nightshade species. Metolachlor and dimethenamid can also be applied PRE. Alachlor cannot be applied PRE because of a lack of tolerance in dry beans (Renner and Kells, 1999).

There are three herbicides registered for control of annual grasses and quackgrass postemergence in dry beans. These are sethoxydim (Poast), quizalofop-P-ethyl (Assure II), and clethodim (Select). These are not used on many acres because annual grasses are controlled with soil-applied herbicides. These soil applied 'grass' herbicides also control broadleaf weeds so they are an important component of the weed control program (Meggit, 1977-1985; Renner and Kells, 1986-1999).

The herbicide options to control broadleaf weeds POST are limited to bentazon (Basagran) and imazethapyr (Pursuit). Bentazon controls velvetleaf, common cocklebur, jimsonweed, smartweed, and wild mustard as well as Canada thistle and yellow nutsedge. Imazethapyr controls redroot pigweed, nightshade spp., and wild mustard and can be applied PPI, PRE, or POST. However there is a 40-month crop rotation restriction on the label for sugarbeets. Since a large amount of the acres planted to dry beans are grown in rotation with sugarbeets imazethapyr is not used extensively as a dry bean herbicide. Fomesafen (Reflex) has been used in Michigan for the past 3 out of 4 years under a Section 18 Emergency Use exemption (Renner, 1999 personal communication). Fomesafen provides excellent control

of giant and common ragweed and good control of redroot pigweed and wild mustard (Renner and Kells, 1999)

Due to the diversity of weed species that can be found in the same field, two or more herbicides are often tank-mixed to achieve the desired spectrum of weed control (Rhodes, Jr. and Coble, 1984). It has been reported by several researchers that when a variety of herbicides are applied in combination with each other overall efficacy can be reduced (Beste and Schreiber, 1972; Dortenzio and Norris, 1979; Selleck and Baird, 1981). The basis for a number of herbicide antagonistic interactions has been a reduction in absorption and/or translocation (Hamill et al., 1972; O'Donovan and O'Sullivan, 1982; Todd and Stobbe, 1980). It has been postulated that the Na-ion in the bentazon formulation inhibits absorption of some herbicides (Rhodes Jr. and Coble, 1984; Wanamarta et al., 1989).

In 1991 and 1992 a postemergence application of imazethapyr at 53 g ha⁻¹ to 'Olathe' pinto beans delayed physiological maturity by 8 and 15 days, respectively, compared to the untreated control. Though pinto bean yields were not reduced compared to the untreated control, the number of days to full maturity increased. Maturity of the beans was not delayed when imazethapyr (53 g ha⁻¹) was tank-mixed with bentazon (840 g ha⁻¹). The tank mixture of bentazon + imazethapyr decreased the amount of injury and increased the chlorophyll a content, a quantitative measure of bean chlorosis, compared with imazethapyr alone (Bauer et al., 1995). Further studies conducted by Bauer et al. (1995) showed that ¹⁴C-imazethapyr absorption by 'Olathe' pinto beans decreased by 40% and translocation from the treated leaf was reduced by 50% when ¹⁴C-imazethapyr was tank-mixed with bentazon compared to ¹⁴C-imazethapyr applied alone. The safening effect observed when imazethapyr and

bentazon were applied in combination was attributed to decreased absorption and translocation by the dry beans.

Chloroacetamide Herbicides

The chloroacetamide herbicides are commonly used to control annual grasses, small-seeded broadleaf weeds, and yellow nutsedge (*Cyperus esculentus* L.) (Anonymous, 1992). The mode of action of this group of herbicides is not completely understood. Deal and Hess (1980) have concluded that growth inhibition of plants caused by herbicides of the chloroacetamide group results from an inhibition of both cell division and cell enlargement.

The first chloroacetamide herbicide that was registered for application in dry edible beans was alachlor in 1978. It was applied at 2.0 lbs ai/acre in a tank mixture banded PRE with chloramben (Amiben). Use of alachlor in recent years has decreased and replaced by metolachlor and more recently dimethenamid. Metolachlor was registered for use in dry beans prior to the 1983 field season. Metolachlor controlled a weed spectrum similar to alachlor, but dry beans were more tolerant to metolachlor. As metolachlor use increased in the corn and soybean market, its use also increased in dry beans. In 1996 a third chloroacetamide, dimethenamid, was registered for use in dry beans. All three herbicides control annual grasses but the spectrum of broadleaf weed control differs. Alachlor and dimethenamid provide good control of redroot pigweed and Eastern black nightshade. Metolachlor controls redroot pigweed equally well but is less effective on Eastern black nightshade (Renner and Kells, 1986-1999).

Cultivars of many different crops have exhibited variable tolerance levels to chloroacetamides (Renner et al., 1988; Driver et al., 1992; Edwards et al., 1976; Sniper et al., 1987; Stephenson et al., 1976). In eight years of field testing, snap bean tolerance to alachlor ranged from outstanding to poor even with similar rates and applications methods. The severity of alachlor injury to snap beans is affected by a number of different factors that may interact. Soil type, temperature, rainfall, placement of the herbicide, and other soil factors appear to be important factors influencing tolerance in the field (Cieslar and Binning, 1974; Putnam and Rice, Jr., 1979).

Alachlor injured snap beans at low and high temperature regimes with day and night temperatures of 16 and 21 C or 27 and 32 C, respectively. The type and severity of the injury differed at the two temperature regimes. At 16 to 21 C the injury appeared much earlier and was much more severe than injury at the high temperature. Plants at the low temperature displayed leaf crinkling or fusion of the leaf margins. At the high temperature plants exhibited cupping and marginal chlorosis (Putnam and Rice, 1979). Penner and Graves (1972) found that 3.32 kg/ha (two times the normal rate) of alachlor caused injury to navy beans at 20 and 25 C but not at 30 C. Navy bean injury by alachlor at the lower temperatures may explain the occasional injury observed in the field.

Putnam and Rice (1979) reported that twice as much alachlor was taken up by snap bean at 27 to 32 C compared with 16 to 21 C. This increase in uptake may be due to increased growth rates and higher transpiration rates at higher temperatures. At the higher temperature regime the majority of the alachlor remained in the plant roots. At the lower

temperature the herbicide was distributed throughout the plants with no one part of the plant accumulating a significantly greater amount of alachlor than any other plant part except the cotyledons in which no alachlor was found. The percentage remaining as parent alachlor was greater at the lower temperature regime. Therefore lower temperatures could result in more crop injury.

Herbicides become more available for plant uptake as soil moisture increases (Jones et al., 1990; Tripp and Baldwin, 1988; Wehtje et al., 1987). Metolachlor uptake increased up to three-fold in grass species when soil moisture increased from 45 to 100% (Gerber et al., 1974.). In a field experiment evaluating different soybean cultivars neither dimethenamid or metolachlor reduced soybean yield when applied at normal use rates with either optimum or excessive moisture. However, injury occurred when dimethenamid or metolachlor were applied above recommended rates and excessive moisture conditions persisted. Some soybean cultivars were more sensitive to dimethenamid compared with metolachlor, but to reveal these differences a 3X herbicide rate combined with excessive moisture were required (Osborne et al., 1992a). Other soybean studies have revealed that the magnitude of soybean injury is often greater with dimethenamid compared with metolachlor (Osborne et al., 1992b). There are also differences in the site of uptake of chloroacetamide herbicides in plants. Application of metolachlor in the shoot zone of corn (*Zea mays*) and barley (*Hordeum vulgare* L.) decreased plant height, emergence, and dry weight but when metolachlor was applied in the root or seed zone there was no detectable effect. When metolachlor was applied in all three zones corn and barley emergence, height,

and dry weight was always reduced (Pillai et al., 1979). Putnam and Rice (1979) demonstrated that snap bean injury decreased when alachlor was applied preplant incorporated compared to a preemergence surface treatment. This increase in crop safety was attributed to the reduction of herbicide in the zone of emergence, thus less alachlor was absorbed by the bean epicotyl. Early uptake of alachlor in snap bean occurred primarily via the hypocotyl portion of the emerging seedling (Rice, Jr. and Putnam, 1980).

The organic matter and clay content affect the biological activity of alachlor and metolachlor (Weber and Peter. 1982). Soil adsorption of herbicides is inversely related to herbicide mobility (Weber and Best, 1972.). Eshel (1969) reported that alachlor was adsorbed by soil colloids and thus partially inactivated in soils high in clay or organic matter. One ppm of alachlor reduced the fresh weight of sorghum by 50% in a sand, sandy loam, and clay loam soil. However 2 ppm of alachlor was needed to cause the same amount of phytotoxicity to sorghum in a clay soil (Eshel, 1969).

The most prevalent way in which chloroacetamides dissipate from the soil is by microbial decomposition. The most favorable environment for metolachlor degradation is warm, moist soils (Saxena et al., 1987). Volatilization plays a significant role in dissipation only when the soil is wet and the weather is windy (Bestman and Deming, 1974). Metolachlor is the most persistent chloroacetamide. The fifty percent dissipation time (DT_{50}) in field studies with metolachlor was 108 days (Saxena et al., 1987). This herbicide is mainly broken down by microbial transformations. Repeated annual applications of alachlor

or metolachlor does not increase the rate of degradation, thus microorganisms are not thought to adapt and cause enhanced degradation (Kotoula-Syke, 1997).

LITERATURE CITED

- Anonymous. 1992. SAN 582G experimental herbicide: A technical overview. Sandoz Agro, Inc., Des Plaines, IL 60018.
- Basset, I.J., and D.B. Munro. 1985. The biology of Canadian weeds. Can. J. Plant Sci. 65:401-414.
- Bauer, T.A., K.A. Renner, and D. Penner. 1995. 'Olathe' pinto bean (*Phaseolus vulgaris*) response to postemergence imazethapyr and bentazon. Weed Sci 43:276-282.
- Beste, C.E. and M.M. Schreiber. 1972. RNA synthesis as the basis for EPTC and 2,4-D antagonism. Weed Sci. 20:8-11.
- Bestman, G.B. and J.M. Deming. 1974. Dissipation of acetanilide herbicides from soils. Agron. J. 66:308-311.
- Blackshaw, R.E. 1991. Hairy nightshade (*Solanum sarrachoides*) interference in dry beans (*Phaseolus vulgaris*). Weed Sci. 39:48-53.
- Blackshaw, R.E. and R. Esau. 1991. Control of annual broadleaf weeds in pinto beans (*Phaseolus vulgaris*). Weed Technol. 5:532-538.
- Burnside, O.C. 1979. Soybean (*Glycine max*) growth as affected by weed removal, cultivar and row spacing. Weed Sci. 27:562-565.
- Burnside, O.C., W.H. Ahrens, B.J. Holder, M.J. Wiens, M.M. Johnson, and E.A. Ristau. 1994. Efficacy and economics of various mechanical plus chemical weed control systems in dry beans (*Phaseolus vulgaris*). Weed Technol. 8:238-244.
- Burnside, O.C., M.J. Wiens, B.J. Holder, S. Weisberg, E.A. Ristau, M.M. Johnson, and J.H. Cameron. 1998. Critical periods for weed control in dry beans (*Phaseolus vulgaris*). Weed Sci. 46:301-306.
- Chikoye, D., L.A. Hunt, and C.J. Swanton. 1996. Simulation of competition for photosynthetically active radiation between common ragweed (*Ambrosia artemisiifolia*) and dry bean (*Phaseolus vulgaris*). Weed Sci. 44:545-554.
- Cieslar, B. and L.K. Binning. 1974. Translocation of ¹⁴C-alachlor in lima beans as related to phytotoxicity. Proc. North Cent. Weed Control Conf. 29:323.

- Dawson, J.H. 1964. Competition between irrigated field beans and annual weeds. *Weeds* 12:206-208.
- Deal, L.M. and F.D. Hess. 1980. An analysis of the growth inhibitory characteristics of alachlor and metolachlor. *Weed Sci.* 28:168-175.
- Dortenzio, W.A. and R.F. Norris. 1979. Antagonistic effects of desmidipham on diclofop activity. *Weed Sci.* 27:539-544.
- Driver, J.E., T.F. Peeper, and A.C. Guenzi. 1992. In vitro selection for increased wheat tolerance to metsulfuron. *Proc. South. Weed Sci. Soc.* 45:316.
- Edwards, C.J., Jr., W.L. Barrentine, and T.C.Kilen. 1976. Inheritance of sensitivity of soybean cultivars to metribuzin. *Crop Sci.* 16:119-120.
- Erdmann, M.H., and M.W. Adams. 1982. Row width, plant spacing and planting depth. p. 124-133. In L.S. Robertson and R.D. Frazier (ed.) *Dry bean production- principles & practices*. Michigan State Univ. Coop. Ext. Serv. Bull. E-1251.
- Eshel, Y. 1969. Phytotoxicity, leachability, and site of uptake of 2-chloro-2,6-diethyl-*N*-(methoxymethyl) acetanilide. *Weed Sci.* 17(4):441-444.
- Evanylo, G.K., and H.P. Wilson. 1988. Common ragweed in snap beans. *Abstr. Proc. Northeast. Weed Sci. Soc.* 42:209.
- Field, R.J. and S. Nkumbula. 1986. Green beans (*Phaseolus vulgaris* cv. Gallatin 50): Effects of plant population and density on yield and quality. *New Zealand J. Exp. Agric.* 14:435-442.
- Gerber, H.R., G. Muller and L. Ebner. 1974. CGA 24705, a new grass killer herbicide. *Roac. 12th Br. Weed Control Conf.* 3:787-794.
- Goulden, D.S. 1976. Effect of plant population and row spacing on yield and components of yield in navy beans (*Phaseolus vulgaris*). *New Zealand J. Exp. Agric.* 4:177-180.
- Hall, M.R., C.J. Swanton, and G.W. Anderson. 1992. The critical period of weed control in grain corn (*Zea mays*). *Weed Sci.* 40:441-447.
- Hamill, A.S., L.W. Smith, and C.M. Seitzer. 1972. Influence of phenoxy herbicides on picloram uptake and phytotoxicity. *Weed Sci.* 20:226-229.

- Jones, R.E., Jr., P.A. Banks, and D.E. Radcliffe. 1990. Alachlor and metribuzin movement and dissipation in a soil profile as influenced by soil surface condition. *Weed Sci.* 38:589-597.
- Kotoula-Syke, E., K.K. Hatzios, D.F. Berry, and H.P. Wilson. 1997. Degradation of acetanilide herbicides in history and nonhistory soils from eastern Virginia. *Weed Technol.* 11:403-409.
- Lamey, H.A., R.K. Zollinger, D.K. McBride, R.C. Venette, and J.R. Venette. 1991. Production problems and practices of northwest dry bean growers in 1989. *North Dakota Farm Res.* 49(2):17-24.
- Leep, R.H., W.F. Meggitt, and M.H. Erdmann. 1982. Weed Control. p. 152-157. In L.S. Robertson and R.D. Frazier (ed.) *Dry bean production- principles & practices*. Michigan State Univ. Coop. Ext. Serv. Bull. E-1251.
- Malik, V.S., C.J. Swanton, and T.E. Michaels. 1993. Interaction of white bean (*Phaseolus vulgaris* L.) cultivars, row spacing, and seeding density with annual weeds. *Weed Sci.* 41:62-68.
- Meggitt, W.F. 1977-1985. Weed control guide for field crops. Michigan State Univ. Coop. Ext. Serv. Bull. E-434.
- Monks, D.W. and L.R. Oliver. 1988. Interactions between soybean (*Glycine max*) cultivars and selected weeds. *Weed Sci.* 36:770-774.
- Neary, P.E., and B.A. Majek. 1990. Common cocklebur (*Xanthium strumarium*) interference in snap beans (*Phaseolus vulgaris*). *Weed Technol.* 4:743-748.
- O'Donovan, J.T. and P.A. O'Sullivan. 1982. The antagonistic action of 2,4-D and bromoxynil on glyphosate phytotoxicity to barley (*Hordeum vulgare*). *Weed Sci.* 30:30-34.
- Ogg, A.G. and B.S. Rogers. 1989. Taxonomy, distribution, biology, and control of black nightshade (*Solanum Nigrum* L.) and related species in the United States. *Weed Sci.* 29:27-32.
- Osborne, B.T., D.R. Shaw, and R.L. Ratliff. 1992a, Soybean cultivar tolerance to SAN 582H and metolachlor as influenced by soil moisture. *Weed Sci.* 43:288-292.
- Osborne, B.T., D.R. Shaw, R.L. Ratliff, and G.P. Ferguson. 1992b. Soybean cultivar tolerance to SAN 581 and metolachlor as influenced by soil moisture. *Proc. South. Weed Sci. Soc.* 45:52.

- Penner D. and D. Graves. 1972. Temperature influence on herbicide injury to navy beans. *Agron. J.* 64:30.
- Pillai, P., D.E. Davis, and B Truelove. 1979. Effects of metolachlor on germination, growth, leucine uptake, and protein synthesis. *Weed Sci.* 27:634-637.
- Putnam, A.R. and R.P. Rice, Jr. 1979. Environmental and edaphic influences on the selectivity of alachlor on snap beans (*Phaseolus vulgaris*). *Weed Sci.* 27:570-574.
- Renner, K.A., and J.J. Kells. 1986-1999. Weed control guide for field crops. Michigan State Univ. Coop. Ext. Serv. Bull. E-434.
- Renner, K.A., W.F. Meggitt, and D. Penner. 1988. Response of corn (*Zea mays*) cultivars to imazaquin. *Weed Sci.* 36:625-628.
- Rhodes, G.N., Jr. and H.D. Coble. 1984. Influence of bentazon on absorption and translocation of sethoxydim in goosegrass (*Eleusine indica*). *Weed Sci.* 32:595-597.
- Rice, R.P., Jr. and A.R. Putnam. 1980. Temperature influences on uptake, translocation, and metabolism of alachlor in snap beans (*Phaseolus vulgaris*). *Weed Sci.* 28(2):131-134.
- Robertson, L.S. and R.D. Frazier (eds.). 1978. Dry Bean Production - Principles & Practices. Michigan State Univ. Ext. Bull. E-1251. East Lansing, U.S.A.
- Saxena, A., R. Zhang, and J.M. Bollag. 1987. Microorganisms capable of metabolizing the herbicide metolachlor. *Appl. Environ. Microbiol.* 53:390-396.
- Selleck, G.W. and D.D. Baird. 1981. Antagonism with glyphosate and residual herbicide combinations. *Weed Sci.* 29:185-190.
- Singh, S.P. 1982. A key for identification of different growth habits of *Phaseolus vulgaris* L. Annual Rpt. Bean Improv. Coop. 25:92-96.
- Sniper, C.E., J.E. Street, and D.L. Boykin. 1987. Influence of flood interval and cultivar on rice (*Oryza sativa*) tolerance to fenoxaprop. *Weed Sci.* 35:842-845.
- Stephenson, G.R., J.E. McLeod, and S.C. Phatak. 1976. Different tolerance of tomato cultivars to metribuzin. *Weed Sci.* 24:161-165.
- Todd, B.G. and E.H. Stobbe. 1980. The basis of the antagonistic effect of 2,4-D on diclofop-methyl toxicity to wild oat (*Avena fatua*). *Weed Sci.* 28:371-377.

Tripp, T.N. and F.L. Baldwin. 1988. Effect of excessive precipitation on soybean injury from imazaquin and chlorimuron. *Weed Sci. Soc. Am. Abstr.* 28:39.

Verma, R.D and R.B.L. Bhardwaj. 1963. Control of farm weeds by use of weedicides. p. 6 New Delhi, Indian Council of Agricultural Research.

Voysest, O. and M. Dessert. 1991. Bean cultivars: classes and commercial seed types. pp. 119-162. *In* A. van Schoonhoven & O. Voysest (eds.), *Common beans: Research for crop improvement*. C.A.B. Int., Wallingford, U.K. & CIAT, Cali, Colombia.

Wanamarta, G., D. Penner, and J.J. Kells. 1989. The basis of bentazon antagonism on sethoxydim absorption and activity. *Weed Sci.* 37:400-404.

Weaver, S.E. and C.S. Tan. 1983. Critical period of weed interference in transplanted tomatoes (*Lycopersicon esculentum*): growth analysis. *Weed Sci.* 31:476-481.

Weber, J.B. and J.A. Best. 1972. Activity and movement of 13 soil-applied herbicides as influenced by soil reaction. *Proc. South Weed Sci. Soc.* 25:403-413.

Weber, J.B. and C.J. Peter. 1982. Adsorption, bioactivity, and evaluation of soil tests for alachlor, acetochlor, and metolachlor. *Weed Sci.* 30:14-20.

Wehtje, G., R. Dickens, J.W. Welcut, and B.F. Hajek. 1987. Sorption and mobility of sulfometuron and imazapyr in five Alabama soils. *Weed Sci.* 35:858-864.

Wilson, R.G., Jr., G.A. Wicks, and C.R. Fenster. 1980. Weed control in field beans (*Phaseolus vulgaris*) in Western Nebraska. *Weed Sci.* 28(3):295-299.

Woolley, B.L., T.E. Michaels, and C.J. Swanton. 1993. The critical period of weed control in white bean (*Phaseolus vulgaris* L.). *Weed Sci.* 41:180-184.

Table 1. Herbicides registered for use on dry beans.

1979	1999
1. alachlor *	1. alachlor
2. trifluralin *	2. trifluralin
3. EPTC *	3. EPTC
4. bentazon *	4. bentazon
5. dinoseb	5. ethalfluralin
6. chloramben	6. pendimethalin
7. dinitramine	7. metolachlor
8. profluralin	8. dimethenamid
	9. imazethapyr
	10. sethoxydim
	11. clethodim
	12. quizalofop-P-ethyl

* Herbicides currently registered for use in dry beans

Chapter 2

TOLERANCE OF DRY BEAN CLASSES AND CULTIVARS TO DIMETHENAMID AND METOLACHLOR

KYLE W. POLING

ABSTRACT

Dimethenamid was applied preemergence to 14 dry bean cultivars from the navy, black, pinto, kidney, cranberry, and small red classes in the greenhouse to determine if there were differences in tolerance between classes and/or cultivars. Navy and black bean cultivars were injured from dimethenamid preemergence at 2.1 kg ha⁻¹. 'Vista' and 'Schooner' navy beans were injured more than 'Avanti' navy bean, and 'Midnight' black bean was injured more than the 'T-39' cultivar. Kidney, cranberry, and small red cultivars were not injured. Kidney and cranberry cultivar emergence was slower (40-42 h) compared to small seeded cultivars in the navy and black bean classes (27-29 h). In the field, metolachlor at 2.9 kg ha⁻¹ (twice the recommended rate) and dimethenamid at 1.3 kg ha⁻¹ caused similar injury to navy and black bean cultivars.

The F₃ generation of a cross between a 'Huron' navy bean and a 'Matterhorn' great northern bean was planted in the field to determine whether there was a relationship between the seed size of dry edible beans and the tolerance of dry beans to dimethenamid. Dimethenamid at 1.3 kg ha⁻¹ was applied to 98 different F₃ lines. The correlation coefficient

between seed size and visual leaf area reduction caused by dimethenamid applied postemergence was significant ($r=-0.41$). This significant r value supports the hypothesis of a negative correlation between seed size and injury resulting from a postemergence application of dimethenamid.

INTRODUCTION

A dry edible bean market class is a category that classifies a dry edible bean according to size and color of seed. Navy beans are white in color and are considered small in size (17-22 g/100 seeds) relative to other classes of dry beans. Black (or black turtle) beans, which genetically are closely related to navy beans, are of similar size to navy beans with a black seed coat. The pinto class of dry beans is tan with dark brown mottling and has a medium seed size (38-42 g/100 seeds). Pinto beans are distantly related to both navy and black beans. Great northern and pink beans are similar in size and shape to the pinto class but with a brilliant white and pink seed coat, respectively. The small red or red Mexican market class is a red bean and is slightly smaller than a pinto bean. The pinto, great northern, pink and small red market classes are all strongly related genetically. Cranberry dry beans have a white-red mottled seed coat and are medium-large in size (45-55 g/100 seeds). Light red and dark red kidney beans are the largest seed of all the market classes (50-60 g/100 seeds). The two kidney bean classes and cranberry market class are closely related (Voysest and Dessert, 1991).

Acreage of each class of dry beans grown can vary dramatically from year to year. This fluctuation is a direct effect of the price a grower can sell a bag (100 lbs) of dry beans for in the months preceding planting. Since navy beans and black beans are so well suited for the climate in Michigan, these market classes account for the majority of dry beans grown. In 1997 Michigan farmers produced 5,033,000 cwt of dry beans ranking the state as the second largest producer in the country. Almost half (48%) of the total acres planted in

Michigan in 1997 were of the navy bean class and 25% were black beans. The following year the acres planted in the state declined from 315,000 to 300,000. The number of navy bean acres accounted for 28% of the total dry beans grown in 1998 while black bean acreage increased greatly to nearly 42% (Varner, 1991 personal communication).

Differences in herbicide tolerance exist between dry bean market classes and varieties and vary from one year to the next. In 1993 'Fleetwood' navy bean sustained more injury from EPTC than 'Mayflower' navy, 'Sacramento' light red kidney, 'T-39' and 'UI-906' black, 'Cranberry-74', and 'Marquis' great northern bean (Urwin et al., 1996). The following year 'Mayflower' navy, 'Sacramento' light red kidney, and 'Marquis' great northern were injured more by EPTC compared to 'Cranberry-74' (Urwin et al., 1996). In other research, imazethapyr was more injurious to the light red kidney cultivar 'Sacramento' and pinto cultivar 'Agate' in 1988 compared to 'Beryl' and 'GN1140' great northern or 'UI 114' and 'Olathe' pinto cultivars (Wilson and Miller, 1991). In 1989 however, injury from imazethapyr was greater to 'Olathe' pinto bean compared with 'Sacramento' light red kidney bean. Bauer et al. (1995) reported greater injury to 'Olathe' pinto from imazethapyr compared to 'Sierra' pinto bean.

Objectives important in breeding dry beans are seed yield, maturity for the area of production, resistance to lodging and shattering, plant architecture, seed quality, tolerance to stress environments, disease resistance, insect resistance and processing quality (Andersen and Robertson, 1982). Desirable traits that are controlled by a single gene can be transferred from one cultivar to another through a succession of backcrosses (Poehlman and Sleper,

1995). For traits that are quantitatively inherited, such as lodging resistance, only one or two backcrosses are performed to combine genes for the desired character into another cultivar (Poehlman and Sleper, 1995). Imazethapyr tolerance in pinto bean appears to be a highly heritable trait, but under quantitative control which suggests that individual plant selection for tolerance would not be feasible (Bauer et al. 1995).

The objectives of our research were (1) to determine if dry bean classes and/or cultivars differed in their susceptibility to dimethenamid or metolachlor and (2) to determine if there was a correlation between seed size and dry bean injury from dimethenamid.

MATERIALS AND METHODS

Greenhouse Study. Dry edible bean tolerance to the herbicide dimethenamid was evaluated in the greenhouse. The experiment was conducted in a completely randomized design with four replications and was repeated in time. Dimethenamid was applied at 0 and 2.1 kg ai ha⁻¹ to 'Vista', 'Schooner', 'Newport', and 'Avanti' navy beans, 'Bill Z', 'Othello' and 'Maverick' pinto beans, 'T-39' and 'Midnight' black beans, 'Montcalm' and 'California Light Red' kidney beans, 'Michigan Improved' and 'Taylor Hort' cranberry beans, and 'Rufus' small red beans. Dry bean seeds were planted at a depth of 2.5 cm in pots containing a Spinks loamy sand (Psammentic Hapludalfs, sandy, mixed mesic) 86% sand, 10% silt and 4% clay with a pH of 6.5 and 1% organic matter. In a preliminary study twice that of the recommended rate was needed to induce significant visual injury. Dimethenamid was

applied at twice the recommended rate determined by soil texture and organic matter to induce significant visual injury (determined in preliminary study).

Injury ratings were recorded at the unifoliate, 1st trifoliate and 3rd trifoliate growth stages of the dry beans. Injury was determined by visually evaluating dry bean injury on a scale from 0 (no injury) to 100% (plants were dead). Upon reaching the 3rd trifoliate growth stage, plants were cut off at the soil surface and leaf area measured with a LI-3000 portable area meter (LI-COR, Lincoln, Nebraska). The percent leaf area reduction was calculated by dividing the leaf area of each plant by the mean leaf area of plants from the untreated control of the same cultivar. Harvested plants were then dried and weights recorded.

Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed means are presented because square root transformation did not alter interpretation of the data. Statistical analysis revealed no experimental run interactions, so the data were combined and are reported as means of the two experiments.

Emergence Study. A greenhouse study was conducted to determine the time to emergence for different classes of dry beans. The same 14 cultivars as listed in the previous study were evaluated. Dry beans were planted by placing seed horizontally at a depth of 2.5 cm in pots containing a Spinks loamy sand soil with 1% organic matter and pH of 6.5. The experiment was arranged in a completely randomized design with four replications and was repeated in time.

Environmental conditions in the greenhouse were maintained at $27\text{ C} \pm 4\text{ C}$, and plants were grown in a 16 h photoperiod of natural light supplemented with incandescent lighting of $1000\text{ uE m}^{-2}\text{s}^{-1}$. The time (in h) from seed planting until the crook stage was recorded. Plants were evaluated every 12 hours. The hypocotyl diameter was also measured at the crook stage.

Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed means are presented because square root transformation did not alter interpretation of the data. Statistical analysis revealed no experimental run interactions, so the data were combined and are reported as means of the two experiments.

Field Screen. A field study was conducted at the Saginaw Valley Bean & Sugar Beet Research Farm in 1998 and 1999 to evaluate the tolerance of navy and black bean cultivars to dimethenamid and metolachlor. In 1998 the soil at the field site was a Misteguay silty clay loam (Aeric Haplaquept, fine, mixed (calcareous), mesic), 9% sand, 45% silt, and 46% clay with a pH of 8.0 and 1.9 % organic matter. The soil in 1999 was a Misteguay silty clay loam (14% sand, 47% silt, and 39% clay) with a pH of 7.8 and 2.6% organic matter. The field was moldboard plowed in the fall prior to the initiation of each study and then tilled with a field cultivator to prepare the seedbed in the spring prior to planting. 'Vista', 'Schooner', and 'Newport' navy beans and 'Midnight' and 'T-39' black beans were evaluated. These cultivars are widely grown in Michigan and had shown differential tolerance to dimethenamid and metolachlor in the greenhouse study.

Dry beans were planted in 71 cm rows on June 1 in 1998 and 1999. Plots were four rows wide by 10 m long. Dimethenamid at 1.3 kg ai ha⁻¹ and 2.6 kg ai ha⁻¹ and metolachlor at 2.9 kg ai ha⁻¹ were applied to each cultivar. Untreated control plots were included for each cultivar. Herbicides were applied preemergence with a tractor mounted compressed-air sprayer with 8003 flat fan spray tips at 177 L ha⁻¹ and 207 kPa. Plots, measuring 2.8 m by 10 m, were organized in a split block design and were replicated three times.

Dry bean injury for each variety was measured visually by recording the percent leaf area reduction at the unifoliate, 1st trifoliate and 3rd trifoliate growth stages. Injury was measured on a scale of 0 (no leaf area reduction) to 100 (total plant defoliation). In addition three plants were randomly chosen from the middle two rows of each plot at each evaluation date, cut off at the soil surface, and leaf area (cm²) measured with a LI-3000 portable area meter (LI-COR, Lincoln, Nebraska). Plots were visually evaluated when approximately 66% of the leaves in the untreated control plots had turned yellow to assess dry bean maturity. When dry beans reached full maturity, 4.6 m of the middle two rows were hand harvested and threshed with a stationary thresher. Yields were measured in kg ha⁻¹ and were adjusted to 18% moisture.

Data were subjected to ANOVA. Visual injury ratings, leaf area, maturity, and yields were compared within years using Fisher's protected LSD test at $P \leq 0.05$. Nontransformed means are presented because square root transformation did not alter interpretation of the data. Data is presented separately by years because of a significant herbicide by year

interactions. In 1998 there was a variety by herbicide interaction for visual injury ratings, leaf area measurements, and seed yield so data is presented separately by variety.

F₃ Study. A field study was conducted to determine the relationship between seed size of dry edible beans and the tolerance to dimethenamid. Dry beans from the F₂ generation of a cross between a 'Huron' navy bean and a 'Matterhorn' great northern bean were grown in the greenhouse. This cross was initially made to breed white mold (*Sclerotinia sclerotiorum*) tolerance from the 'Huron' cultivar into the 'Matterhorn' cultivar. Upon reaching full maturity seed was harvested from each plant separately. The F₂ generation was segregating thus the offspring (F₃) of different plants had different seed sizes. In our greenhouse research 'Matterhorn' great northern displayed 10% injury from 2.1 kg ha⁻¹ dimethenamid while injury to 'Huron' navy reached 90% 10 DAP (data not presented).

A field experiment was conducted in 1999 at the Saginaw Valley Dry Bean and Sugar Beet Research Farm, Saginaw, Michigan. The soil type was a Misteguay silty clay loam (14% sand, 47% silt, and 39% clay) with a pH of 7.8 and 2.6% organic matter. The experimental design was a randomized complete block with two replications. There were 98 different F₃ lines in each replication. The parent lines, 'Huron' navy beans and 'Matterhorn' great northern beans, were included in each replication to compare the herbicide tolerance in the F₃ lines to the tolerance in the parent lines. Plots were one row (56 cm) by 6.1 m. Dimethenamid was applied PRE at 2.6 kg ha⁻¹, which is twice the recommended rate, to the plots. Dry beans were not injured from dimethenamid preemergence due to a lack of rainfall. Therefore, dimethenamid at 1.3 kg ha⁻¹ was applied

POST at the 3rd trifoliate growth stage. Injury was visually evaluated at 7 and 14 days after postemergence treatment. When dry beans reached full maturity, each plot was hand harvested and threshed with a stationary thresher. Seed size (g 100 seed⁻¹) was measured for each plot.

A correlation of the seed size (g 100 seeds⁻¹) with visual injury that resulted from dimethenamid postemergence was analyzed using Statistical Analysis System (SAS Institute, 1996).

RESULTS AND DISCUSSION

Greenhouse Study. Dimethenamid PRE at the 2X rate injured ‘Schooner’ and ‘Vista’ navy bean cultivars more than it injured the ‘Avanti’ cultivar, when evaluated at the 1st and 3rd trifoliate growth stages (Table 1). The ‘Bill Z’ pinto and ‘Midnight’ black bean cultivars were injured more than the other cultivars within the pinto and black bean classes, respectively (Table 1). The leaf area reduction of ‘Bill Z’ (61 %) was significantly greater than that of the ‘Othello’ and ‘Maverick’ pinto beans at the 3rd trifoliate growth stage. The leaf area of ‘Midnight’ and ‘T-39’ black beans was reduced by 88 and 52%, respectively, from dimethenamid PRE. Injury to kidney, cranberry and small red bean was less than 7% and the reduction in leaf area was not significant. A reduction in leaf area could delay maturity or reduce seed yield since the development of the plants would be reduced while the dry beans metabolized the herbicide.

Emergence Study. Under the conditions of adequate moisture, temperature of $27\text{ C} \pm 4\text{ C}$, and 16 h photoperiod ‘Schooner’ and ‘Avanti’ navy bean , as well as the pinto and black bean cultivars emerged faster in the greenhouse than the kidney, cranberry, and small red varieties. ‘California Light Red’ kidney had a slower time to emergence (crook stage) than the ‘Montcalm’ cultivar (Table 2). All other cultivars had similar times to crook stage as other cultivars within the same dry bean class (Table 2). The time of dry bean emergence in the greenhouse is similar to the time of emergence in the field (Kelly, 1999 personal communication), although emergence time may vary by seed lot and temperature conditions. Slower emergence may allow a longer time period for dry bean hypocotyl exposure to herbicides

The hypocotyl diameters of the kidney and cranberry varieties were significantly greater than the cultivars within the navy, pinto, black, and small red classes (Table 2). If a dry bean with a small hypocotyl diameter (<29 mm) absorbed a similar amount of herbicide as one with a large hypocotyl diameter (>40 mm), the internal herbicide concentration would be higher in the dry bean with the small hypocotyl. Increased internal herbicide concentration could account for greater navy and black bean injury from dimethenamid and metolachlor.

There was a trend in the time required for emergence to increase as hypocotyl diameter increased. Navy and black bean varieties with hypocotyl diameters less than 29 mm emerged 83 to 91 h after planting. Kidney and cranberry beans (hypocotyl diameter greater than 40 mm) reached the crook stage 95 to 105 h after planting.

Small seed size may contribute to quicker emergence which would reduce the time of hypocotyl exposure to herbicide-treated soil. However, the magnitude of difference in time of emergence was low (22 h) between all dry bean classes. Thus susceptibility of navy and black beans to dimethenamid and metolachlor may not be related to the length of time the bean hypocotyl is exposed to herbicide, but may be related to the smaller diameter of the navy and black bean hypocotyls resulting in an increase in internal concentration.

Field Screen. In 1998 dimethenamid at the 2X rate (2.6 kg ha^{-1}) caused greater injury to the 'Vista', 'Schooner', and 'Avanti' navy beans and 'Midnight' black bean compared with the 1X rate of dimethenamid when evaluated at the 1st trifoliolate growth stage (Table 3). There were no differences in injury to the other cultivars from the two rates of dimethenamid. The leaf area of 'Vista', 'Schooner', 'Newport', and 'Midnight' was significantly reduced by dimethenamid at the 2.6 kg ha^{-1} rate compared to the untreated control (Table 3). Leaf area of 'Newport' was reduced by dimethenamid at 1.3 kg ha^{-1} . The injury to the five dry beans cultivars from metolachlor at the 2X rate (2.9 kg ha^{-1}) was similar to that of dimethenamid at the 1X rate (1.3 kg ha^{-1}). Only the leaf area of 'Newport' navy bean was reduced by metolachlor. In 1998 dimethenamid at 2.6 kg ha^{-1} delayed maturity of 'Schooner' and 'Newport' navy bean compared to the untreated control (Table 4). Applications of dimethenamid or metolachlor did not reduce the seed yield of any of the five cultivars compared to the untreated control.

In 1999 there was less injury to dry beans from dimethenamid. Dimethenamid at 2.6 kg ha^{-1} was more injurious to all cultivars except 'Vista' compared to dimethenamid at 1.3 kg ha^{-1} .

kg ha⁻¹ (Table 5). Dimethenamid at 1.3 kg ha⁻¹ and metolachlor at 2.9 kg ha⁻¹ caused similar visual injury to the dry bean cultivars. None of the herbicide applications reduced the leaf area compared with the untreated control at the 1st trifoliolate growth stage (Table 5). However, all herbicide applications caused the maturity of the ‘Newport’ cultivar to be delayed, and dimethenamid at 1.3 and 2.6 kg ha⁻¹ delayed maturity of ‘Schooner’ navy bean (Table 5). There were however no differences in seed yield between the untreated control plots and those treated with herbicide (Table 5).

F₃ Study. Dimethenamid PRE did not injure any F₃ line because of limited rainfall from the time of planting to the 3rd trifoliolate growth. Therefore, dimethenamid (1.3 kg ha⁻¹) was applied postemergence to dry beans at the 3rd trifoliolate growth stage to determine the response of the F₃ generation. Visual injury 7 days after dimethenamid POST ranged from 15 to 30%. The visual leaf area of the ‘Huron’ navy bean parent line was reduced by 25% while the leaf area of ‘Matterhorn’ great northern parent line was reduced by only 9%. There was no visual injury 14 days after dimethenamid postemergence (data not presented). The correlation coefficient between seed size and visual leaf area reduction caused by dimethenamid postemergence was negative and significant ($r = -0.41$) (Figure 1). This supports the hypothesis of a negative correlation between seed size and injury resulting from dimethenamid POST. However further testing of the F₄ generation is warranted to determine the correlation between seed size and PRE application of dimethenamid.

SUMMARY

Navy and black bean cultivars were more susceptible to dimethenamid at the recommended field rate than to metolachlor. Michigan State University recommends herbicide rates based on soil type (Renner, 1999 personal communication). Cultivars within the same class of dry beans differed in their tolerance to dimethenamid and metolachlor (Table 3). No difference in uptake, translocation, or metabolism of dimethenamid between pinto, navy, and black bean classes has been found (Brunk et al., 1998). The hypocotyl diameter of dry beans with a large seed size (kidney and cranberry beans) was greater than that of dry beans with small seeds (navy and black beans). Additionally, dry beans with large seeds took longer to emerge than dry beans with small seeds. This observation does not support the hypothesis that small seeded dry beans sustain greater injury since the hypocotyl was exposed to herbicide-treated soil for a shorter, rather than a longer time period compared to larger seeded dry beans. However smaller diameters of navy and black bean may result in an increase in the internal concentration of dimethenamid and result in decreased dry bean class tolerance. The correlation between seed size and injury to dry beans from dimethenamid postemergence was negative. Therefore as seed size decreased, dry bean tolerance decreased also. It would be of interest to determine the relationship of seed size and herbicide tolerance in the F_4 generation with dimethenamid PRE. Decreased seed size is under control of dry bean class and may be difficult to incorporate into a dry bean breeding program.

LITERATURE CITED

- Andersen, A.L. and L.S. Robertson. 1982. The Michigan dry edible bean industry - History. p. 1-15. *In* L.S. Robertson and R.D. Frazier (ed.) Dry bean production- principles & practices. Michigan State Univ. Coop. Ext. Serv. Bull. E-1251.
- Bauer, T.A., K.A. Renner, D. Penner, and J.D. Kelly. 1995. Pinto bean (*Phaseolus vulgaris*) varietal tolerance to imazethapyr. *Weed Sci.* 43:417-424.
- Brunk, G, L. Randrich, D. Kazarian, P.M. Miller, S. Nissen, and P. Westra. 1998. Absorption and fate of dimethenamid in pinto, black and navy beans. *Proc. Western Weed Sci. Soc.* 51:60.
- Poehlman, J.M. and D.A. Sleper. 1995. Breeding soybean. p. 310-311 *In* Breeding field crops. Iowa State University Press, Ames, IA.
- Voysest, O. and M. Dessert. 1991. Bean cultivars: classes ad commercial seed types. pp. 119-162. *In* A. van Schoonhoven & o. Voysest (eds.), Common beans: Research for crop improvement. C.A.B. Int., Wallingford, U.K. & CIAT, Cali, Colombia.

Table 1. Dry bean injury from dimethenamid preemergence at 2.1 kg ha⁻¹ (twice the recommended rate).

Class	Variety	Injury at 1 st Trifoliate Growth Stage	Leaf Area Reduction at 3 rd Trifoliate Growth Stage
		—— % ——	—— % ——
Navy	Vista	26	78
	Schooner	29	75
	Newport	20	67
	Avanti	15	50
Pinto	Bill Z	19	61
	Othello	7	29
	Maverick	10	20
Black	T-39	15	52
	Midnight	31	88
Kidney	Montcalm	6	21
	California Light Red	1	13
Cranberry	Michigan Improved	2	13
	Taylor Hort	5	12
Small Red	Rufus	5	17
LSD (P≤0.05)		—— 8 ——	—— 25 ——
CV (%)		—— 58 ——	—— 59 ——

Table 2. Time to emergence and diameter of the hypocotyl at the crook stage of 14 different cultivars of dry beans from six classes.

Class	Variety	Time ^a	Diameter of Hypocotyl
		—— h ——	—— mm ——
Navy	Vista	87	27
	Schooner	82	29
	Newport	91	27
	Avanti	84	27
Pinto	Bill Z	85	30
	Othello	85	31
	Maverick	85	33
Black	T-39	85	26
	Midnight	83	26
Kidney	Montcalm	105	40
	California Light Red	96	42
Cranberry	Michigan Improved	99	42
	Taylor Hort	95	41
Small Red	Rufus	94	33
LSD ($P \leq 0.05$)		—— 8 ——	—— 3 ——
CV (%)		—— 10 ——	—— 8 ——

^a time from planting to emergence (crook stage) in h.

Table 3. Injury and leaf area at the 1st trifoliolate resulting from dimethenamid and metolachlor applied PRE in 1998.

Herbicide	Rate	Injury					Leaf Area				
		Vista	Schooner	Newport	Midnight	T-39	Vista	Schooner	Newport	Midnight	T-39
	kg ha ⁻¹			%					cm ²		
Dimethenamid	1.3	16	15	20	22	18	139	127	71	105	129
Dimethenamid	2.6	32	23	36	36	22	76	92	53	56	93
Metolachlor	2.9	18	18	23	21	17	115	111	61	89	113
Untreated		–	–	–	–	–	137	138	111	116	129
LSD (p≤0.05)				5					41		
CV (%)				12					24		

Table 4. Dry bean maturity and seed yield following PRE applications of dimethenamid and metolachlor in 1998.

Herbicide	Rate kg ha ⁻¹	Maturity ^a					Seed Yield ^b				
		Vista	Schooner	Newport	Midnight	T-39	Vista	Schooner	Newport	Midnight	T-39
				%					kg ha ⁻¹		
Dimethenamid	1.3	67	57	86	62	82	2223	2122	1879	1901	1868
Dimethenamid	2.6	57	38	63	48	70	1991	2010	1816	1924	1927
Metolachlor	2.9	62	47	81	53	83	1865	2096	1677	1972	2189
Untreated		67	63	86	55	81	2241	1928	1602	1819	1972
LSD (p≤0.05)				22					269		
CV (%)				20					8		

^a maturity was visually evaluated when approximately 66% of the leaves in the untreated control plots had turned yellow

^b adjusted to 18% moisture

Table 6. Dry bean maturity and seed yield following PRE applications of dimethenamid and metolachlor in 1999.

Herbicide	Rate kg ha ⁻¹	Maturity ^a					Seed Yield ^b				
		Vista	Schooner	Newport	Midnight	T-39	Vista	Schooner	Newport	Midnight	T-39
				%					kg ha ⁻¹		
Dimethenamid	1.3	70	55	50	67	60	3549	5278	3183	4576	4374
Dimethenamid	2.6	73	58	50	65	58	3646	4901	3112	4554	4374
Metolachlor	2.9	70	62	52	67	60	3560	4882	2985	4610	4363
Untreated		73	67	63	67	60	3650	5129	3026	4460	4509
LSD (p≤0.05)				7					266		
CV (%)				7					4		

^a maturity was visually evaluated when approximately 66% of the leaves in the untreated control plots had turned yellow

^b adjusted to 18% moisture

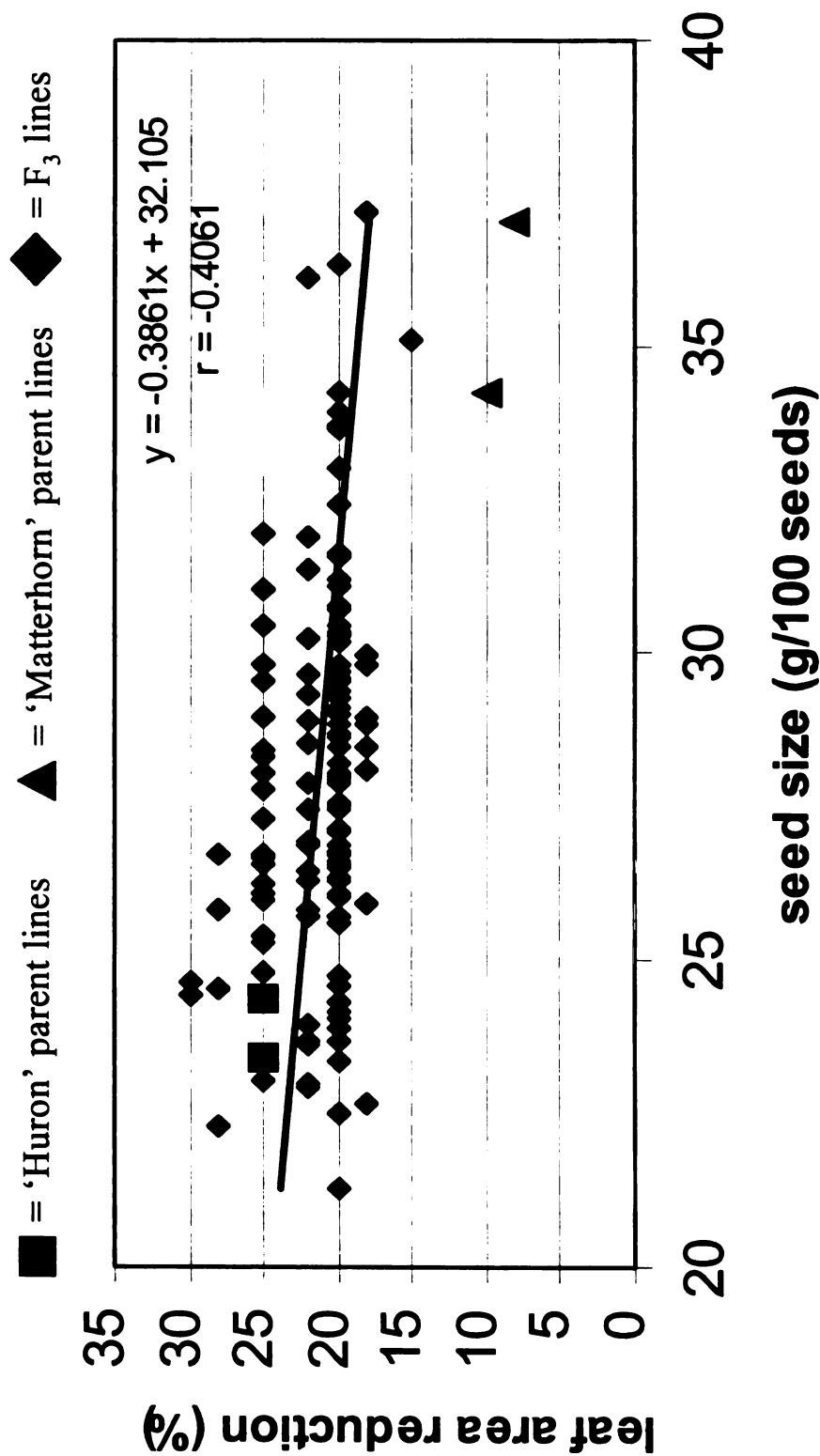


Figure 1. Relationship between seed size to visual leaf area reduction 7 days after dimethenamid applied postemergence to the F₃ progeny of 'Huron' navy bean crossed with 'Matterhorn' great northern bean.

Chapter 3

DRY BEAN RESPONSE TO DIMETHENAMID AND METOLACHLOR AS INFLUENCED BY TIMING OF APPLICATION

KYLE W. POLING

ABSTRACT

Dimethenamid preemergence at 2.1 kg ha⁻¹ was more injurious to dry beans than metolachlor at 2.9 kg ha⁻¹ when evaluated at the 1st and 3rd trifoliolate growth stages in the greenhouse. ‘Othello’ pinto bean was more tolerant to dimethenamid and metolachlor than cultivars in the black and navy bean classes. There was no difference in injury from PPI compared to PRE applications of dimethenamid and metolachlor. However injury to ‘Vista’ navy bean was greatest when dimethenamid and metolachlor were available for uptake in the navy bean hypocotyl compared to the root zone.

In the field dimethenamid and metolachlor at the recommended rates caused severe injury to ‘Vista’ navy bean when applied at the crook or unifoliolate growth stages. Early season injury delayed plant maturity but did not reduce seed yield. Dimethenamid and metolachlor PPI resulted in 3 to 4% injury to navy beans while these herbicides PRE injured dry beans 5 to 7%. Tank-mixing dimethenamid at 1.05 kg ha⁻¹ with bentazon at 0.84 kg ha⁻¹ plus dimethoate at 1.12 kg ha⁻¹ plus COC at 2.34 L ha⁻¹ caused less injury to navy bean compared to than dimethenamid applied alone at the 2nd trifoliolate growth stage.

INTRODUCTION

Chloroacetamide herbicides are applied in dry beans to control annual grasses, small-seeded broadleaf weeds, and yellow nutsedge (*Cyperus esculentus* L.). Deal and Hess (1980) and others (Anonymous, 1992) have concluded that chloroacetamide herbicides inhibit both cell division and cell enlargement in plants. Chloroacetamide herbicides registered for use on dry beans include alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)-acetanilide], metolachlor [2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl) acetamide, and dimethenamid [2-chloro-*N*-(2,4-dimethyl-3-thienyl)-*N*-(2-methoxy-1-methylethyl)-acetamide]. These herbicides are applied preplant incorporated (PPI) or preemergence (PRE), prior to dry bean emergence (Renner and Kells, 1999).

Metolachlor has become the standard herbicide treatment for preemergence grass control in dry beans (Renner, 1999 personal communication). In 1996, dimethenamid, a chloroacetamide herbicide developed for use in corn and soybeans, was granted registration from the United States Environmental Protection Agency for use in dry beans (Renner and Kells, 1999). Dimethenamid can cause more injury to soybeans than metolachlor (Osborne et al., 1992). Dimethenamid injured some dry bean fields in Michigan in 1996. Injury occurred most often after a preemergence or application at the early crook stage.

The site of chloroacetamide uptake differs in plant species. Metolachlor applied in the shoot zone of corn (*Zea mays*) and barley (*Hordeum vulgare* L.) decreased plant height, emergence, and dry weight (Pillai et al., 1979). However when metolachlor was applied in the root or seed zone there was no detectable effect. When metolachlor was applied in all

three zones, emergence, height, and dry weight of corn and barley were always reduced (Pillai et al., 1979). Early uptake of alachlor in snap bean occurred primarily via the shoot portion of the emerging seedling (Rice and Putnam, 1980). Putnam and Rice (1979) demonstrated that snap bean injury was lessened when alachlor was applied preplant incorporated compared with a preemergence surface treatment. An increase in crop safety was attributed to the reduction of herbicide in the zone of emergence, thus less alachlor was absorbed by the bean hypocotyl.

Alachlor and metolachlor are not registered for postemergence application in dry beans. Dimethenamid is registered for postemergence application to dry bean (Anonymous, 1999) but may be injurious to the crop. Injury to dry beans from postemergence applications of imazethapyr decreased when bentazon was tank-mixed with imazethapyr (Bauer et al., 1995). Bentazon decreased absorption and translocation of imazethapyr in pinto beans (Bauer et. al., 1995).

The objectives of this research were (1) to determine if placement or application timing of dimethenamid influenced dry bean tolerance to dimethenamid and (2) to determine if tank-mixing bentazon with dimethenamid influenced dry bean response to postemergence applications of dimethenamid.

MATERIALS AND METHODS

Greenhouse Placement Study. Tolerance of six dry bean cultivars to preplant incorporated and preemergence dimethenamid and metolachlor was evaluated. Dimethenamid at 2.1 kg ha⁻¹ and metolachlor at 2.9 kg ha⁻¹ were applied preplant incorporated or preemergence to

‘Vista’ and ‘Schooner’ navy beans, ‘Midnight’ and ‘T-39’ black beans, and ‘Othello’ and ‘Bill Z’ pinto beans in the greenhouse. Treatments were applied in a factorial arrangement. All pots were arranged in a completely randomized design. Each treatment was replicated four times and the experiment was repeated. Untreated controls were included for each cultivar.

Pots measuring 10 cm in height and 12 cm in diameter were filled with 7 cm of a Spinks loamy sand (Psammentic Hapludalfs, sandy, mixed mesic), 86% sand, 10% silt and 4% clay with a pH of 6.5 and 1% organic matter. One seed per pot was placed on top of the soil. In preparation for the preemergence treatments, additional soil (2.5 cm) was placed over the seed. The preemergence treatments were then sprayed using an 8001-SS nozzle at 234 L ha⁻¹ and 207 kPa. For the PPI applications, sixteen flats (31 by 61 cm) were filled with 2.5 cm of the Spinks loamy sand soil. The flats of soil were treated with herbicide. The herbicide and soil were then mixed together in a bucket to simulate preplant incorporation of a herbicide in the field. The treated soil in each bucket was then placed in the pots to cover the seed. The remaining pots of each cultivar had 2.5 cm of untreated soil placed over them. Environmental conditions were maintained at 27 C $\pm$ 4 C, and plants were grown in a 16 h photoperiod of natural lighting supplemented with incandescent lighting with PAR of 1000 μ E m⁻² s⁻¹.

Visual injury ratings were recorded at the unifoliate, 1st trifoliate and 3rd trifoliate growth stages of the dry beans. Plants were then cut off at the soil surface and leaf area measured with a LI-3000 portable area meter (LI-COR, Lincoln, Nebraska). The percent leaf area reduction was calculated by dividing the leaf area of each plant by the mean leaf area

of plants from the untreated control of the same cultivar. Harvested plants were then dried and weights recorded.

Data were subjected to analysis of variance. Visual injury ratings, leaf area reduction, and dry weights were compared using Fisher's protected LSD test at $P \leq 0.05$. The data presented are the combined means over the two runs.

Volatility Study. Dimethenamid volatilization was examined in an experiment conducted in growth chambers. The study was a completely randomized design and the experiment was repeated two times. Two separate growth chambers were used in the experiment and were the experimental units.

'Vista' navy beans were planted in pots at a depth of 2.5 cm in a Spinks loamy sand soil (86% sand, 10% silt and 4% clay) with a pH of 6.5 and 1% organic matter. Plants were grown in growth chambers with a 16 h photoperiod at 28 C day / 17 C night temperature regime with 85% relative humidity. When the navy beans reached the crook growth stage, five randomly selected pots were removed from one of the growth chambers. Dimethenamid at 2.1 kg ha⁻¹ was applied to these pots as previously described and the pots were immediately returned to the growth chamber. The other growth chamber was the untreated control and did not contain any dimethenamid treatments.

Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed means are presented because square root transformation did not alter interpretation of the data. Statistical analysis revealed no experimental run interactions, so the data were combined and are reported as means of the two experiments.

Site of Uptake Experiment. An experiment was conducted in the greenhouse to determine if the hypocotyl, seed, or roots of 'Vista' navy beans preferentially absorbed dimethenamid and metolachlor. The experiment was a completely randomized design arranged as a two-factor factorial with four replications and was repeated in time. Sites of herbicide uptake included the hypocotyl, seed, root, hypocotyl + seed, and root + seed. A charcoal barrier method similar to that employed by Gray and Weierich (1969) was used to prevent the movement of herbicide in the soil in order to expose only the hypocotyl, root, or seed zones in the various treatments.

An application rate eight times the recommended rate was needed for visual injury to occur. This excessive rate of herbicide was needed because any herbicide coming into contact with the charcoal layer was absorbed and not available for uptake by the dry beans. Dimethenamid at 8.4 kg ha⁻¹ and metolachlor at 11.4 kg ha⁻¹ were applied to flats of soil (2.5 cm) as described previously. Soil was then placed in a bucket and mixed thoroughly to incorporate the herbicide into the soil.

Different models with various arrangements of charcoal barrier(s) were used to evaluate the uptake of herbicide by the hypocotyl, seed, and roots alone, as well as the hypocotyl plus seed and root plus seed zones (Figure 1). In all models the seed was placed at a depth of 4 cm. To expose only the dry bean hypocotyl to herbicide, 5.5 cm of a Spinks loamy sand soil (86% sand, 10% silt and 4% clay) with a pH of 6.5 and 1% organic matter was placed in the bottom of a pot measuring 9 cm in height. One seed was placed at a depth of 1 cm into the untreated soil. A 0.5 cm layer of a mixture (1:1, v/v) of powdered activated

charcoal and moist untreated soil was added and leveled. Herbicide-treated soil (2.5 cm) was placed above the charcoal layer and leveled (Figure 1a).

For root exposure (Figure 1b), 2.5 cm of herbicide-treated soil was placed in the bottom of a pot followed by a charcoal barrier (0.5 cm). Untreated soil (5.5 cm) was placed on top of the charcoal barrier. For exposing the seeds, the layers from top to bottom were; 2.5 cm untreated soil, 0.5 cm charcoal, 2.5 cm of soil containing the seeds, 0.5 cm charcoal, and 2.5 cm untreated soil (Figure 1c). For seed plus root exposure (Figure 1d) the charcoal and soil arrangement were as follows: 2.5 cm of herbicide treated soil was placed on the bottom the pot, 2.5 cm of untreated soil containing the seed, 0.5 cm charcoal, and 2.5 cm untreated soil. To expose hypocotyl plus seed parts, the above procedure was repeated with the charcoal layer (0.5 cm) located 2.5 cm from the bottom of the pot and the treated soil being placed in the top of the pot (Figure 1e). An untreated control was included for each charcoal model. Pots were alternately surface and subsurface watered every day to maintain moisture and reduce the herbicide adsorption by the charcoal layer(s).

Leaf area reduction was visually evaluated at the unifoliate, 1st trifoliate and 3rd trifoliate growth stages. After the 3rd trifoliate rating, all plants were cut off at the soil surface. The total leaf area of each plant was measured using a LI-3000 portable area meter (LI-COR, Lincoln, Nebraska). The percent leaf area reduction was calculated by dividing the leaf area of each plant receiving a herbicide treatment by the mean leaf area of the plants from the respective untreated control (same location of charcoal barriers). The harvested leaves and stems from each plant were then dried and weights recorded.

Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed means are presented because square root transformation did not alter interpretation of the data. Statistical analysis revealed no experimental run interactions, so the data were combined and are reported as means of the two experiments.

Timing of Application Study. Dry bean tolerance to dimethenamid and metolachlor applied at various timings was determined in a field study in 1998 and 1999. The ground was tilled twice with a field cultivator prior to planting to remove weeds and prepare the seedbed. 'Vista' navy bean, a 98 day maturity bean, was planted at a population of 272,000 seeds ha⁻¹ in 76 cm rows. The navy beans were planted on June 2, 1998 and June 4, 1999. The soil type in 1998 was a Capac loam (Aeric Ochraqualfs, fine-loamy, mixed mesic), 45% sand, 37% silt and 18% clay with a pH of 7.8 and 2.4% organic matter. In 1999, the soil was a Capac sandy loam (52% sand, 34% silt and 14% clay) with a pH of 7.1 and 2.5% organic matter.

Plots were 3 m wide (four rows) by 9.1 m in length. Fourteen treatments were replicated four times in a randomized complete block design with a two factor factorial arrangement of treatments. The factors were two herbicides and six application timings. Dimethenamid (1.3 kg ha⁻¹) and metolachlor (1.4 kg ha⁻¹) were each applied preplant incorporated (PPI), preemergence (PRE), and at the early crook stage, unifoliate, 1st trifoliate and 2nd trifoliate growth stages. An untreated control for each herbicide was included in each block. Plots were maintained weed-free for the entire season to eliminate the confounding factor of weed interference on navy bean maturity and yield.

Plots receiving a herbicide treatment were visually compared to the untreated plots in their respective block. Visual leaf area reduction was evaluated at the unifoliate, 1st trifoliate and 3rd trifoliate growth stages. Postemergence applications were also rated visually for leaf area reduction 3, 7, and 14 days after treatment. All plots were evaluated 35 days after planting for visual leaf area reduction. Visual maturity ratings were taken by recording the percent leaf yellowing when approximately two-thirds of the leaves in the untreated control plots had turned yellow. The middle two rows of each plot were harvested with a self-propelled combine and yield adjusted to kg ha⁻¹ at 18 % moisture.

Visual estimates of leaf area reduction were arcsine transformed prior to statistical analysis and subjected to ANOVA procedures. Means of the transformed leaf area reduction data, maturity, and yields were separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed data are presented for clarity. Statistical analysis revealed no experimental run interactions, so the data were combined and are reported as means of the two experiments.

Dimethenamid / S-dimethenamid. The tolerance of dry edible beans to dimethenamid and S-dimethenamid was evaluated in 1998 and 1999. In 1998 the soil was a Capac loam (45% sand, 37% silt and 18% clay) with a pH of 7.8 and 2.4% organic matter. In 1999 the soil was a Capac loam (50% sand, 31% silt and 19% clay) with a pH of 7.2 and 2.3% organic matter. Plots were maintained weed-free the entire season to eliminate the confounding factor of weed interference on navy bean maturity and yield.

The seedbed was prepared with two passes of a Danish S-tine field cultivator in the spring of both years. 'Schooner' navy beans were planted on June 2, 1998 and June 4, 1999

at a population of 272,000 seeds ha⁻¹ in plots measuring 3 m by 9.1 m with a crop row spacing of 76 cm.

Dimethenamid at 1.3 and 2.6 kg ha⁻¹ and S-dimethenamid at 0.72 and 1.44 kg ha⁻¹ were applied PRE or at the 1st trifoliolate growth stage. Leaf area reduction was visually rated at the unifoliolate, 1st trifoliolate and 3rd trifoliolate stages. Leaf area reduction was also evaluated at 3, 7, and 14 days after the 1st trifoliolate growth stage application and all plots were also evaluated 35 days after planting. To estimate relative maturity the percent leaf yellowing was recorded when two-thirds of the leaves in the control plot had yellowed. The middle two rows of each plot were harvested with a self-propelled combine. Seed yield was adjusted to kg ha⁻¹ at 18% moisture.

Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed means are presented because square root transformation did not alter interpretation of the data. Data is presented separately by years because of a significant herbicide by timing by year interaction.

Postemergence Application of Basagran Plus Dimethenamid. A field study in 1998 and 1999 was conducted to determine dry bean tolerance to dimethenamid in the presence and absence of bentazon and/or dimethoate insecticide. Treatments included 0.84 kg ha⁻¹ bentazon, 1.05 kg ha⁻¹ dimethenamid, 1.12 kg ha⁻¹ dimethoate, and 2.34 L ha⁻¹ crop oil concentrate (COC).

The seedbed was prepared each year with fall moldboard plowing followed by two applications with a Danish S-tine field cultivator in the spring. 'Vista' navy beans were planted on June 1, 1998 and June 3, 1999. The soil type in 1998 was a Misteguay silty clay

loam (Aeric Haplaquept, fine, mixed (calcareous), mesic), 9% sand, 45% silt, and 46% clay with a pH of 8.0 and 1.9% organic matter. In 1999 the soil was a Misteguay silty clay loam (14% sand, 47% silt, and 39% clay) with a pH of 7.8 and 2.6% organic matter. Navy beans were planted in 2.8 m by 5.6 m plots with row spacing of 72 cm at a population of 272,000 seeds ha⁻¹ in both years.

Treatments were applied at either the 1st trifoliate or 2nd trifoliate growth stage of the dry beans. An untreated control plot was included for comparison at each application timing. Plots were rated visually for leaf area reduction at 3, 7, and 14 days after treatment. Visual maturity ratings were measured by recording percent leaf yellowing when two-thirds of the leaves in the untreated control were yellow. The middle two rows of each plot were harvested with a self-propelled combine and seed yield was converted to kg ha⁻¹ at 18% moisture.

Treatments were replicated four times in a split plot design with the main plot application timing and the subplot the pesticide treatments. Visual estimates of leaf area reduction were subjected to square root transformation transformed prior to statistical analysis and subjected to ANOVA procedures. Means of the transformed leaf area reduction data, maturity, and yields were separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Nontransformed data are presented for clarity.

RESULTS AND DISCUSSION

Greenhouse Placement Study. Plants were stunted and leaf area reduced by dimethenamid and metolachlor applied PPI or PRE. There were no significant difference in injury from PPI

compared to PRE applications when evaluated at the 1st or 3rd trifoliolate growth stage (Table 1). Dry beans at the unifoliolate and 1st trifoliolate growth stages grew more rapidly and trifoliolate leaves emerged faster when treated with a herbicide compared with plants that did not receive a herbicide application (data not presented).

Dimethenamid caused greater injury than metolachlor when evaluated at the 1st trifoliolate and 3rd trifoliolate growth stages (Table 1). Dry weights however were similar for dimethenamid and metolachlor because 80 % of the dry weight consisted of the stem weight while only a minimal percent of the weight was from the leaves (data not presented).

Dry bean varieties differed in their tolerance to dimethenamid and metolachlor. ‘Othello’ pinto bean was more tolerant than the black and navy bean cultivars (Table 1). ‘Midnight’ and ‘T-39’ black beans did not differ in tolerance to these chloroacetamide herbicides, nor did ‘Vista’ navy bean tolerance differ from that of ‘Schooner’ navy bean. ‘Schooner’ navy bean leaf area was reduced at the 3rd trifoliolate growth stage compared with leaf area of ‘Midnight’ black bean and the pinto cultivars (Table 1).

Our research results concur with Kazarian et al. (1999) where navy and black beans showed greater sensitivity to dimethenamid, S-dimethenamid, and metolachlor compared to pinto beans. Our data indicated dimethenamid to be more injurious than metolachlor. Research in soybean has shown that the magnitude of soybean injury is often greater from dimethenamid compared to metolachlor (Osborne et al., 1992b). The injury that dimethenamid and metolachlor caused to the dry beans did not differ from PPI compared with PRE applications on the same cultivar. Our research did not concur with Putnam and

Rice (1979) where snap bean injury decreased when alachlor was preplant incorporated compared with a preemergence surface treatment.

Volatility Study. Only dry beans treated with dimethenamid showed injury symptoms (data not presented). Some dry bean growers have attributed the injury caused by dimethenamid from PPI or PRE applications to volatilization of the herbicide. This research conducted in the growth chambers does not support this hypothesis because dimethenamid injury was only apparent on dry beans that were treated with dimethenamid at the crook stage of growth. Dimethenamid has a 100-fold lower vapor pressure (2.76×10^{-4} mm Hg at 25 C) compared to EPTC (*S*-ethyl dipropylthiocarbamate) (3.4×10^{-2} mm Hg at 25 C), a herbicide known to readily volatilize (Weed Science Society of America, 1994).

Site of Uptake Experiment. Chloroacetamides caused the greatest injury and leaf area reduction when placed in the hypocotyl plus seed zone (Table 2). Dry bean injury was negligible when herbicide was placed in the seed zone, followed by placement only in the root zone (Table 2). In previous research Rice and Putnam (1980) found early uptake of alachlor in snap bean occurred primarily via the hypocotyl portion of the emerging seedling. Snap bean tolerance increased when the amount of alachlor in the zone of emergence was reduced, thus less alachlor was absorbed by the bean hypocotyl (Rice and Putnam, 1980). Therefore, placement of dimethenamid or metolachlor in the upper 3 cm of the soil profile may increase dry bean response to these chloroacetamide herbicides because of hypocotyl exposure to the concentrated herbicide area.

Timing of Application Study. Dimethenamid and metolachlor caused more injury to dry beans when applied at the crook or unifoliate growth stages compared with PPI, PRE, or

postemergence applications at the 1st and 2nd trifoliate growth stages (Table 3). Dimethenamid at the unifoliate growth stage caused greater leaf area reduction of 'Vista' navy bean compared to metolachlor (Table 3). However evaluation of leaf area reduction at the 3rd trifoliate stage showed similar response of navy bean to dimethenamid and metolachlor applied at the crook and 1st trifoliate growth stages (Table 3).

Dimethenamid and metolachlor PPI caused less leaf area reduction compared with PRE applications however the relative difference was small. Putnam and Rice (1979) demonstrated that snap bean injury decreased when alachlor was applied preplant incorporated compared to a preemergence surface treatment and our site of uptake research also supports more potential injury from PRE applications. However, in our greenhouse study (Table 1) there was no difference in bean response to PPI and PRE applications. Possibly the pots and 10 cm soil depth in the greenhouse allowed herbicide to remain available for uptake regardless of the application method.

The early season injury caused by applications of dimethenamid at the crook and unifoliate stages delayed physiological maturity compared with the untreated control (Table 3). Dimethenamid at the unifoliate stage delayed maturity by 27% compared to the untreated control. Metolachlor caused a delay in maturity only when applied at the unifoliate growth stage. This delay in maturity of dry beans following early season injury has been reported for applications of imazethapyr on pinto, great northern, and light red kidney beans (Bauer et al., 1995; Wilson and Miller, 1991). Dimethenamid applied at the unifoliate stage reduced seed yield compared to the untreated control. Imazethapyr did not always reduce seed yield even when maturity was delayed (Bauer et al., 1995; Wilson and Miller, 1991).

Dimethenamid / S-dimethenamid. There was no difference in injury from dimethenamid and S-dimethenamid at similar rates and application timings (Table 4). In 1998 and 1999, preemergence applications of dimethenamid and S-dimethenamid at 2.6 and 1.4 kg ha⁻¹ (twice the suggested application rate for this soil type), respectively, were significantly more injurious than applications at 1.3 and 0.7 kg ha⁻¹, respectively (Table 4). There were no differences in dry bean injury from applications of dimethenamid or S-dimethenamid at the recommended field rate compared with the 2X rate when applied at the 1st trifoliolate growth stage in 1998 (Table 4). However, in 1999 dimethenamid or S-dimethenamid applied at the 2X rate injured the navy beans significantly more than the herbicides applied at the 1X rates (Table 4). Injury following PRE herbicides in 1998 was greater than applications at the 1st trifoliolate growth stage (Table 4). In 1998, when the dry beans were just emerging from the soil, 0.94 cm of precipitation was received. Putnam and Rice (1979) reported that injury to snap bean corresponded with heavy rainfall and warm temperature during and immediately after germination. In 1999 dimethenamid and S-dimethenamid applied PRE resulted in only minimal injury (Table 4). It did not rain from the time of planting until the dry beans emerged from the soil in 1999. S-dimethenamid is an isomer of dimethenamid (John Balles, BASF, personal communication). An isomer is a chemical whose molecules contain the same number and kind of atoms as another chemical but are arranged differently. The crop response to soil-applied treatments of dimethenamid and S-dimethenamid should be similar (John Balles, BASF, personal communication). Dimethenamid and S-dimethenamid applied PRE did not delay physiological maturity in 1998 (Table 4). However, in 1998 dimethenamid at the 2X rate applied at the 1st trifoliolate growth stage delayed maturity more

than S-dimethenamid at the 2X rate applied at the same time (Table 4). The early season injury of the dry beans did not result in a maturity delay in 1999 (Table 4).

Dry bean response to dimethenamid postemergence has not been reported previously, nor has information on the S-dimethenamid formulation. Isomers of metolachlor have not resulted in weed control or crop response differences (Renner and Kells, 1999) and our research suggest that dry bean tolerance to S-dimethenamid will be similar to dry bean tolerance to dimethenamid. In 1998 and 1999 there were no differences in seed yield between plots receiving an application of dimethenamid or S-dimethenamid PRE or at the 1st trifoliate stage, with the exception of dimethenamid applied PRE at the 1X rate in 1998 (Table 4).

Postemergence Application of Basagran Plus Dimethenamid. Injury for all treatments was minimal ($\leq 10\%$) (Table 5). The addition of bentazon to dimethenamid and dimethenamid + COC applied at the 1st trifoliate growth stage did not influence crop injury. However, the addition of bentazon to dimethenamid + dimethoate + COC at the 1st trifoliate growth stage increased crop injury (Table 5). At the 2nd trifoliate growth stage, the addition of bentazon to dimethenamid and dimethenamid + COC reduced crop injury. However bentazon did not reduce crop response to dimethenamid + dimethoate + COC at the 2nd trifoliate growth stage. Temperature at the time of treatment at the 1st trifoliate was 8 C higher in 1998 and 2 C higher in 1999 compared with the temperature at the 2nd trifoliate timing.

Bentazon decreased dry bean injury from dimethenamid in all tank-mixtures except for dimethenamid + bentazon + dimethoate + COC at the 2nd trifoliate application timing

(Table 5). All plots matured at the same rate with no differences observed between the treated plots and the untreated control (data not presented). Dry bean yields from treated plots were not significantly different from yield of the untreated control in 1998 and 1999 (Table 5). In our study bentazon reduced dry bean injury from dimethenamid and dimethenamid + COC at the 2nd trifoliate growth stage, however injury was minimal from all treatments and the addition of bentazon would be economically justified in this study only if bentazon was needed for weed control.

SUMMARY

Applications of dimethenamid and metolachlor at the recommended rate can cause injury to dry beans. Similar to the findings of Osborne et al. (1992) in soybeans, the magnitude of injury in dry beans is often greater with dimethenamid compared with metolachlor. There was no difference in injury to dry beans between dimethenamid or metolachlor applied preemergence and preplant incorporated in the greenhouse. However, in our research, injury to 'Vista' navy beans was greatest when dimethenamid or metolachlor was available in the hypocotyl zone rather than the root zone. Therefore a concentrated layer of herbicide in the hypocotyl zone could increase the potential for injury from these herbicides applied PRE. In our field research dimethenamid or metolachlor PRE caused more injury than dimethenamid or metolachlor PPI. Injury to dry beans from dimethenamid and metolachlor reduced leaf area early in the growing season. Visual injury and leaf area reduction also resulted in delayed maturity but did not reduce seed yield. To minimize the chance of severe injury these herbicides should not be applied at the crook or unifoliate

growth stages. Dimethenamid postemergence at the 1st trifoliate growth stage reduced leaf area from 0 to 21% when measured at the 3rd trifoliate growth stage (Tables 3 and 4), depending on the site and year. This difference in injury from dimethenamid postemergence at 1st trifoliate stage suggests that delaying application to the 2nd trifoliate stage may reduce the potential for leaf area reduction. Maturity was never delayed, nor seed yield reduced from dimethenamid applied at the 2nd trifoliate stage (Table 3, 4, and 5). Tank-mixing with bentazon reduced dry bean injury from dimethenamid or dimethenamid + COC and may be suggested when a postemergence application needs to be made at the 2nd trifoliate stage of dry beans because weeds are at the recommended height for herbicide application.

LITERATURE CITED

- Anonymous. 1992. SAN 582G experimental herbicide: A technical overview. Sandoz Agro, Inc., Des Plaines, IL 60018.
- Anonymous. 1999. Frontier 6.0 herbicide product label. BASF Corp., Agricultural Products, Research Triangle Park, NC 27709.
- Bauer, T.A., K.A. Renner, and D. Penner. 1995. 'Olathe' pinto bean (*Phaseolus vulgaris*) response to postemergence imazethapyr and bentazon. *Weed Sci* 43:276-282.
- Deal, L.M. and F.D. Hess. 1980. An analysis of the growth inhibitory characteristics of alachlor and metolachlor. *Weed Sci.* 28:168-175.
- Kazarian, D., P.M. Miller, S. Nissen, and P. Westra. 1998. Dry edible bean response to shoot and foliar applications of dimethenamid, BAS 656, and metolachlor. *Proc. Western Weed Sci. Soc.* 51:60.
- Osborne, B.T., D.R. Shaw, and R.L. Ratliff. 1992. Soybean cultivar tolerance to SAN 582H and metolachlor as influenced by soil moisture. *Weed Sci.* 43:288-292.
- Pillai, P., D.E. Davis, and B. Truelove. 1979. Effects of metolachlor on germination, growth, leucine uptake, and protein synthesis. *Weed Sci.* 27:634-637.
- Putnam, A.R. and R.P. Rice, Jr. 1979. Environmental and edaphic influences on the selectivity of alachlor on snap beans (*Phaseolus vulgaris*). *Weed Sci.* 27:570-574.
- Renner, K.A., and J.J. Kells. 2000. Weed control guide for field crops. Michigan State Univ. Coop. Ext. Serv. Bull. E-434.
- Rice, R.P., Jr. and A.R. Putnam. 1980. Temperature influences on uptake, translocation, and metabolism of alachlor in snap beans (*Phaseolus vulgaris*). *Weed Sci.* 28(2):131-134.
- Weed Science Society of America. 1994. Pages 119-121 and 264-266 in *Herbicide Handbook*, seventh edition. *Weed Sci. Soc. Am.*, Champaign, IL.
- Wilson, R.G. and S.D. Miller. 1991. Dry edible bean (*Phaseolus vulgaris*) response to imazethapyr. *Weed Technol.* 5:22-26.

Table 1. Response of six dry bean cultivars to preplant incorporated and preemergence dimethenamid and metolachlor in the greenhouse.

Variable	1 st trifoliolate injury	Leaf area reduction at 3 rd trifoliolate growth stage
	—— % ——	—— % ——
Application method		
PRE	12 a	32 a
PPI	11 a	32 a
CV (%)	—— 65 ——	—— 63 ——
Herbicide		
Dimethenamid	15 a	40 a
Metolachlor	8 b	25 b
CV (%)	—— 65 ——	—— 63 ——
Cultivar (class)		
Vista (navy)	15 a	37 ab
Schooner (navy)	14 a	42 a
T-39 (black)	11 ab	35 ab
Midnight (black)	12 ab	27 b
Bill Z (pinto)	9 bc	27 b
Othello (pinto)	7 c	12 c
CV (%)	—— 65 ——	—— 63 ——

Table 2. Effect of exposing different parts of dry bean seedlings to dimethenamid and metolachlor-treated soil using charcoal barriers to prevent movement of the herbicide.

Site of Uptake	Visual leaf area reduction at 1 st trifoliate stage	Leaf area reduction at 3 rd trifoliate stage
	—— % ——	—— % ——
Root	28 c	24 cd
Hypocotyl	63 b	53 b
Seed	18 c	8 d
Root + Seed	32 c	32 c
Hypocotyl + Seed	86 a	84 a
CV (%)	—— 67 ——	—— 80 ——

Legend	
	Charcoal Layer
	Untreated Soil
	Herbicide-Treated Soil

- a. hypocotyl only.
- b. roots only.
- c. seed only.
- d. roots + seed
- e. hypocotyl + seed.

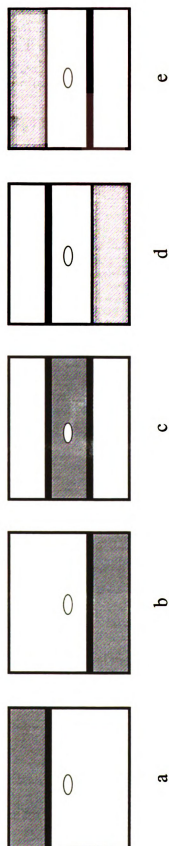


Figure 1. Position of charcoal layers, untreated soil, and herbicide-treated soil for exposure of dry beans to dimethenamid and metolachlor to determine site of uptake.

Table 3. Effect of timing of application of dimethenamid and metolachlor on 'Vista' navy beans in 1998 and 1999.

Application Timing	3 rd Trifoliolate Leaf Area Reduction		Physiological Maturity ^a		Seed Yield ^b	
	dimethenamid	metolachlor	dimethenamid	metolachlor	dimethenamid	metolachlor
	—— % ——		—— % yellowing ——		—— kg ha ⁻¹ ——	
PPI	4 e	3 e	61 a	61 a	3821 abc	3889 ab
PRE	7 d	5 d	58 a	60 a	3756 bc	3848 abc
Crook	21 c	20 c	48 b	57 a	3683 bc	3889 ab
Unifoliolate	34 a	26 b	36 c	46 b	3561 c	3836 abc
1 st Trifoliolate	16 c	17 c	56 a	56 a	3768 abc	4078 a
2 nd Trifoliolate	6 d	5 d	61 a	60 a	3812 abc	3897 ab
Untreated	0 f	0 f	63 a	63 a	3918 ab	3771 abc
CV (%)	—— 25 ——		—— 14 ——		—— 8 ——	

^a maturity was visually evaluated when approximately 66% of the leaves in the untreated control plots had turned yellow

^b adjusted to 18% moisture

Table 4. Effect of applications of dimethenamid and S-dimethenamid when applied PRE and at the 1st trifoliate growth stage on 'Schooner' navy beans in 1998 and 1999.

Herbicide	Rate — kg ha ⁻¹ —	Application Timing	3 rd Trifoliate Injury		Physiological Maturity ^a		Seed Yield ^b	
			1998	1999	1998	1999	1998	1999
			— % —		— % yellowing —		— kg ha ⁻¹ —	
dimethenamid	1.3	PRE	29	12	70	55	2768	4124
	2.6	PRE	46	21	62	53	3242	3771
s-dimethenamid	0.7	PRE	28	12	70	55	3042	3810
	1.4	PRE	50	18	63	58	3102	4006
dimethenamid	1.3	1 st Trifoliate	20	20	67	48	3097	4281
	2.6	1 st Trifoliate	20	43	65	63	2941	4006
s-dimethenamid	0.7	1 st Trifoliate	21	15	71	53	2937	4606
	1.4	1 st Trifoliate	22	39	65	58	2981	3530
CV (%)			— 9 —	— 25 —	— 6 —	— 18 —	— 9 —	— 7 —

^a maturity was visually evaluated when approximately 66% of the leaves in the untreated control plots had turned yellow

^b adjusted to 18% moisture

Table 5. 'Vista' navy bean injury and yield following application of various tank-mixtures of dimethenamid, bentazon, dimethoate, and crop oil concentrate (COC)^a at the 1st and 2nd trifoliolate growth stages combined over 1998 and 1999.

Treatments	Injury 7 DAPO		Seed Yield			
	1 st trifoliolate application	2 nd trifoliolate application	1 st trifoliolate application	2 nd trifoliolate application		
	———— % —————		———— g ha ⁻¹ —————			
dimethenamid	1 g	9 b	2884	abc	2879	abc
dimethenamid + COC	2 f	10 a	2949	abc	2817	abc
bentazon + COC	1 g	4 e	3070	ac	2933	abc
dimethenamid + bentazon	1 g	5 d	2787	bc	2799	c
dimethenamid + bentazon + COC	2 f	5 d	2804	bc	2791	c
dimethoate	0 h	1 g	2904	abc	2970	abc
dimethenamid + dimethoate	2 f	7 c	2886	abc	2755	c
dimethenamid + dimethoate + COC	2 f	10 a	2967	abc	2858	abc
dimethenamid + bentazon + COC	1 g	5 d	2933	abc	2834	abc
dimethenamid + bentazon + dimethoate + COC	7 c	9 b	2849	abc	2758	c
bentazon	0 h	1 g	2831	abc	3021	ab
untreated	0 h	0 h	2848	abc	2996	abc
CV (%)	———— 55 —————		———— 9 —————			

^aHerbicide rates: 0.84 kg ha⁻¹ bentazon, 1.05 kg ha⁻¹ dimethenamid, 1.12 kg ha⁻¹ dimethoate, and 2.34 kg ha⁻¹ crop oil concentrate (COC)

Chapter 4

INFLUENCE OF ENVIRONMENTAL CONDITIONS AT THE TIME OF PLANTING AND EMERGENCE ON DRY BEAN TOLERANCE TO DIMETHENAMID AND METOLACHLOR

KYLE W. POLING

ABSTRACT

'Vista' and 'Schooner' navy bean cultivars were planted on five dates in 1998 and 1999 to determine the influence of planting date on dry bean response to dimethenamid and metolachlor. Dimethenamid at 2.3 kg ha⁻¹ and metolachlor at 2.8 kg ha⁻¹ were applied PRE immediately after planting. Dimethenamid and metolachlor injured both cultivars on the June 1 and June 22 planting dates in 1998. Dry bean response to either herbicide was minimal to all planting dates in 1999. Environmental conditions at the time of emergence affected dry bean tolerance to these herbicides. On the June 1 and June 22 planting dates in 1998 0.69 cm and 0.58 cm of rain, respectively, fell during the time of emergence (5 to 7 DAP). At the other planting dates in 1998 and at all planting dates in 1999, rainfall at the time of emergence was 0 to 0.18 cm. Moderate temperature (22 to 31 C) did not appear to play a significant role in dry bean injury from dimethenamid or metolachlor.

INTRODUCTION

The chloroacetamide herbicides are commonly used to control annual grasses, small-seeded broadleaf weeds, and yellow nutsedge (*Cyperus esculentus* L.) in corn (*Zea mays*), soybeans (*Glycine max*) and dry edible beans (*Phaseolus vulgaris*) (Anonymous, 1992). Cultivars of these crops have exhibited variable tolerance to chloroacetamides (Renner et al., 1988; Driver et al., 1992; Edwards et al., 1976; Sniper et al., 1987; Stephenson et al., 1976). Temperature, rainfall, placement of the herbicide, soil texture and organic matter were important factors influencing tolerance in the field (Cieslar and Binning, 1974; Putnam and Rice, Jr. 1979).

Alachlor injured snap beans at both low and high temperature regimes with day and night temperatures of 16 and 21 C or 27 and 32 C, respectively (Putnam and Rice, 1979). At 16 to 21 C the injury appeared much earlier and was more severe compared with injury at the high temperature. Plants at the low temperature displayed leaf crinkling or fusion of the leaf margins, while plants at the high temperature exhibited leaf cupping and marginal chlorosis (Putnam and Rice, 1979). Penner and Graves (1972) found that alachlor applied at 3.32 kg/ha (twice the normal rate) caused injury to navy beans at 20 and 25 C but not at 30 C. Navy bean injury from alachlor at the lower temperatures may explain the occasional injury observed in the field (Penner and Graves, 1972).

Putnam and Rice (1979) reported that twice as much alachlor was taken up by snap bean at the 27 to 32 C compared to the 16 to 21 C temperature regime. However, increased growth rates and transpiration rates occur at higher temperatures. At the higher temperature regime the majority of the alachlor remained in the plant roots. The percentage remaining

as parent alachlor was greater at the lower temperature. Alachlor was distributed throughout the plant with no single part of the plant accumulating a significantly greater amount of alachlor than any other plant part except for the cotyledons in which no alachlor was found. Therefore lower temperatures could result in more crop injury.

Many herbicides become more available for uptake by the plant as soil moisture increases (Jones et al., 1990; Tripp and Baldwin, 1988; Wehtje et al., 1987). Metolachlor uptake increased in grass species up to three-fold when soil moisture increased from 45 to 100% (Gerber et al., 1974.). In a field experiment evaluating different soybean cultivars neither dimethenamid or metolachlor reduced soybean yield when applied at normal use rates with either optimum or excessive moisture. However, injury occurred when dimethenamid or metolachlor were applied above recommended rates and excessive moisture conditions persisted. Some soybean cultivars were more sensitive to dimethenamid compared to metolachlor, but to reveal these differences a 3X herbicide rate combined with excessive moisture were required (Osborne et al., 1992*b*). Other soybean studies indicate that the magnitude of soybean injury is greater with dimethenamid compared with metolachlor (Osborne et al., 1992*a*).

In 1996 dry bean planting was delayed until late June in Michigan because of excessive rainfall in late May and early June. Dimethenamid injured dry bean in some fields in Michigan. Environmental conditions at the time of planting and bean emergence may have influenced dry bean response to dimethenamid. The objective of this research was to determine whether environmental conditions at the time of planting and emergence influenced dry bean tolerance to dimethenamid or metolachlor.

MATERIALS AND METHODS

Field experiments were conducted in 1998 and 1999 at the Saginaw Valley Dry Bean and Sugar Beet Research Farm, Saginaw, Michigan. In 1998 the study was conducted on a Misteguay silty clay loam (Aeric Haplaquept, fine, mixed (calcareous), mesic), 9% sand, 45% silt, and 46% clay with a pH of 8.0 and 1.9 % organic matter. When the experiment was repeated in 1999 the soil type was a Misteguay silty clay loam (14% sand, 47% silt, and 39% clay) with a pH of 7.8 and 2.6% organic matter. To eliminate the confounding factor of weed interference on navy bean maturity and yield, plots were maintained weed-free by hand-hoeing for the duration of the growing season.

The seedbed was prepared with moldboard plowing in the fall followed by two passes with a Danish S-tine field cultivator in the spring. 'Vista' and 'Schooner' navy beans were planted in strip plots on five planting dates in 1998 and 1999 (Table 1). The first planting date each year was during the third week of May. Dry beans were planted approximately every 10 days from the first date of planting through early July. The plots, 4 rows wide and 6.7 m in length, were seeded at a population of 272,000 seeds ha⁻¹ with a crop row spacing of 71 cm.

Herbicide treatments applied to each navy bean cultivar included dimethenamid at 2.3 kg ha⁻¹ PRE and metolachlor at 2.8 kg ha⁻¹ PRE. Navy bean injury was evaluated by visually assessing the percent leaf area reduction at the unifoliate, 1st trifoliate and 3rd trifoliate stages. In addition three plants were randomly chosen from the middle two rows of each plot at each evaluation date, cut off at the soil surface, and leaf area (cm²) measured with a LI-3000 portable area meter (LI-COR, Lincoln, Nebraska).

Dry beans reach full maturity upon completing Stage R9. This development stage is characterized by leaf senescence, leaf desiccation and leaf abscission. Physiological maturity was determined by visually recording percent leaf yellowing on a scale from 0 (plants still in Stage R8, pod filling) to 100% (plants are fully mature and ready for harvest). The maturity of each cultivar was compared to dry bean maturity in the untreated control plots. Ratings were taken when leaves in the untreated control plots were two-thirds yellow. Beans from 4.3 m of the center two rows were hand-harvested by pulling and threshed with a stationary thresher. Yields were adjusted to kg ha⁻¹ at 18% moisture.

The experiment was conducted twice as a randomized complete block design in a multi-location split-plot arrangement. The 'Vista' and 'Schooner' navy beans were planted in three 4 rows strips on each planting date. Treatments were randomized in the same arrangement on each planting date within the strips. The five planting date were each planted in different locations within the same field. Dry bean cultivar was the main-plot factor and herbicide treatment was the sub-plot factor. Data were subjected to analysis of variance and means separated using Fisher's protected LSD test at $P \leq 0.05$ level of probability. Visual estimates of leaf area reduction were subjected to square root transformation prior to statistical analysis. Nontransformed data are presented for clarity. Data from 1998 and 1999 are presented separately because of year by date of planting by treatment interactions.

RESULTS AND DISCUSSION

In 1998 dry bean injury from dimethenamid and metolachlor was greatest for the June 1 and June 22 planting dates (Tables 1 and 2). Dimethenamid was more injurious to 'Vista' navy bean compared to metolachlor for all planting dates except May 21 in 1998 (Table 1). Dimethenamid also was more injurious to the 'Schooner' navy bean compared to metolachlor for the June 1, 1998 planting date only (Table 1). Both herbicides reduced the leaf area of 'Vista' navy bean planted on June 1 and June 22 and 'Schooner' navy bean planted on June 22, 1998. Additionally, dimethenamid reduced the leaf area of the 'Vista' cultivar compared to the untreated control on the July 2, 1998 planting date. Because the injury from dimethenamid or metolachlor varied greatly from one plant to another, the visual injury ratings were more representative of the amount of injury caused by these herbicides. In 1998 the leaf area of the plants treated with metolachlor was greater than the plants in the untreated control plots on May 21, June 11, and July 2 (Table 2).

In 1999 dimethenamid was significantly more injurious to dry beans than metolachlor on May 20 and June 10 (Table 1). Dimethenamid reduce the leaf area of the 'Vista' and 'Schooner' cultivars for the May 20, 1999 planting date when compared to the untreated control (Table 2).

Early season injury to dry beans from dimethenamid delayed maturity of 'Vista' and 'Schooner' navy beans for every planting date in 1998 except May 21. Metolachlor delayed maturity of 'Vista' navy bean for the June 1, June 11, and June 22 planting dates, and for the 'Schooner' cultivar on the June 1 and June 22 planting dates in 1998. Dimethenamid delayed the maturity of the 'Vista' cultivar at the May 20 and June 21 planting dates in 1999

(Table 3), while metolachlor delayed for the June 21 planting date in 1999. Maturity and yields were not recorded for the July 6 planting in 1999 due to a frost prior to seed maturity. Seed yields for each planting date in 1998 and 1999 were not reduced where dimethenamid or metolachlor were applied compared with the untreated control (Table 4).

Dry beans planted on June 1 and June 22, 1998 incurred the greatest injury from dimethenamid and metolachlor PRE at twice the recommended rates (Table 1 and Table 2). Penner and Graves (1972) found that alachlor at 3.32 kg/ha (twice the normal rate) caused injury to navy beans at 20 and 25 C but not at 30 C. The lowest mean temperature 0 to 10 days after planting (DAP) occurred after the June 1, 1998 and May 20, 1999 planting dates (Table 5). Therefore cool temperature may have contributed to the injury seen for the June 1, 1998 planting date.

Many herbicides become more available for plant uptake as soil moisture increases (Jones et al., 1990; Tripp and Baldwin, 1988; Wehtje et al., 1987). The amount of rainfall received during the 10 DAP varied over the dates of planting in 1998 and 1999. The amount of rain which fell in the 10 DAP on the June 1 planting date in 1998, 0.69 cm, was the lowest recorded for the five planting dates in that year (Table 5). The dry beans planted on June 22 received 1.07 cm over this period of 10 DAP (Table 5). The amount of rain that fell during the 10 DAP on the five dates of planting in 1999 ranged from 0.66 to 3.15 cm. There was minimal injury from dimethenamid and metolachlor to navy beans for all of these planting dates (Table 5).

The amount of rain which fell during the 3-day period of bean emergence (5 to 7 DAP) was greatest for the June 1, 1998 and June 22, 1998 planting dates (Table 5). The

rainfall received at the time of emergence (crook stage) for the other three planting dates in 1998 and all planting dates in 1999 was 0.18 cm or less (Table 5). Dimethenamid and metolachlor became readily available for uptake at this time when the bean hypocotyl was growing through the PRE herbicide treatment and emerging from the soil surface. In greenhouse research dry bean injury was greatest when the hypocotyl was exposed to dimethenamid (Poling and Renner, 1998). In other field research, dimethenamid applied PRE to navy beans in 1999 resulted in 40% injury 10 DAP compared with the untreated control (Renner and Kells, 1999). In this research 1.2 cm of rain fell during the time of emergence (5 to 7 DAP). Our results do not agree with that of Osborne et al. (1992b) where injury to soybeans occurred when dimethenamid or metolachlor were applied above recommended rates and excessive moisture conditions persisted. In our research moisture at the time of dry bean emergence appeared to be a critical factor in dry bean injury from dimethenamid or metolachlor PRE.

SUMMARY

Environmental conditions that occur following application of dimethenamid or metolachlor affect dry bean tolerance to these herbicides. The quantity of precipitation that a dry bean field receives at the crook stage following an application of dimethenamid or metolachlor is crucial. Rice and Putnam (1980) observed that early uptake of alachlor in snap bean occurred primarily via the shoot portion of the emerging seedling. Rain at the time of emergence could increase the amount of herbicide absorbed by the dry bean

hypocotyl and result in crop injury. Moderate temperature (22 to 31 C) did not appear to play a significant role in dry bean injury from dimethenamid or metolachlor in our research.

LITERATURE CITED

- Anonymous. 1992. SAN 582G experimental herbicide: A technical overview. Sandoz Agro, Inc., Des Plaines, IL 60018.
- Cieslar, B. and L.K. Binning. 1974. Translocation of ¹⁴C-alachlor in lima beans as related to phytotoxicity. Proc. North Cent. Weed Control Conf. 29:323.
- Driver, J.E., T.F. Peeper, and A.C. Guenzi. 1992. In vitro selection for increased wheat tolerance to metsulfuron. Proc. South. Weed Sci. Soc. 45:316.
- Edwards, C.J., Jr., W.L. Barrentine, and T.C. Kilen. 1976. Inheritance of sensitivity of soybean cultivars to metribuzin. Crop Sci. 16:119-120.
- Gerber, H.R., G. Muller and L. Ebner. 1974. CGA 24705, a new grass killer herbicide. Proc. 12th Br. Weed Control Conf. 3:787-794.
- Jones, R.E., Jr., P.A. Banks, and D.E. Radcliffe. 1990. Alachlor and metribuzin movement and dissipation in a soil profile as influenced by soil surface condition. Weed Sci. 38:589-597.
- Osborne, B.T., D.R. Shaw, and R.L. Ratliff. 1992a. Soybean cultivar tolerance to SAN 582H and metolachlor as influenced by soil moisture. Weed Sci. 43:288-292.
- Osborne, B.T., D.R. Shaw, R.L. Ratliff, and G.P. Ferguson. 1992b. Soybean cultivar tolerance to SAN 582 and metolachlor as influenced by soil moisture. Proc. South. Weed Sci. Soc. 45:52.
- Poling, K.W. and K.A. Renner. 1998. Dry edible bean response to dimethenamid and metolachlor. Proc. North Central Weed Sci. Soc. Vol. 43:120.
- Penner D. and D. Graves. 1972. Temperature influence on herbicide injury to navy beans. Agron. J. 64:30.
- Putnam, A.R. and R.P. Rice, Jr. 1979. Environmental and edaphic influences on the selectivity of alachlor on snap beans (*Phaseolus vulgaris*). Weed Sci. 27:570-574.
- Renner, K.A., W.F. Meggitt, and D. Penner. 1988. Response of corn (*Zea mays*) cultivars to imazaquin. Weed Sci. 36:625-628.
- Renner, K.A. and J. Kells. 2000. 2000 Weed Control Results in Field Crops. Department of Crop and Soil Sciences. Michigan State University.

Rice, R.P., Jr. and A.R. Putnam. 1980. Temperature influences on uptake, translocation, and metabolism of alachlor in snap beans (*Phaseolus vulgaris*). Weed Sci. 28(2):131-134.

Sniper, C.E., J.E. Street, and D.L. Boykin. 1987. Influence of flood interval and cultivar on rice (*Oryza sativa*) tolerance to fenoxaprop. Weed Sci. 35:842-845.

Stephenson, G.R., J.E. McLeod, and S.C. Phatak. 1976. Differential tolerance of tomato cultivars to metribuzin. Weed Sci. 24:161-165.

Tripp, T.N. and F.L. Baldwin. 1988. Effect of excessive precipitation on soybean injury from imazaquin and chlorimuron. Weed Sci. Soc. Am. Abstr. 28:39.

Wehtje, G., R. Dickens, J.W. Welcut, and B.F. Hajek. 1987. Sorption and mobility of sulfometuron and imazapyr in five Alabama soils. Weed Sci. 35:858-864.

Table 1. Injury on 'Vista' and 'Schooner' navy bean from dimethenamid at 2.3 kg ha⁻¹ and metolachlor 2.8 kg ha⁻¹ PRE at the 1st trifoliolate growth stage on five planting dates in 1998 and 1999.

		Visual injury at 1 st trifoliolate growth stage									
		1998					1999				
Treatment		May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6
		_____ %					_____ %				
Vista											
dimethenamid	4 e	27 a	4 e	24 a	7 d	7 a-e	11 ab	4 ef	8 a-c	5 c-f	
metolachlor	4 e	21 b	0 g	16 c	3 f	1 g	9 ab	3 f	8 a-c	4 ef	
untreated	0 g	0 g	0 g	0 g	0 g	0 g	0 g	0 g	0 g	0 g	
Schooner											
dimethenamid	4 e	25 a	1 g	22 ab	6 de	7 a-e	9 ab	4 ef	7 a-e	11 a	
metolachlor	3 f	18 bc	0 g	19 bc	4 e	1 g	7 a-e	1 g	7 a-e	11 a	
untreated	0 g	0 g	0 g	0 g	0 g	0 g	0 g	0 g	0 g	0 g	
CV (%)		_____ 18					_____ 31				

Table 2. Effect of dimethenamid at 2.3 kg ha⁻¹ and metolachlor 2.8 kg ha⁻¹ PRE on 'Vista' and 'Schooner' navy dry bean leaf area at the 1st trifoliate growth stage on five different planting dates in 1998 and 1999.

		Leaf area at 1 st trifoliate growth stage									
		1998					1999				
Treatment		May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6
		cm ²					cm ²				
Vista											
dimethenamid	119	56	218	130	139	82	175	258	152	301	
metolachlor	153	81	324	170	346	146	173	200	185	326	
untreated	113	157	224	270	296	163	209	276	273	406	
Schooner											
dimethenamid	174	80	294	80	297	104	161	285	159	323	
metolachlor	148	99	242	127	276	163	161	274	187	269	
untreated	175	127	217	232	361	151	209	266	240	394	
LSD (p≤0.05)	- 31 -	- 54 -	- 59 -	- 106 -	- 83 -	- 55 -	- 49 -	- 89 -	- 137 -	- 138 -	
CV (%)	- 9 -	- 24 -	- 10 -	- 28 -	- 13 -	- 18 -	- 12 -	- 15 -	- 30 -	- 18 -	

Table 3. Effect of dimethenamid at 2.3 kg ha⁻¹ and metolachlor at 2.8 kg ha⁻¹ PRE on 'Vista' and 'Schooner' navy bean maturity from five planting dates in 1998 and 1999.

Treatment	Maturity ^a									
	1998					1999				
	May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6
	_____ % _____					_____ % _____				
Vista										
dimethenamid	63	58	37	47	50	55	80	72	23	-
metolachlor	63	63	42	53	62	68	83	67	30	-
untreated	63	73	63	60	65	67	85	68	41	-
Schooner										
dimethenamid	67	53	53	43	48	67	70	47	62	-
metolachlor	67	58	61	52	55	73	68	50	60	-
untreated	67	68	63	65	58	73	75	56	63	-
LSD (p≤0.05)	_____	_____ 7 _____				_____	_____ 10 _____			
CV (%)	_____	_____ 7 _____				_____	_____ 9 _____			

^a maturity was visually evaluated when approximately 66% of the leaves in the untreated control plots had turned yellow

Table 4. Effect of applications of dimethenamid at 2.3 kg ha⁻¹ and metolachlor at 2.8 kg ha⁻¹ PRE on dry bean yield from five planting dates in 1998 and 1999.

Treatment	Yield ^a									
	1998					1999				
	May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6
	_____ kg ha ⁻¹ _____					_____ kg ha ⁻¹ _____				
Vista										
dimethenamid	1770	1864	2140	1718	1871	4647	3306	4053	3534	—
metolachlor	1703	2009	2115	1883	2185	4672	3429	4590	3455	—
untreated	1826	1972	1909	2058	2178	4355	3366	4135	3246	—
Schooner										
dimethenamid	1924	1987	2088	2152	2502	3743	3937	4893	3713	—
metolachlor	1939	2092	2222	2197	2450	4266	3970	4665	3635	—
untreated	1875	2170	2140	2092	2454	3937	1767	4904	3735	—
LSD (p≤0.05)	_____	_____	ns _____	_____	_____	_____	_____	ns _____	_____	_____
CV (%)	_____	_____	7 _____	_____	_____	_____	_____	8 _____	_____	_____

^a adjusted to 18% moisture

Table 5. Mean temperature (10 DAP), rainfall intervals (10 DAP) and accumulative rainfall at the crook stage at each date of planting in 1998 and 1999.

Environmental Parameter	1998						1999			
	May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6
Mean Temperature (0-4 DAP)	- C - 19	19	27	33	27	22	24	29	29	28
Mean Temperature (5-7 DAP)	- C - 29	22	28	32	26	14	33	19	31	26
Mean Temperature (8-10 DAP)	- C - 23	25	33	28	27	29	32	25	27	29
Mean Temperature (0-10 DAP)	- C - 28	22	29	31	25	22	29	25	29	28
Rainfall (0-4 DAP)	- cm- 0.74	0.00	0.91	0.49	1.22	1.85	0.56	2.36	0.00	0.46
Rainfall (5-7 DAP)	- cm- 0.08	0.69	0.13	0.58	0.10	0.18	0.00	0.10	0.13	0.03
Rainfall (8-10 DAP)	- cm- 0.58	0.00	0.00	0.00	0.00	0.00	0.10	0.00	3.02	0.03
Accumulative Rainfall (0-10 DAP)	- cm- 1.40	0.69	1.04	1.07	1.32	2.03	0.66	2.46	3.15	0.56

APPENDIX

Appendix Table 1. Effect of applications of dimethenamid and metolachlor PRE on 'Vista', 'Schooner', and 'Newport' navy dry bean and 'Midnight' and 'T-39' black bean leaf area at the unifoliate growth stage in 1998 and 1999.

Herbicide	Rate	1998					1999				
		Vista	Schooner	Newport	Midnight	T-39	Vista	Schooner	Newport	Midnight	T-39
	kg ha ⁻¹			cm ²					cm ²		
Dimethenamid	1.3	32	42	20	20	37	81	86	72	84	54
Dimethenamid	2.6	18	35	29	15	40	94	83	69	89	75
Metolachlor	2.9	15	23	17	15	22	88	82	75	83	74
Untreated		65	50	31	44	44	96	75	73	90	79
LSD (p≤0.05)				15					16		
CV (%)				30					12		

Appendix Table 2. Effect of applications of dimethenamid and metolachlor PRE on 'Vista', 'Schooner', and 'Newport' navy dry bean and 'Midnight' and 'T-39' black bean leaf area at the 3rd trifoliolate growth stage in 1998 and 1999.

Herbicide	Rate	1998					1999				
		Vista	Schooner	Newport	Midnight	T-39	Vista	Schooner	Newport	Midnight	T-39
	kg ha ⁻¹	cm ²					cm ²				
Dimethenamid	1.3	400	392	344	264	302	608	685	629	588	560
Dimethenamid	2.6	372	358	331	379	348	673	501	647	563	546
Metolachlor	2.9	272	347	213	266	344	642	489	541	475	469
Untreated		496	423	364	332	505	602	733	689	744	533
LSD (p≤0.05)		122					221				
CV (%)		21					22				

Appendix Table 3. Effect of applications of dimethenamid at 2.3 kg ha⁻¹ and metolachlor at 2.8 kg ha⁻¹ PRE on 'Vista' and 'Schooner' navy dry bean leaf area at the unifoliate growth stage in 1998 and 1999.

Leaf area at unifoliate growth stage											
1998											
1999											
Treatment	May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6	
	cm ²					cm ²					
Vista											
dimethenamid	51	11	69	43	71	41	51	66	67	69	
metolachlor	49	16	80	53	91	68	57	65	67	68	
untreated	36	48	60	98	94	64	59	70	140	74	
Schooner											
dimethenamid	53	12	52	46	85	104	57	56	85	61	
metolachlor	43	22	71	56	87	163	53	69	82	73	
untreated	54	45	60	92	129	151	54	81	113	90	
LSD (p≤0.05)	—43—	—7—	—22—	—20—	—43—	—29—	—13—	—6—	—30—	—15—	
CV (%)	—39—	—12—	—15—	—14—	—21—	—23—	—10—	—4—	—14—	—9—	

Appendix Table 4. Effect of applications of dimethenamid at 2.3 kg ha⁻¹ and metolachlor at 2.8 kg ha⁻¹ PRE on 'Vista' and 'Schooner' navy dry bean leaf area at the 3rd trifoliate growth stage in 1998 and 1999.

Treatment	Leaf area at 3 rd trifoliate growth stage									
	1998					1999				
	May 21	June 1	June 11	June 22	July 2	May 20	June 1	June 10	June 21	July 6
	cm ²					cm ²				
Vista										
dimethenamid	531	350	745	429	335	385	711	447	361	530
metolachlor	514	503	691	461	404	660	656	418	390	707
untreated	563	516	661	740	426	718	792	598	585	789
Schooner										
dimethenamid	446	327	438	462	355	415	582	443	366	483
metolachlor	533	342	748	495	348	528	584	463	389	480
untreated	479	454	692	479	447	562	768	536	633	818
LSD (p≤0.05)	- 150 -	- 80 -	- 142 -	- 228 -	- 104 -	- 330 -	- 291 -	- 162 -	- 282 -	- 152 -
CV (%)	- 13 -	- 9 -	- 9 -	- 20 -	- 12 -	- 27 -	- 19 -	- 15 -	- 27 -	- 11 -

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