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Crop residue position and interference with wheat seedling development

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Abstract

Unweathered crop residues can produce growth-inhibiting substances, stimulate pathogen growth, and immobilize nutrients. The location of seed relative to residue may be an important factor in the early health of a crop. This greenhouse study simulated sowing conditions possible under annual dryland winter wheat (*Triticum aestivum* L.) production to evaluate the likelihood of inhibitory effects. We placed newly harvested, unweathered winter wheat residue on the soil surface, mixed with the seed, immediately above the seed, or 3 cm below the seed. Treatments using a plastic residue substitute and treatments using pasteurized soil and residue provided comparisons to the natural soil and wheat residue. Residue mixed with or placed above the seed caused a temporary delay in emergence. Since this occurred with both wheat and plastic residue, the delay is explained by the physical impedance of coleoptile growth. Wheat residue 3 cm below the seed reduced the height and rate of wheat plant development, indicating a biological inhibitory effect of the wheat residue. This reduction in height and development rate at 20 days after planting did not occur when the soil and residue were pasteurized. We conclude that winter wheat seedling growth can be inhibited if roots encounter unweathered residues. Published by Elsevier Science B.V.

Keywords: Crop residue; Seedling establishment; Emergence

1. Introduction

The retention of crop residues on the soil surface to reduce erosion, water loss, and field operations affects weed and disease control, nitrogen immobilization, seed–soil contact, and possibly seed germination and plant health. Laboratory and field studies have documented that crop residues can produce phytotoxic chemicals or support microbial activity inhibitory to plant growth (Patrick and Toussoun, 1965; Elliot et al., 1978). Laboratory procedures, using simple water extractions or long incubations under either aerobic or anaerobic conditions, have produced inhibition of germination, shoot, and root growth up to 90% (Kimber, 1973; Cochran et al., 1977; Mason-Sedun et al., 1986; Lodhi et al., 1987; Martin et al., 1990). In some greenhouse and field research the promotion of *Pythium* infection by wheat residues has explained most, if not all, of the residue effect measured (Cook et al., 1990). Some studies have demonstrated inhibition under field conditions (Lovett and Jessop, 1982; Purvis, 1990). Even where growth inhibition at early stages is not followed by yield reductions, the reduction of vigor at the early stages of crop development

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has negative implications for disease and weed control.

Stubble loses much of its inhibitory capacity over a period of weeks to months after harvest even when kept dry. Recently harvested plant residues that have not been dampened by rain have the greatest potential to produce phytotoxic effects (Kimber, 1967; Mason-Sedun et al., 1986; Cook et al., 1990; Purvis and Jones, 1990).

Residue can inhibit growth under sterile laboratory conditions and non-sterile laboratory and field environments (Kimber, 1967; Martin et al., 1990). The presence of soil between residue and seedling plants reduces and sometimes eliminates the effect of toxins produced by residue, indicating that soil microorganisms can detoxify phytotoxins (Patrick and Toussoun, 1965; Marshall and Naylor, 1984). If the soil can protect plants from phytotoxins, then the position of the residue in relation to growing seedling is important (Elliot et al., 1978).

We designed this greenhouse experiment to determine how the position of residue relative to seed affects germinating or seedling wheat.

2. Materials and methods

The principal comparison was among four positions of wheat residue relative to the seed. The four residue positions were (1) on the surface of the soil, (2) mixed with the seed, (3) directly above the seed, and (4) 3 cm below the seed (Fig. 1). The difference between the mixed residue and residue-above treatments is that in the mixed treatment seed is surrounded by residue, whereas in the residue-above treatment the seed is surrounded by soil except for the upper surface of the seed. To determine whether effects were due to physical interference, the same residue positions were repeated using a plastic residue substitute. To separate effects of soil or residue microbial activity from the effects of non-microbial phytotoxic substances, a set of treatments with pasteurized soil and residue was included. The experimental design, therefore, consisted of three factors: residue position, residue type, and natural versus pasteurized soil and residue. Seven replicate pots of each treatment were used in a completely randomized design.

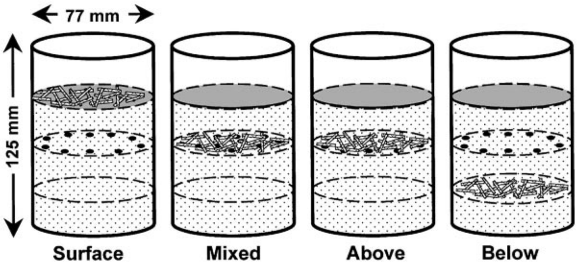

Fig. 1. Position of residue relative to position of seed in the four placement treatments.

The wheat residue was a pooled sample from four separate fields of ‘Stephens’ winter wheat planted the previous fall. The fields were grown under standard fertility with 90–135 kg N ha^{-1} added to reach a total soil residual and fertilizer N of 224 kg N ha^{-1}. The residue had not been rained on since maturity, and would be typical of the type and age of residue into which annual winter wheat would be planted. Stems, leaves and sheaths harvested from standing stubble in the field were cut to approximately 2 cm and stored at field moisture (8% w/w). Before pot assembly, the wheat residue was moistened in plastic bags (2.5 g wheat residue and 3.8 g water) and stored at 20°C for 36 h. For the pasteurized treatment, residue was placed in a 70°C oven for 1.2 h before adding water, and then returned to the oven for 8 h. The pasteurization process did not affect the appearance of the residue, and no difference in stiffness was noted. The weight of dry residue per pot would be equivalent to 5.3 Mg ha^{-1}.

The plastic residue was drinking straws (4 mm outer diameter, 0.2 mm wall thickness) cut to approximately 2 cm. The quantity of wheat residue used in each pot represented 5.3 Mg ha^{-1}; the quantity of plastic residue was an equivalent volume when compressed under a 750 g weight in the pots. Nine seeds of the winter wheat cultivar Madsen were planted in each pot. The seeds were commercially treated with the fungicides difenoconazole (1-{2-[4-(chlorophenoxy)-2-chlorophenyl-(4-methyl-1, 3-dioxolan-2-yl)-methyl]}-1H-1,2,4-triazole), and metalaxyl (methyl-*N*-(2-methoxyacetyl)-*N*-(2,6-xylyl)-DL-alaninate), and the insecticide lindane (γ-isomer of 1,2,3,4,5,6-hexachlorocyclohexane).

The soil was Walla Walla silt loam top soil (coarse-silty, mixed, mesic Typic Haploxeroll) from a field previously in spring wheat followed by summer fallow. The soil was thoroughly moistened, mixed, and half of the soil pasteurized in aluminum vessels with tightly fitting lids at 70°C for 13 h, at which time the soil had been above 60°C for at least 6 h. All soil was screened through a 4 mm screen and checked for equivalent moisture at 22% w/w$\pm$0.2. This is above -0.05 MPa according to moisture release curves performed on disturbed soil samples.

Pots were PVC water pipe measuring 77 mm inner diameter and 125 mm length. Aluminum foil adhesive tape created the pot bottom. The pots were assembled by adding soil in three 180 g portions (approximately 3 cm depth when tamped), with residue and seed added where appropriate for that treatment (Fig. 1). The soil was leveled and tamped lightly with a 750 g weight after each addition. Residue position treatments were assembled as follows: (1) residue on surface — bottom soil layer, middle soil layer, seed, top soil layer, layer of residue on surface; (2) residue mixed with seed — bottom soil layer, middle soil layer, layer of residue, seed placed on top of residue and allowed to fall into residue layer, top soil layer; (3) residue-above seed — bottom soil layer, middle soil layer, seed pressed into surface of middle soil layer, layer of residue, top soil layer; (4) residue-below seed — bottom soil layer, layer of residue, middle soil layer, seed, top soil layer.

The soil-filled portions of the pots were inserted into a chamber kept at a constant 13°C, leaving the tops of the pots and emerging plants exposed to greenhouse light and temperature conditions (Smiley and Uddin, 1993). Light intensity was about 440 microeinsteins m^{-2} s^{-1} at midday. Pot locations were re-randomized daily. The pots were covered with petri-dish lids to retard moisture loss until the first seedling in each pot touched the lid. Surface crusting was not a problem even for the later emerging treatments. When the driest pots had lost 20 g we added water to bring all pots to their original weight.

Emergence counts were made daily. Height and haun plant growth stage (Haun, 1973) of each plant were measured on days 14 and 20. On day 14 we also recorded the number of plants in each pot with abnormal geotropic response (growing at less than a 45° angle to the soil) and the number with abnormal leaf color or shape. On day 21 the soil was washed off the roots to allow evaluation of root and stem disease and coleoptile straightness.

Our experimental objectives concerned plant growth under natural conditions; the pasteurized treatment is included only as a comparison. Therefore, two analyses were performed, one using only natural treatments and the other including all treatments. Emergence, abnormal geotropic response, stunted leaves, and coleoptile straightness were arcsine transformed (Little and Hills, 1978) before analysis of variance and mean separation. Individual *t*-tests (at $\alpha=0.05/n$, $n=8$ for natural treatments alone, $n=16$ for all data) were performed to separate means where significant *F*-tests were found.

3. Results

3.1. Emergence

Residue position had a significant effect on emergence at day 8 ($p>F=0.0001$, natural treatments, Fig. 2). Residue mixed with or above the seed delayed emergence when compared to residue on the soil surface or residue 3 cm below the seed. After day 12 there were no differences in emergence among the four residue positions in the natural treatments. The delay in emergence appeared to be due to residue preventing individual coleoptiles from growing straight to the soil surface. A few plants germinated but never emerged. This is why some of the treatments had emergence ratings of less than 100% at day 18.

Plastic residue delayed emergence less than wheat residue ($p>F=0.0001$, natural treatments). This may simply reflect differences in physical impedance between the smooth tubular plastic and the more varied shapes of the wheat residue, which included stems and leaf sheaths and may have presented more horizontal surfaces to obstruct vertical growth. It could also involve a phytotoxic/pathogenic effect of the wheat residue on coleoptile growth. Since the plastic and wheat residues cannot be guaranteed to be equivalent in their physical impedance to growth of the coleoptile, a possible phytotoxic effect cannot be separated from the physical effect.

3.2. Height and development

Wheat residue caused a reduction in height and haun stage (Figs. 3 and 4). In the natural treatments, at

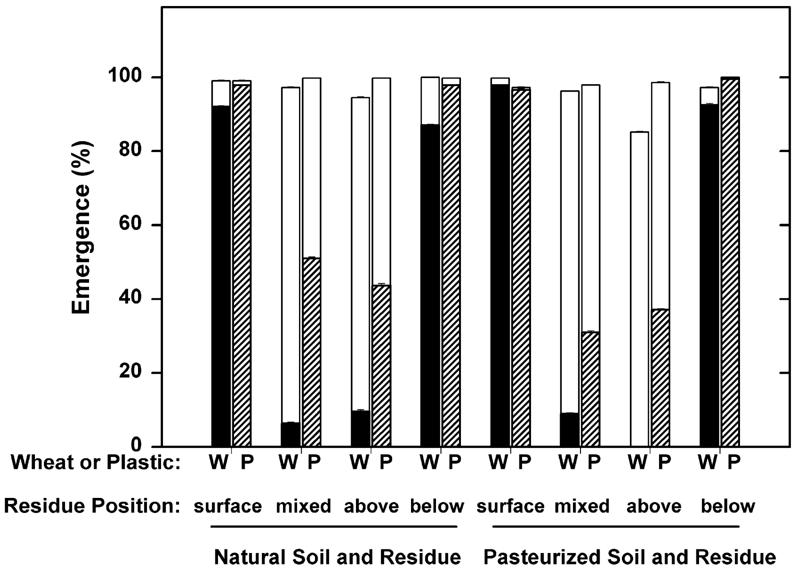

Fig. 2. Emergence (%) on day 8 (filled) and day 18 (empty). Error bars are standard deviation. Some of the error bars are too small to be visible in this figure.

day 14 the average height of plants is less for wheat residue than for plastic residue in the mixed and above treatments. When the pots were disassembled it was obvious that this was a result of physical impairment of emergence in those treatments. There was also decreased height where there could be no physical interference with emergence: the treatment with wheat residue placed below the seed. Furthermore, by day 20 the height differences between wheat and plastic residues decreased in other residue placements but

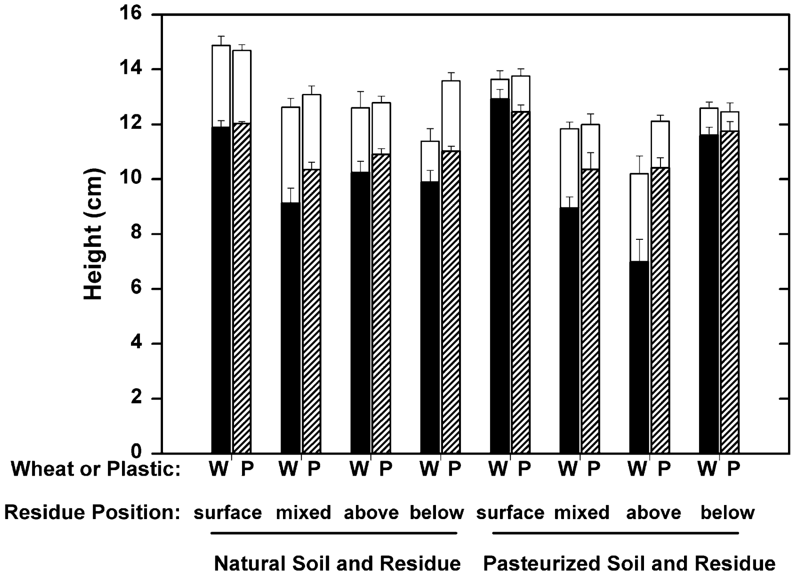

Fig. 3. Height (cm) of seedlings on day 14 (filled) and day 20 (empty). Error bars are standard deviation.

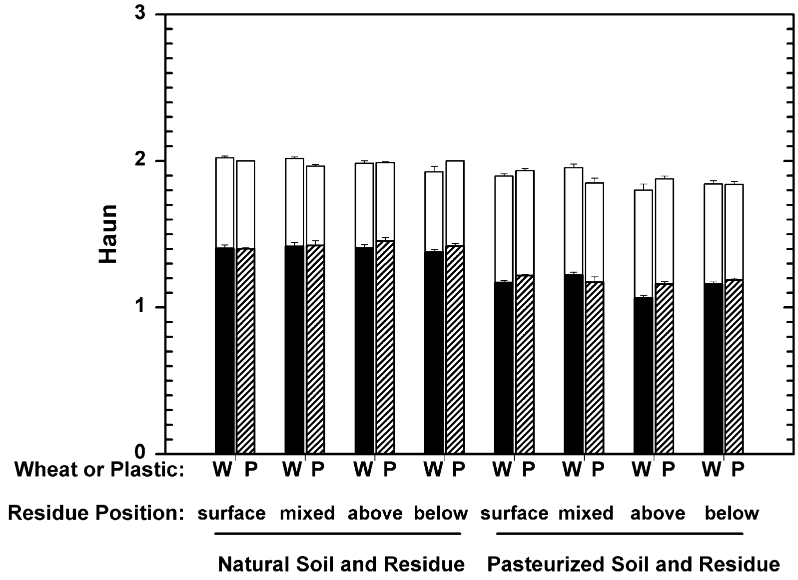

Fig. 4. Haun of seedlings on day 14 (filled) and day 20 (empty). Error bars are standard deviation.

increased in the below placement. The results show that the growth of plants whose roots encountered wheat residue lagged behind the growth of plants whose roots encountered plastic residue, producing a statistically significant difference in plant height on day 20 ($p{>}t{=}0.0001$). Since residue placed below the seed could not physically hinder coleoptile growth, the difference between wheat and plastic residue must have been caused by an effect on the roots. This effect was sensitive to soil and straw pasteurization. When the pots were disassembled, we noticed no differences in root length or location due to the residue layer below the seed. There was no evidence of a physical difference in root penetration of the two types of residue. A slight browning and a decrease of root hairs occurred in the zone where the roots passed through wheat residue. Discoloration of roots by toxins or pathogens was also observed by Patrick and Toussoun (1965), and Cook and Haglund (1982). Roots penetrating the wheat residue must have encountered toxins or pathogens which slowed growth between the first and second height measurements. Immobilization of nutrients could also explain a reduction in height. Roots encountering phytotoxins or pathogens could also explain the slight delay in emergence (not statistically significant) compared to the other surface and below placements.

Plants with wheat residue below the seed were not only affected in height but also development rate. A small difference in haun stage between wheat and plastic below the seed in the natural treatments increased between the first and second measurements to become a statistically significant difference ($p{>}t{=}0.0026$, natural treatments alone, Fig. 4). As was the case for height measurements, plants with roots growing through wheat residue were inhibited in growth compared to plants with roots growing through plastic residue.

In the pasteurized treatments wheat residue positioned below seed did not decrease height or haun stage; seedling growth was very similar (Figs. 3 and 4). This indicates that the toxic, pathogenic, or immobilization effect causing reduced development in the natural treatment involved microorganisms which were killed by the pasteurization process.

The magnitude of the effects of pasteurization were not of primary interest, but for completeness the statistically significant interactions from analysis of variance of all treatments are noted here: interaction of natural/pasteurized treatment by residue position — height and haun at day 14 ($p{>}F{=}0.0001$ and 0.0023), height at day 20 ($p{>}F{=}0.0214$), and abnormal geotropic response ($p{>}F{=}0.0468$); interaction of all three experimental factors — height at day 14 ($p{>}F{=}$

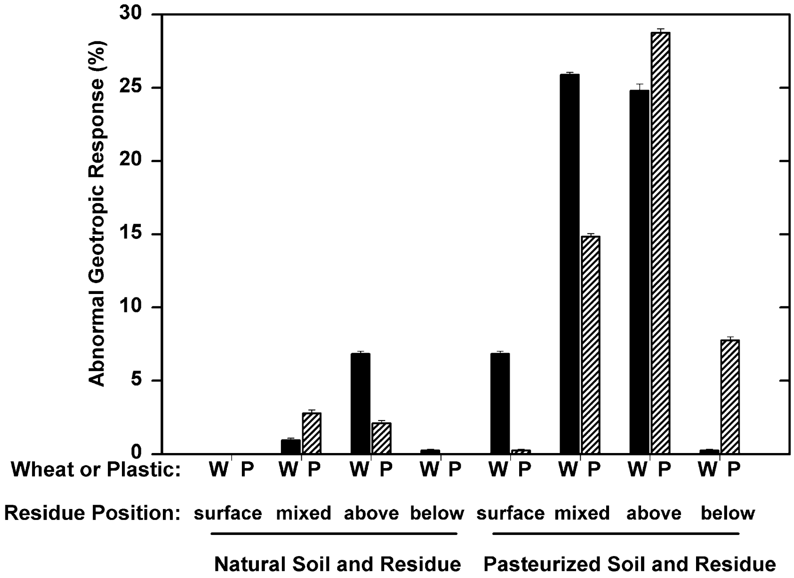

Fig. 5. Plants (%) with abnormal geotropic response on day 14. Error bars are standard deviation.

0.0065), height and haun at day 20 ($p>F=0.0016$ and 0.0287), and abnormal geotropic response ($p>F=0.0118$).

3.3. Abnormal growth

Some plants did not emerge perpendicular to the soil but at ≤45° angle to the soil surface. Purvis and Jones (1990) called this an abnormal geotropic response. At day 14 the number of plants with an abnormal geotropic response were counted (Fig. 5). Since these abnormal plants occurred in both wheat and plastic residues, it is assumed not to be a symptom of phytotoxins but instead mostly a result of physical interference. Trends in abnormal geotropic response data follow trends in emergence data. Position has the only statistically significant effect on abnormal geotropic response ($p>F=0.0009$) in an analysis of natural treatments alone. In an analysis of all treatments, position and natural/pasteurized treatments have significant effects ($p>F=0.0001$). Differences between wheat and plastic residues were not significant.

The pots were also scored for plants with stunted leaves on day 14 (Fig. 6). Leaves were considered stunted if yellow, spotted, unusually curled, or misshapen. Only residue type was a statistically significant factor ($p>F=0.0081$) in natural treatments. In an analysis of all treatments, differences were statistically significant for position ($p>F=0.0005$), residue ($p>F=0.0002$), and natural versus pasteurized (p>F= 0.0225).

Root disease symptoms were very minor and consisted of some browning of root tips. The incidence was low enough that no effect on plant growth would be expected. A few plants with stem lesions were found in treatments with natural soil and wheat residue, but their effect on growth was insignificant.

Pots with pasteurized soil produced roots with a greater root hair density, which means the roots might have received a higher proportion of photosynthate. This difference in partitioning of plant resources may explain some of the height and haun differences between natural and pasteurized treatments. The difference between natural and pasteurized treatments in haun stage was highly significant at both measurement dates ($p>F=0.0001$). The haun stages were delayed for pasteurized when compared to natural on day 14 and 20. Differences were significant in height on day 20 ($p>F=0.0001$). Heights in pasteurized treatments were less than corresponding residue positions in natural treatments. The effect of pasteurization was to decrease growth and increase abnormalities, as has been reported by other researchers (Rovira and Bowen, 1966). This is an indication of

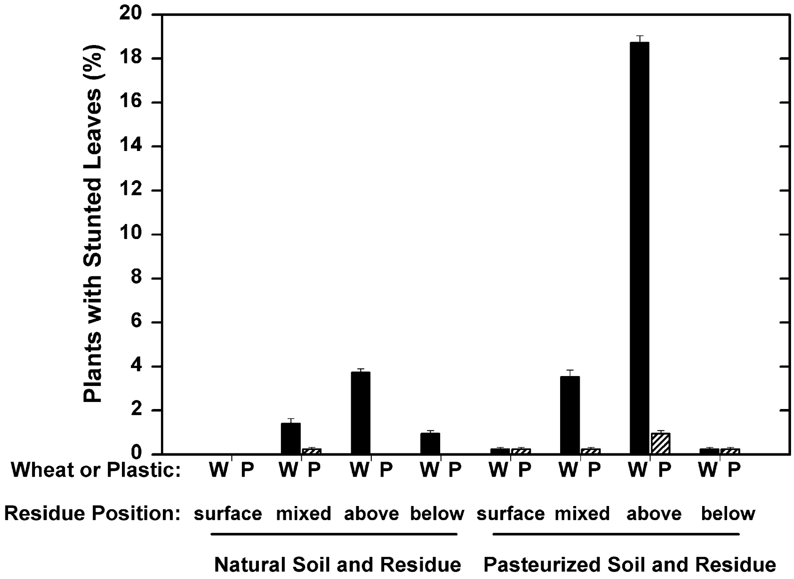

Fig. 6. Plants (%) with stunted leaves on day 14. Error bars are standard deviation.

the complexities of the rhizosphere's microbial ecology.

Lack of seed–soil contact, which occurred in the mixed residue position, did not delay emergence compared to the residue-above treatment. This corroborates research showing that water vapor transport to the seed is sufficient to produce imbibition and germination, at rates comparable to seeds with excellent seed–soil contact (Wuest et al., 1999).

4. Discussion

The differences between treatments measured in this experiment are relatively small, even though statistically significant. It is not known if the differences in height and development rate would continue to diverge beyond 21 days and result in yield potential differences. It is possible that interception of unweathered residues by wheat roots contributes to stand unevenness.

This experiment was not designed to determine the cause of growth effects due to residue placement. Promotion of root pathogens or production of phytotoxic chemicals are possibilities. The seed used in this experiment was treated with metalaxyl, which has been shown to be very effective in preventing symptoms of *Pythium* (Cook et al., 1990). The seed treatment would not prevent infection of roots, however. Immobilization of nitrogen was not likely a major cause because the plants with wheat residue below the seed did not have visual symptoms of nitrogen deficiency. Only extremely nitrogen-deficient wheat exhibits delayed development at the seedling stage (Andrews et al., 1991).

This research indicates that it is important to minimize direct contact between crop roots and residues left from the past crop in annual winter wheat cropping systems. Sowing equipment which minimizes mixing of residue into the seed zone may produce healthier stands. Clearing surface residue from the seed row may be advantageous and needs to be investigated further. Kimber (1973), and Lovett and Jessop (1982) demonstrated that thick layers of residue on the surface of the soil can impair emergence and tillering. They watered pots in such a way that leachates from the residue would be rinsed into the soil. This study and that of Cochran et al. (1982) measured no phytotoxic effect of surface residue. Considering the need for light to produce good tillering in winter wheat (Wilkins et al., 1988), it may be best to move most of the residue away from the seed row, both to increase light penetration and to reduce the possible effects of residue leachate.

We should account for the physical effects of residue and soil clods on emergence of seedlings when comparing sowing into surface residues versus sowing into residue free, tilled soil. Plastic residue above the seed impaired emergence much like wheat residue. While residue can interfere with seed–soil contact, the authors believe the assumption that seed–soil contact provides for faster imbibition and germination is false (Wuest et al., 1999). Residue can, however, prevent adequate cover over the seed and increase vapor loss from the seed zone.

In tillage-based cropping systems, where residue is removed from the seed zone by plowing or other soil inversion techniques, seedlings which encounter buried residues may be injured if the residues have not had enough time and moisture to lose their pathogenicity. Inhibition of plants growing in freshly plowed residue may be a common occurrence which goes undetected because the symptoms are difficult to see or are confounded by pathogenic symptoms.

Based on this research, root contact with unweathered crop residues should be avoided. The benefits and risks of leaving surface residue undisturbed in a particular system requires further study.

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