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Herbicide effects on soil arthropod dynamics and wheat straw decomposition in a North Carolina no-tillage agroecosystem *

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Summary. Herbicide combinations of paraquat, glyphosate, alachlor, linuron, fluazifopbutyl, aciflurofen, and bentazon were investigated for their impact on soil arthropod population dynamics and surface wheat straw decomposition (weight loss) within a North Carolina coastal plain agroecosystem. Herbicides were applied twice (preemergence and mid-bloom) at recommended field rates to soybeans no-till planted into wheat residue. Separate measurements were made for surface crop residue and soil-dwelling (0–3 cm depth) arthropods. Decomposition of herbicide (glyphosate) and nonherbicide-treated wheat straw residue was compared using mesh bag techniques. Decay rate constants were estimated for glyphosate and nonherbicide-treated wheat straw residue by fitting a two-component model to the data. Comparison of soil microarthropod numbers from herbicide and nonherbicide treatments showed no consistent trend, suggesting that abiotic factors such as soil temperature and moisture were probably more significant than herbicide effects in regulating soil microarthropod number and activity. Herbicides had no effect on soil macroarthropod number or activity until late in the season when macroarthropods were most abundant under weedy, no-tillage conditions. Moist soil and litter, low soil temperature, floral diversity, and high weed-seed availability probably enhanced macroarthropod numbers in nonherbicide treatments. Decomposition (ash-free weight loss) of nonherbicided, surface crop residues was more rapid than herbicide (glyphosate) treated, indicating that herbicide effects occur at the decomposer as well as producer level of agroecosystems.

Key words: Decomposition – Glyphosate – Herbicide – No-tillage – Paraquat – Soil arthropods – Wheat straw

No-tillage practices generate soil litter conditions different from conventionally plowed systems. No-tillage leaves the soil surface covered with the previous crop's residue, generating many changes in soil properties. An increase in organic matter and nutrient concentrations at shallow depths (ca. 0–10 cm) have been shown to occur following several years of continuous no-tillage (Hargrove et al. 1982; Blevins et al. 1983; Stinner et al. 1983; House et al. 1984). Soil biota are also affected by the elimination of tillage. At and near the soil surface (ca. 0–5 cm) of no-tillage systems, enyzme activity (Dick 1984), microbial biomass (Doran 1980), and faunal (House and Parmelee 1985) numbers are enhanced. Moisture loss is reduced under no-tillage and the surface crop residues provide a relatively continuous substrate for decomposers (Crossley et al. 1984).

Weed control under no-tillage management is currently achieved almost exclusively through herbicides, some of which have been reported to affect soil arthropods negatively (Eijsackers and van de Bund 1980; Subuja and Snider 1981). Yet data are lacking on the combined effects of no-tillage methods and recently developed postemergence herbicides on soil arthropods. Since soil microarthropods as well as microorganisms influence decomposition and nutrient dynamics in natural ecosystems (Elkins and Whitford 1982; Anderson et al. 1983; Seastedt 1984; Seastedt and Crossley 1984), alteration of soil arthropod and other faunal populations resulting from herbicide application should have corresponding effects on crop residue decomposition.

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The present study had two objectives: (1) to compare soil arthropod population dynamics under herbicide and nonherbicide no-tillage systems and (2) to quantify the influence of the soil arthropod fauna on wheat straw decomposition in herbicide and nonherbicide treatments through generation of decay rate constants.

Materials and methods

Site description. Field research was conducted at the Central Crops Research Station, Clayton, NC, a site representative of the coastal plain of the southeastern United States. The soil of the agricultural plots is Norfolk loamy sand (Typic Paleudult), and the plots are relatively flat (slopes < 3%). The average length of the frost-free growing season is 205 days. Winters are mild and summers are hot, with an average annual temperature of 16 °C. The site typically receives 1120 mm precipitation year^{-1}; however, periods of drought sufficient to influence plant growth are common during the growing season.

Cropping practices. Twelve 0.06-ha plots were established using a randomized complete block design. After conventional seedbed preparation, all plots were planted with wheat (*Triticum aestivum* L.) on 1 October 1983. Following wheat harvest on 17 June 1984, soybeans were no-till planted on 27 June 1984 in 1-m rows at a rate of 50 kg seeds ha^{-1}. Plots received no soil disturbance other than that from the seed opening slot on the no-till planter. A thick mulch of wheat straw was left on the soil surface. On 28 June, the following preemergence herbicide treatments were established: (1) paraquat at 0.56 kg ai (active ingredient) ha^{-1}, alachlor at 2.24 kg ai ha^{-1}, and linuron at 0.56 kg ai ha^{-1} (hereafter referred to as paraquat treatment); (2) glyphosate at 1.57 kg ai ha^{-1}, alachlor at 2.24 kg ai ha^{-1}, linuron at 0.56 kg ai ha^{-1} (hereafter referred to as glyphosate treatment); and (3) no herbicide. A second postemergence herbicide treatment was applied to all herbicide-treated plots on 1 August: fluazifopbutyl 0.56 kg ai ha^{-1}, acifluronfen 0.84 kg ai ha^{-1}, and bentazon 1.68 kg ai ha^{-1}. Soybeans were combine harvested on 16 November 1984.

Arthropod sampling. Microarthropods were collected in soil cores (5 cm diameter by 3 cm deep) and in surface crop residues (100-cm^2 quadrat) from glyphosate-treated and nonherbicide treated plots on six dates during the 1984 soybean growing season: 29 June, 16 July, 1 August, 17 August, 30 October, and 16 November. Sampling location was restricted to within 10 cm of the crop row. Microarthropods were extracted separately from soil and surface residues into 95% alcohol using modified Tullgren funnels (Merchant and Crossley 1970).

Macroarthropods were collected from glyphosate, paraquat, and control (nonherbicide) treatments using pitfall traps (1-l plastics cups containing 250 ml ethylene glycol to kill and preserve arthropods). Pitfall traps were left covered except for 24-h trapping periods on three dates: 28 June, 29 June, and 10 August.

Litterbag study. Information on decomposition (weight loss) of surface crop residue in glyphosate and nonherbicide treatments was gleaned from replicated polyester screen, 10×10 cm mesh bags. Four mesh sizes, 0.05 mm, 0.20 mm, 1.00 mm, and 5.00 mm, were used; 0.05 mm allowed access of microflora and nematodes only, 0.20 mm allowed access of microarthropods and smaller organisms, while 1.00-mm and 5.00-mm mesh sizes allowed access of all but the largest fauna. Three grams of unground wheat straw were placed in each bag and sewn closed. This amount of crop residue represented approximately the amount of surface litter that was left on the field after wheat harvest. Mesh bags containing wheat residue were placed on the soil surface on 2 July in nonherbicide and in the glyphosate treatments.

To estimate weight loss from abiotic sources, an additional set of litter bags was treated with a saturated solution of mercuric chloride and copper sulfate, according to the methods of Vossbrinck et al. (1979). Mercury-treated bags were placed in the field on 2 July and collected twice, on 30 October 1984 and 30 September 1985.

During the soybean growing season, mesh bags from glyphosate-treated and nonherbicide-treated plots were collected on four dates: 1 August 1984, 30 October 1984, 5 March 1985, and 30 September 1985. In the laboratory, each bag was extracted for arthropods using the methods previously described. Arthropods were identified and enumerated into the following groups: mites (Acari), springtails (Collembola), and other arthropods (spiders, beetles, etc.). Crop residue material inside each bag was then oven dried at 60 °C for 72 h and weighed. To correct for soil entering the litterbags, subsamples were ashed in a muffle-furnace at 500 °C for 1 h. Ash-free weights of crop residue within each bag were then calculated. Results are thus expressed as ash-free dry weight remaining.

Decomposition rate constants were estimated from a two-component exponential model:

$$AFWT = AFWTO\ (KO + (1 - KO) \exp(-K1 \cdot t)),$$

where $AFWT$ = ash-free weight of crop residue remaining, $AFWTO$ = original ash-free weight of crop residue, KO = final proportional value for AFWT (the lower asymptote is thus $KO{*}AFWTO$), and $K1$ = decay rate constant.

Statistical analyses were made using the Statistical Analysis System (Barr et al. 1979). Each data set was subjected to analysis of variance and Duncan's multiple range test (general linear model procedure). Analyses were conducted by sample collection date (randomized complete block design). Values of F were considered to be significant at $\alpha = 0.05$.

Weather information concerning precipitation as well as soil and air temperature was obtained from meteorological instruments on the Central Crops Research Station, Clayton, NC. Soil temperature was measured monthly at 3 depths (2 cm, 5 cm, and 10 cm) using electronic digital thermometers. Soil moisture (0–5 cm depth) was estimated monthly using gravimetric techniques.

Results and discussion

Microarthropods

Extraction efficiency of Tullgren funnels was estimated from comparison with a xylene-flotation method (Marston and Hennessey 1978). Acari (mites) were extracted with an efficiency of 61.9%, while collembolan extraction was much less efficient at only 30.7%. Other microarthropods such as Coleoptera, Diptera, and Aranae (spiders) were recovered from Tullgren funnels with the relatively high extraction efficiency of 67.9%.

Microarthropod densities ranged from less than 1000 to nearly 30000 individuals m^{-2} in the surface crop residue on 1 August 1984 (Fig. 1A). Collembola comprised 25% to nearly 40% of the total number of microarthropods, while Acari accounted for nearly 60%. The taxonomic composition of Collembola included several species of Entomobryidae [*Lepidocyrtus cinereus* Folsom, *Orchesella ainsliei* Folsom, and

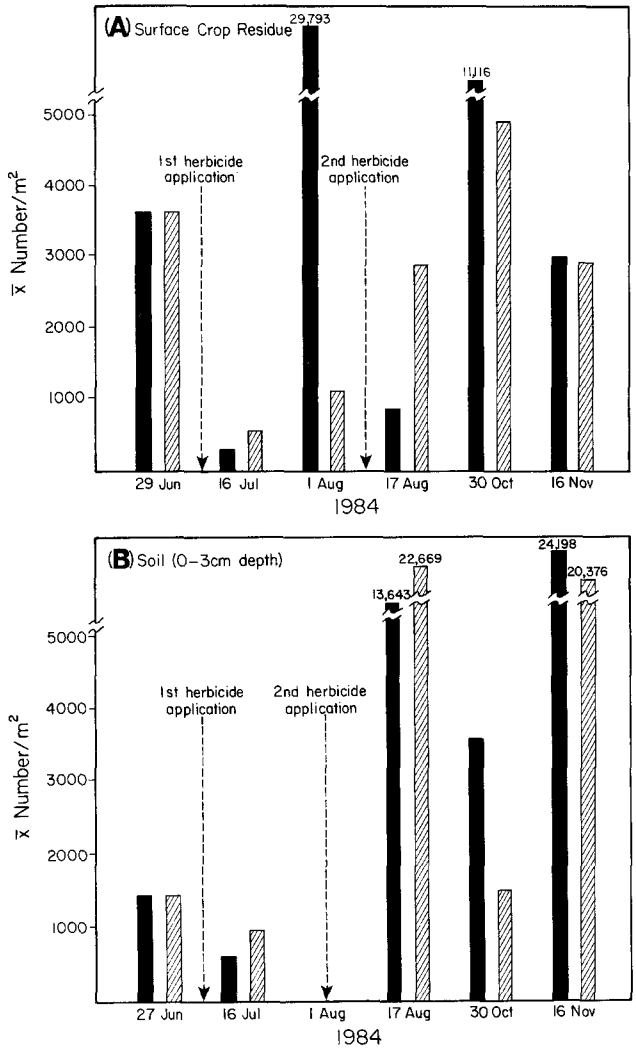

Fig. 1A, B. Seasonal dynamics of the number of microarthropods per square meter occurring in: **A** surface crop residue and **B** soil (0–3 cm depth) in glyphosate and nonherbicided, no-tillage soybean systems. Mean values are shown. Treatment paris were significantly different ($P<0.05$) on 1 August, 17 August, and 30 October 1985. ■: no-tillage, no herbicide; ▨: no tillage, herbicide

Tomocerus flavescens (Tullgren)], two species of Poduridae [*Brachystomella parvula* (Schaeffer) and *Tullbergia granulata* Mills], one Isotomidae (*Isotoma trispinata* MacGillivray), and one Sminthuridae (*Sminthurinus minutus* (MacGillivray)]. Acari taxonomic composition included: (1) four families of Mesostigmata: Laelapidae (*Cosmolaelaps* sp. and *Gaeolaelaps* sp.), Phytoseiidae (*Amblyseius* spp.), Ascidae (*Lasioseius* sp.), and Macrochelidae (*Macrochelus* spp.); (2) Acaridida; (3) two families of Prostigmata: Tarsonemidae and Cunaxidae; and (4) Oribatida in the family Galumnidae and other unidentified families. Oribatid mites comprised 70% or more of the Acari collected.

Comparison of herbicide and nonherbicide treatments indicated that glyphosate in combination with other herbicides did not suppress surface crop residue microarthropods (Fig. 1A). Fluctuations in the population dynamics of microarthropods cannot be attributed to the direct effects of herbicides. No consistent trend between treatments occurred, suggesting that microarthropod population dynamics were influenced more by the depth, structural complexity, nutritional quality, and moisture and temperature conditions of surface litter than by adverse effects of herbicides (Curry 1970; Edwards and Stafford 1978; Bultman and Uetz 1984; Mallow et al. 1985).

Soil-dwelling microarthropod population dynamics (Fig. 1B) also suggested that glyphosate plus other herbicides had no adverse impact on number. Microarthropod population fluctuations probably reflect responses to shifts in soil microclimatic conditions, rather than stress effects of herbicides (Moore et al. 1984). Spring and summer soil temperatures taken at 2 cm, 5 cm, and 10 cm were significantly higher ($P<0.01$) under herbicide than nonherbicide treatments. In addition, soil moisture (0–5 cm depth) was slightly lower ($P<0.1$) under herbicide than nonherbicide treatments. Throughout the growing season, soil temperatures were 1°–2 °C higher for herbicide than nonherbicide treatments, while soil moisture for herbicide treatments was at least 2% lower than that for nonherbicide treatments.

There is an apparent inverse trend between the soil and surface microarthropods. Comparison of the number of microarthropods occurring in the surface crop residue (Fig. 1A) with those occurring in the soil (Fig. 1B) suggest a vertical pattern of movement, probably in response to fluctuations in temperature and moisture. When soil microarthropod numbers were low, surface soil numbers were high. This trend was especially evident on 17 August when surface temperatures were high; the reverse trend occurred on 16 November when surface litter temperatures were presumably cool and soil temperatures warmer (Fig. 1B). Microarthropods were apparently quite mobile under no-tillage conditions, moving freely between the soil and surface crop residue in response to microclimatic changes.

Macroarthropods

Differences between glyphosate, paraquat, and untreated plots did not occur until late in the soybean growing season (10 August 1984), when the number of macroarthropods, especially carabid beetles of the genus *Harpalus* were significantly higher ($P<0.05$) in the nonherbicide than in either herbicide treatments (Fig. 2). Additional Carabidae genera and species collected included: *Acupalpus* sp., *Agonum* spp., *Amara* spp., *Anisodactylus* spp., *Bembidion* sp., *Calathus*

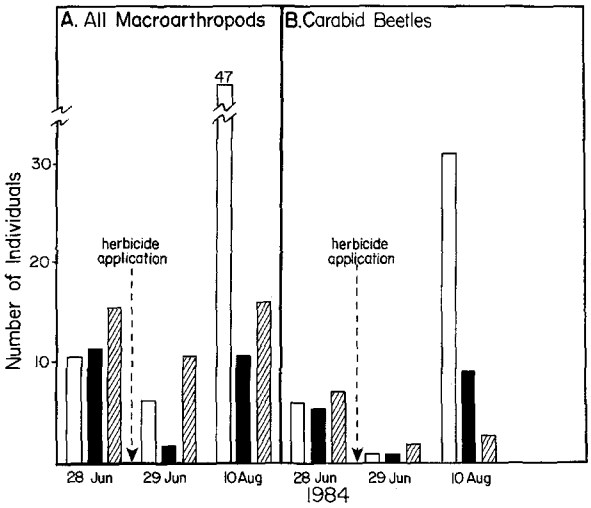

Fig. 2. Seasonal dynamics of total macroarthropods and carabid beetles collected in pitfall traps from nonherbicided, glyphosate-treated, and paraquat-treated no-tillage soybean systems. Mean values are shown. Nonherbicide was significantly different ($P<0.05$) from both herbicide treatments on 10 August 1985 only. □: no herbicide; ■: glyphosate; ▨: paraquat

opaculus LeConte, *Calosoma* spp., *Colliuris pennsylvanicus* L., *Cratacanthus dubius* Beau., *Galerita janus* F., *Pterostichus chalcites* Say, *Selenophorus opalinus* LeConte, *Stenolophus* spp., *Tachys* sp., and *Tetragonoderus* sp. Two species of Cicindelidae were also commonly collected: *Megacephala carolina* L. and *M. virginica* L.

In a similar study, Boiteau (1984) found carabids were significantly less abundant in herbicide-treated than nonherbicide-treated potatoes. Classes of herbicides do differ in their toxic effects on arthropods (Edwards and Stafford 1978). In laboratory studies, we found that when topically applied separately at recommended field rates, alachlor and atrazine both resulted in higher carabid beetle mortality than either paraquat and glyphosate, which did not differ from untreated controls (House and Brust, unpublished data). In addition, alachlor and atrazine both appeared to delay burrowing by ground beetles.

By mid- to end-of-season, habitat structure and floral diversity differences were pronounced between herbicide and nonherbicide treatments (i.e., weed biomass was very high in nonherbicide treatments). Since *Harpalus* spp. are weed seed-consuming beetles (Lund and Turpin 1977), their elevated numbers in the nonherbicide treatment, we suspect, were nutritionally linked. In a laboratory study, we found that two species of carabids, *Harpalus pennsylvanicus* and *H. caliginosus,* given free choice among several weed seed species, displayed a voracious appetite for seeds of johnsongrass [*Sorghum halepense* (L.)Pers.], ragweed (*Ambrosia artemisiifolia* L.), and redroot pigweed (*Amaranthus retroflexus* L.) (House, unpublished data). The impact of such weed seed feeding on plant densities the next growing season is unknown but could have weed management significance for continuous no-tillage or old fields returned to crop production using no-tillage methods.

Wheat straw decomposition

Ash-free weight mass loss from mercuric chloride-treated litterbags was significantly less ($P<0.01$) than from either glyphosate or nonherbicide bags (Fig. 3). Comparison of decay rate constants (combined over all four mesh sizes) for glyphosate and nonherbicide indicated that wheat straw decomposed more slowly in glyphosate treatments. Although the decay curves for glyphosate and nonherbicide treatments appear similar, the decay rate constants are significantly different at the 10% level (glyphosate $K1 = 0.22944 \pm 0.02687$; nonherbicide $K1 = 0.35258 \pm 0.03746$; mean ± asymptotic SD), strongly suggesting a slower decay rate for glyphosate compared to nonherbicide treatments. Earlier studies have also shown that direct treatment of plant residue with herbicides results in a general retardation of decomposition rate (Grossbard and Harris 1981; Hendrix and Parmelee 1985). We used an asymptotic decay curve to accommodate our data leveling-off at a positive quantity (KO). This model, we feel, provided a more precise approximation of the mass loss curves (Wieder and Lang 1982). Fitting our data to a single exponential model consistently overestimated early values and underestimated later values of organic material remaining. The implicit assumption of the exponential model is that the response will eventually decline to zero. Over the relatively short time period of this study (15 months), our data did not support this assumption. Instead our data declined to a value greater than zero.

Mesh size had no significant effect on the rate of decomposition within glyphosate or nonherbicide treatments, suggesting that microarthropod comminution of wheat straw residue was nominal in our field study. However, there was a general trend toward more microarthropods from nonherbicide than glyphosate treatments, especially on the first three sample dates (Table 1). Although we cannot offer a cause and effect relationship, we speculate that the large number of microarthropods in the nonherbicide treatment may have indirectly accelerated wheat straw decomposition through grazing on adhering microflora. In contrast, Hendrix and Parmelee (1985) reported larger numbers of microarthropods from glyphosate-treated than from nonherbicide-treated johnsongrass residue. They proposed that the overall effect of microarthropod grazing would be both to slow weight loss and to decrease fragmentation of residues. The response of microarthropods to glyphosate thus remains inconsistent. However, microarthropod consumption of microbes on various plant residues has been shown to in-

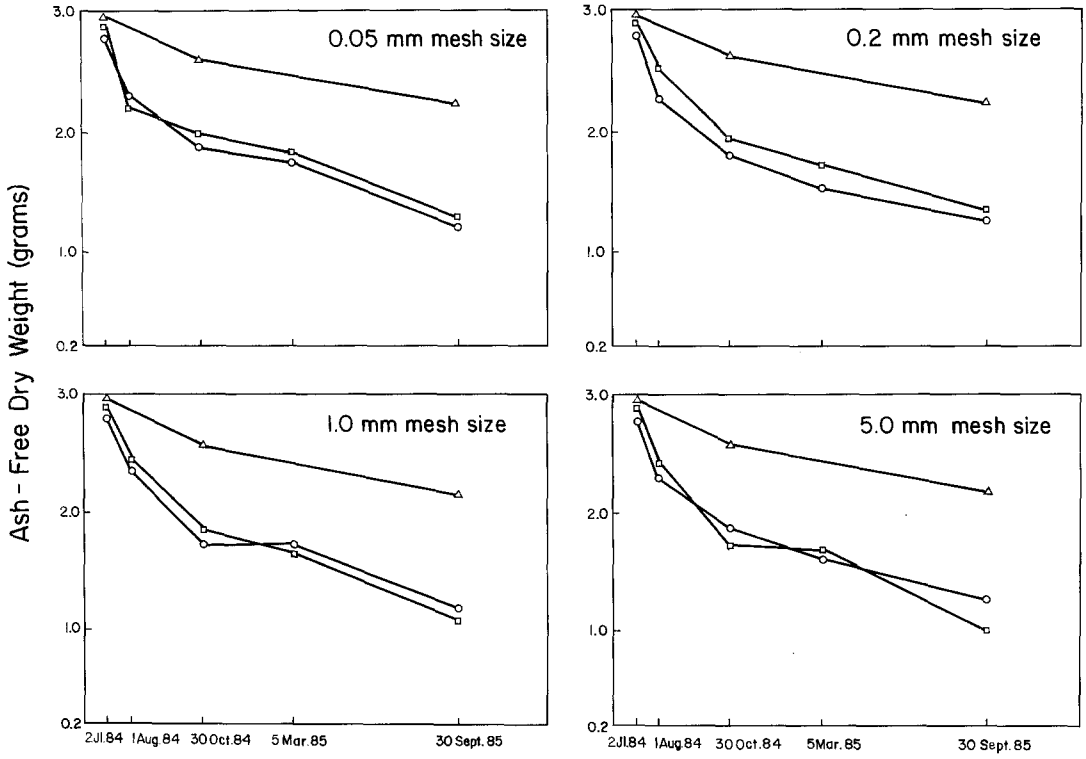

Fig. 3. Decomposition (ash-free dry weight mass loss) of wheat straw in glyphosate, nonherbicide, and mercuric chloride treatments. Mean values of each of four mesh sizes, 0.05 mm, 0.2 mm, 1.0 mm, and 5.0 mm, are shown. ○: non-herbicide; □: glyphosate; △: mercuric treated

Table 1. Mean number of microarthopods extracted from litterbags of four mesh sizes on four dates, treated and untreated, with herbicide (glyphosate, alachlor, linuron). Treatment pairs followed by different letters indicate statistical difference ($P<0.05$)

Mesh size	Herbicide treatment	1 August 1984	30 October 1984	5 March 1985	30 September 1985
0.05 mm	None	14 a	57 a	4 a	16 a
	Herbicide	11 a	54 a	11 a	31 a
0.20 mm	None	160 a	314 a	30 a	20 a
	Herbicide	31 b	235 a	21 a	53 a
1.00 mm	None	96 a	223 a	35 a	33 a
	Herbicide	93 a	134 a	2 b	25 a
5.00 mm	None	150 a	168 a	39 a	59 a
	Herbicide	105 a	171 a	8 b	75 a
All mesh sizes combined	None	420 a	762 a	108 a	128 a
	Herbicide	240 a	594 a	42 b	184 a

fluence microbial respiration. Hanlon and Anderson (1979) and Hanlon (1981) found that changes in microarthropod population density generated a bell-shaped fungal respiration response to increases in grazing intensity. Microarthropods can therefore enhance decomposition at low population densities by stimulation of microbial activity, or slow decomposition by depressing microfloral growth and activity when their population, and hence feeding, is high.

Conclusions

Although laboratory studies have shown that herbicides decrease soil arthropod populations (Eijsackers 1978; Subuja and Snider 1981; Hoy 1985), in the field direct toxic effects of herbicides on soil microarthropods are absent or minimal (Moore et al. 1984; Eijsackers 1985). Apparently, the indirect effects of herbicides, such as plant structural and metabolic changes, are a greater influence on the soil fauna than the herbicides themselves (Mahn and Kastner 1985). In our litterbag study, herbicides reduced the decay rate of wheat straw residue and lowered the total number of microarthropods, although to a lesser extent. Here, as in previous studies, direct treatment of plant residue with herbicides retarded decomposition through alteration of soil abiotic and biotic condi-

tions. It is clear, then, that herbicides not only directly affect primary producers, but also indirectly affect decomposer, and probably consumer level organisms. In our study, we suspect that herbicides, by inhibiting the growth of an interrow weed canopy, decreased the soil moisture content and raised soil temperatures, resulting in a slower decomposition of surface litter. In addition, soil microarthropod numbers were reduced, probably limiting their grazing and comminution activity, and, hence, reducing their regulatory influence over decomposition.

Finally, we mention an agronomically significant benefit of the slow disappearance of herbicide-treated surface crop residue: enhanced soil moisture conservation. Thus, herbicides through their various indirect, interactive effects can have positive as well as negative impacts on agroecosystems. Increasing our knowledge of the indirect ecological consequences of herbicides should help to rationalize our utilization of herbicides as agroecosystem management devices.

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