11-1-1986

Division S-4-Soil Fertility and Plant Nutrition: Recovery of Fertilizer Nitrogen by Wheat as Affected by Fallow Method

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DIVISION S-4—SOIL FERTILITY AND PLANT NUTRITION

Recovery of Fertilizer Nitrogen by Wheat as Affected by Fallow Method[1]

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ABSTRACT

The fate of fertilizer N applied to crops is of both environmental and economic concern. To follow fertilizer N recovery in western Nebraska, depleted-^{15}N NH_4NO_3 was surface broadcast in April on winter wheat (*Triticum aestivum* L.) growing on plots fallowed the previous year by plowing, subtillage, and no-till. Quantities of labeled N taken up by the growing crop, in the upper 100 mm of soil as inorganic N, and in both visible and partially decomposed crop residues, were followed on two sets of plots through the crop-fallow-crop sequence (approximately 117 weeks). About 16 to 18% of the labeled N was removed in the grain of the first wheat crop, with an additional 3 to 5% in the second crop. Labeled inorganic soil N decreased to <5% within 1 yr, with little effect of fallow method. No more than 4% was in visible residues at any time for all except no-till fallow, for which 7 to 13% of the labeled N was found in visible residues from heading of the first crop through the entire fallow period until the second crop was seeded. Likewise, 4 to 9% of the labeled N applied was found in partially decomposed residues of no-till during this period, compared to no more than 2% for the plow and subtill treatments. Total N in both residue pools combined decreased 50% from October to April of the fallow year for N-fertilized wheat and 25% for unfertilized wheat. Most of the labeled N in the straw found in the visible residue pool by October was transferred over winter to either the partially decomposed pool or to other undetermined pools (including soil organic matter, microbial biomass, and losses to the atmosphere). Results show that, compared to plow and subtill, no-till fallow enhanced retention of labeled N in the several crop residue pools and increased N uptake by the two wheat crops.

***Additional Index Words:* *Triticum aestivum* L., no-till, residue management, N cycling, N-use efficiency.**

Power, J.F., W.W. Wilhelm, and J.W. Doran. 1986. Recovery of fertilizer nitrogen by wheat as affected by fallow method. Soil Sci. Soc. Am. J. 50:1499–1503.

[1] Contribution from USDA-ARS, in cooperation with the Nebr. Agric. Res. Div. Published as Paper no. 7937, Journal Series, Nebr. Agric. Res. Div. Received 28 Oct. 1985.

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THE EFFECTS OF FALLOW METHOD on various crop production parameters have been extensively studied for winter wheat (*Triticum aestivum* L.)-fallow rotations in semiarid regions (Black and Power, 1965; Power et al., 1984; Unger and McCalla, 1980; Zingg and Whitfield, 1957). Most studies were initially concerned with effects of tillage method on water conservation because water availability usually limits production in semiarid regions (Duley and Russel, 1939). Earlier research has shown that maintaining crop residues on the soil surface during the fallow period usually increased the amount of available water stored in the soil (Fenster and Peterson, 1979; Smika and Wicks, 1968). No-till methods of fallow (ecofallow) often maximize water conservation and thus produce greatest potential for grain production.

A review of published data on wheat yields obtained after fallowing by various methods revealed that the extra water conserved by leaving crop residues on the soil surface often failed to increase yields (Fenster and Peterson, 1979; Power et al., 1984; Unger and McCalla, 1980). Also, in many studies, protein content of grain was lowered with reduced and no-tillage methods (Power et al., 1984; Unger and McCalla, 1980; Zingg and Whitfield, 1957). These observations have suggested that leaving crop residues on the soil surface in some manner limits availability and uptake of N by wheat.

With these observations and 9 yr of previous data from an ongoing tillage experiment at Sidney, NE (Fenster and Peterson, 1979), comprehensive research was initiated near Sidney to study the soil environment, microbial populations, and N transformations resulting from microbial activity as affected by tillage practices (Broder et al., 1984; Linn and Doran, 1984; Mielke et al., 1984; Wilhelm et al., 1982). The experiment reported here was conducted with isotopic techniques to determine the effects of fallow method on the cycling and uptake of fertilizer N by winter wheat.

Table 1. Effect of fallow method on N-fertilized winter wheat dry-matter and grain yield, and uptake of total and labeled N (average of the two sets of plots).

Fallow method	First crop				Second crop		
	May	June	July		May	July	
			Straw	Grain		Straw	Grain
	Dry-matter production, Mg ha^{-1}						
Plow	2.40	6.73	4.48	2.19	3.82	4.42	3.37
Subtill	2.44	6.60	4.88	2.30	3.31	4.45	3.50
No-till	1.99	7.08	5.51	2.43	3.91	5.09	3.23
$LSD_{0.05}$	0.31	NS	0.62	NS	0.42	NS	NS
	Total N uptake, kg N ha^{-1}						
Plow	50.4	78.8	25.6	52.6	74.2	23.9	76.1
Subtill	48.3	82.6	27.0	54.5	66.2	16.2	75.8
No-till	48.1	81.0	35.0	49.6	71.1	21.6	70.4
$LSD_{0.05}$	NS	NS	4.8	NS	7.8	6.1	NS
	Labeled-N uptake, kg N ha^{-1}						
Plow	6.7	15.2	5.2	7.4	2.0	0.5	2.2
Subtill	7.7	13.6	2.4	7.1	3.1	0.7	1.6
No-till	9.0	12.6	2.9	8.1	3.5	0.8	1.7
$LSD_{0.05}$	2.2	NS	2.4	NS	NS	NS	NS

Table 2. Total and labeled soil inorganic N (0-100 mm) as affected by fallow method and fertilization (average of the two sets of plots).

Fallow method	N rate	First crop			Fallow		Second crop		
		May	June	July	Oct.	April	Oct.	April	July
		kg labeled N ha^{-1}							
		Total soil inorganic N							
Plow	0	14	13	12	12	7	25	11	10
Subtill	0	14	14	12	13	8	25	10	12
No-till	0	15	14	16	16	10	34	13	13
$LSD_{0.05}$		NS	NS	3	3	NS	4	NS	3
Plow	45	52	29	22	19	8	32	15	17
Subtill	45	55	27	25	23	10	30	13	13
No-till	45	46	27	24	29	13	39	18	17
$LSD_{0.05}$		6	NS	NS	5	3	5	3	3
		Labeled soil inorganic N							
Plow	45	19	7	3	2	1	0	0	0
Subtill	45	17	5	3	2	0	1	1	0
No-till	45	15	4	2	3	2	1	1	1
$LSD_{0.05}$		3	3	NS	NS	NS	NS	NS	NS

METHODS

A tillage experiment was initiated at the Nebraska Agricultural Experiment Station High Plains Agricultural Laboratory, 11 km north of Sidney, NE in 1969, to study the effects of summer-fallowing method upon winter wheat production in a wheat-fallow rotation (Fenster and Peterson, 1979). Fallow methods were conventional tillage (moldboard plow), stubble mulch (subsurface tillage), and no-till (chemical weed control). Primary tillage (100-mm depth) occurred in April, followed by use of a rodweeder for the remainder of the summer for plow and stubble-mulch treatments. All plots were split to accommodate 0 and 45 kg N ha^{-1} broadcast as NH_4NO_3 in April of each cropped year. Whole-plot treatments, arranged in a randomized, complete block design, were replicated four times. Subplots were 4.3 by 61.2 m. Soil type was Alliance silt loam (fine-silty, mixed, mesic Aridic Argiustolls) with surface pH of about 6.5 and 9 mg g^{-1} organic C in the upper 150 mm. This site had been in crested wheatgrass [*Agropyron desertorum* (Fisch ex Link) Schultz] from 1957 to 1969.

On 19 April 1979, ^{15}N-depleted NH_4NO_3 was surface broadcast at 45 kg N ha^{-1} on 66 m^2 of all fertilized plots. On 23 May, when wheat was fully tillered, aboveground growth was harvested from 1.22 m^2, dried, weighed, and analyzed for total N concentration and N-isotope ratio (USDA-ARS Northern Regional Research Center, Peoria, IL, courtesy of Robert Kleiman). Nine soil cores, 100-mm diam and 100-mm deep, were also collected from each plot, three from within the row (0.30-m spacing) and six between rows. Roots and visible crop residues were screened from air-dried soil with a 6-mm screen. Partially decomposed residues were removed with a vacuum hose covered with a double layer of surgical gauze (Clark, 1977). Soil was then subsampled and analyzed for 1 *M* KCl-extractable NH_4 and NO_3-N with the autoanalyzer using phenate and brucine procedures, respectively. Isotope-ratio of the inorganic soil N fraction was also determined. The visible and partially decayed residues were oven-dried at 70°C, ground, and analyzed for total N and N-isotope ratio.

The above sampling procedure was repeated at anthesis (26 June) and at maturity (20 July). For plant samples collected at maturity, grain and straw were analyzed separately for total N and N-isotope ratio. At maturity, plant samples were harvested from a 9.8-m^2 area. Additional sets of residue and soil samples were collected during the approximately 14-month fallow period on 17 Oct. 1979 and on 16 Apr., 10 July, and 16 Sept. 1980. The second wheat crop was seeded on 9 Sept. 1980 and fertilized with commercial NH_4NO_3 on 17 Apr. 1981, before which another set of soil and residue samples was collected. The final sampling was at harvest of the 1981 wheat crop on 16 July. Soil samples were also collected to the 120-cm depth each spring and analyzed for 1 *M* KCl-extractable inorganic N.

The same procedure was followed on the companion set of plots in this crop-fallow rotation—i.e., those plots that were in crop in 1980 and 1982, and fallowed during the summers of 1979 and 1981. Again, the same sampling techniques were used, with samples collected approximately monthly during the crop year, and every 3 to 6 months while in fallow.

Quantity of isotopic N derived from fertilizer in each sample was calculated from the N-isotope ratio data. Data from all sampling dates were analyzed with analysis of variance, and means were separated with LSD at the 5% probability level of significance. Results of analysis of variance of data from the two sets of plots (cropped and fallowed) indicated essentially the same trends and levels of significance, allowing the two sets of data to be averaged and statistically analyzed.

RESULTS AND DISCUSSION

Wheat dry-matter and grain yields during the 4 yr were not significantly affected by the fallow method (Table 1), even though no-till fallow soil contained more water than that for other treatments (Broder et al., 1984; Mielke et al., 1984). Likewise, N uptake by the wheat crop was not consistently affected by fallow method (Table 1). Total N uptake (grain plus straw) for the first crop increased little between the June and July samplings. About 60 to 75% of the labeled N taken up by first-year wheat was translocated to the grain, with 25 to 40% being returned to the soil in the straw. The second wheat crop took up an additional 2 to 3.5 kg of labeled N ha^{-1}, again with most going to the grain. Thus, about 9 of the 45 kg labeled N ha^{-1} originally applied as fertilizer was physically removed from the plot area in the harvested grain. The data suggest that little additional recovery of labeled N in the grain would be expected had the experiment continued beyond the second crop.

Soil inorganic N concentrations in the 0- to 100-

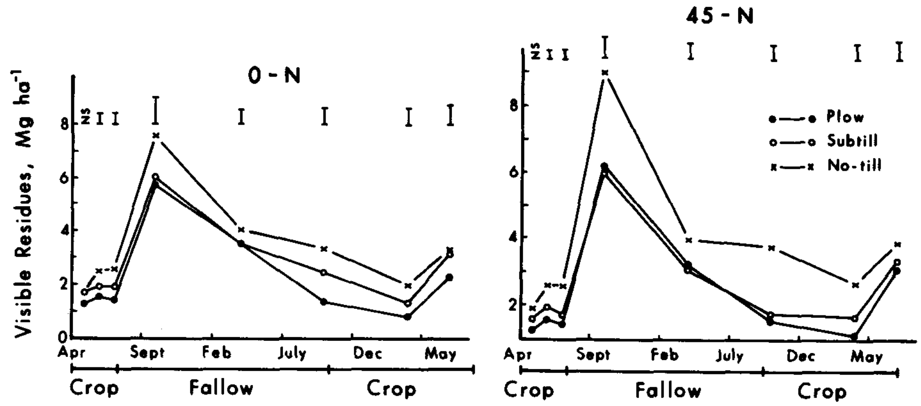

Fig. 1. Dry weight of visible wheat residues as affected by fallow method and N fertilization. ($LSD_{0.05}$ values indicated by bars at top of figure.)

mm soil depth were not greatly influenced by fallow method (Table 2). However, except immediately after fertilization, values were usually greater for no-till than for plowed fallow (although not always significant at $P = 0.05$). Effects of N fertilization diminished with time after fertilizer application (April of cropped year), and soil inorganic N levels were greater for N-fertilized soils than for those without fertilizer. The interaction between fallow method and N rate was not significant at any sampling date. Except for samples collected shortly after fertilization, most of the variation in soil inorganic N levels resulted from variation in NO_3-N levels (NO_3-N concentrations varied from 4–24 $\mu g\ g^{-1}$). Doran and associates (Broder et al., 1984; Linn and Doran, 1984) also sampled these plots and found that, at deeper soil depths, plowed soil usually contained more NO_3-N than did no-till soil, probably because of greater microbial biomass at this depth in plowed compared to no-till soil.

The quantity of labeled N found in the upper 100 mm as soil inorganic N rapidly decreased after fertilization (Table 2). By harvest of the first crop (July), labeled-N levels had decreased to 3 kg ha^{-1} or less for all tillage methods, and remained at that level thereafter. Except for the first month or two after fertilization, fallow tillage method appeared to have little, if any, effect upon labeled N in inorganic form. Labeled N disappeared from the inorganic pool more rapidly immediately after fertilization for no-till than for plowed soil, probably because the broadcast N was immobilized rapidly by the surface residues on no-till soil. Soil samples collected the following spring to the 120-cm depth indicated essentially no labeled inorganic N was found below the 100-mm depth.

Quantity of visible residues (primarily straw, leaves, and crowns) on or near the soil surface was greatest for no-till and least for the plow treatments (Fig. 1). Although values for fertilized were often larger than respective values for unfertilized treatments, differences were seldom significant. Likewise, interactions between fallow method and N rate seldom occurred. Usually, quantity of visible residues increased slightly during the cropped season, probably from leaf fall. A large increase occurred in October of the fallow year because of the addition of the combine-harvested straw and stubble to the soil surface. Between October and April of the fallow year, 40 to 60% of the visible residues disappeared from all treatments (April samples were collected before primary tillage of fallow occurred). Even though the soil was frozen much of this time, this reduction was probably primarily the result of decomposition of residues because there was no evidence of residue removal by wind or water during the winter. During the summer of fallow (April to October), an additional 33% of visible residues present the previous October disappeared from the upper 100 mm of plowed fallow, compared to 20 and 6% for subtill and no-till fallow, respectively (October sampling occurred shortly after winter wheat planting). During the second winter—October to April of the second crop period—visible residues decreased an additional 8, 10, and 14%, respectively, for plow, subtill, and no-till treatments, followed by the usually modest increase during the growing season for the second crop (April–July). For no-till, most visible residues were on the soil surface, whereas for plow, residues were mixed in the upper 100 mm of soil.

Quantity of total N in visible residues varied in a manner that paralleled dry weights of visible residues (Fig. 2). Values were greatest for no-till, and values for fertilized residues usually exceeded those of unfertilized visible residues. Interactions between fallow method and N rate were not significant. Total N concentrations in visible residues (data not shown) were generally near 10 mg g^{-1} during cropping, but in the 5 to 7 mg g^{-1} range during fallow, and were usually significantly greater (1–2 mg g^{-1}) for fertilized than for unfertilized residues.

Only a few kilograms per hectare of labeled N were present in visible residues at most sampling dates (Table 3). On only one occasion did this quantity exceed 3 kg ha^{-1}—for no-till at the beginning of the fallow year after fresh straw had been returned to the soil surface. Values were consistently (but not significantly) greater for no-till than for other tillage methods.

Tillage treatment affected dry weights of the partially decomposed residues similar to visible residues (Fig. 3). Dry weights were greater for fertilized than unfertilized treatments (except in April of the fallow year), greatest for no-till, and were maximum during the year of fallow. Interactions of fallow method × N rate were not significant. For all tillage methods, maximum dry weights for partially decomposed residues were observed in April of the fallow year, instead of the previous October as was observed for visible res-

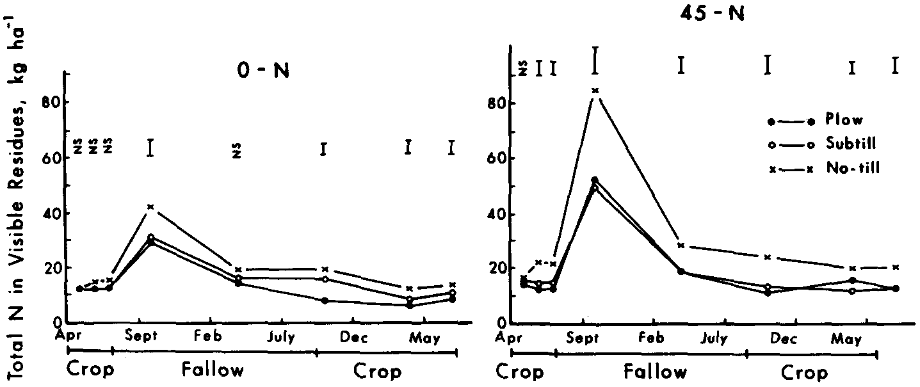

Fig. 2. Total N in visible wheat residues as affected by fallow method and N fertilization. ($LSD_{0.05}$ values indicated by bars at top of figure.)

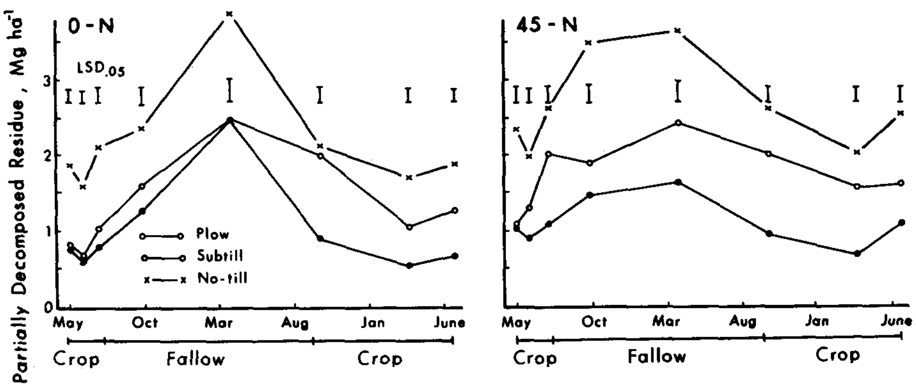

Fig. 3. Dry weight of partially decomposed wheat residues as affected by fallow method and N fertilization. ($LSD_{0.05}$ values indicated by bars at top of figure.)

idues. This suggests that, during the October-to-April period, some of the visible residues were decomposed sufficiently to show up in the partially decomposed fraction in April. This is supported by the fact that the sum of dry weights of partially decomposed and visible residues in April usually approximated the dry weight of visible residues the previous October. Therefore, a concurrent disappearance over winter of a quantity of partially decomposed residues roughly equivalent to that present at the beginning of the winter (October) had to occur as well. This biomass was either lost to the atmosphere or was incorporated into soil organic matter because Broder et al. (1984), working on these same plots, found that microbial populations and biomass were greater in the 0- to 75-mm depth of no-till soil than in soil of other treatments. There was no evidence of loss by wind erosion.

Total N in partially decomposed residues (Fig. 4) varied similar to that for visible residues except, again, maximum or near-maximum values were found in April of the fallow year. Values were greater for no-till than for plowed fallow and were increased by N fertilization. Also, the sum of total N in partially decomposed and visible residues in April approximated the quantity of total N in visible residues the previous fall, especially on unfertilized plots. Up to 4 kg ha^{-1} of labeled N was found in partially decomposed residues for no-till (Table 3), with greatest values occurring after maturity of the fertilized crop. Lesser amounts were found for the other fallow tillage treatments. Total N concentrations in partially decomposed residues varied in a manner similar to that for visible residues, but values were generally about 2 mg g^{-1} greater.

The distribution of labeled N among the various N pools sampled is given in Table 4. By the time of harvest of the first wheat crop, labeled N accounted for in these pools was greatest for the no-till system. Throughout the fallow year and the second crop year, accountability of labeled N remained greatest for the no-till system. No-till treatments had more labeled N as soil inorganic N and N in both visible and partially decomposed residues than other treatments. Also, uptake of labeled N in the second wheat crop was greatest for no-till. These results indicate that more of the

Table 3. Labeled N in visible and partially decomposed wheat residues as affected by fallow method.

Fallow method	First crop May	First crop June	First crop July	Fallow Oct.	Fallow April	Second crop Oct.	Second crop April	Second crop July
	kg labeled N ha^{-1}							
	Visible residues							
Plow	Tr	2	2	2	2	Tr	1	Tr
Subtill	Tr	2	2	2	2	1	1	Tr
No-till	1	3	3	6	3	2	2	1
	Partially decomposed residues							
Plow	Tr	Tr	1	1	1	Tr	Tr	Tr
Subtill	Tr	Tr	1	1	1	1	1	Tr
No-till	1	1	4	3	2	2	2	Tr
	Total residues (visible plus partially decomposed)							
Plow	Tr	2	3	3	3	Tr	1	Tr
Subtill	Tr	2	3	3	3	2	2	Tr
No-till	2	4	7	9	5	4	4	1
$LSD_{0.05}$	NS	NS	NS	4	NS	NS	NS	NS

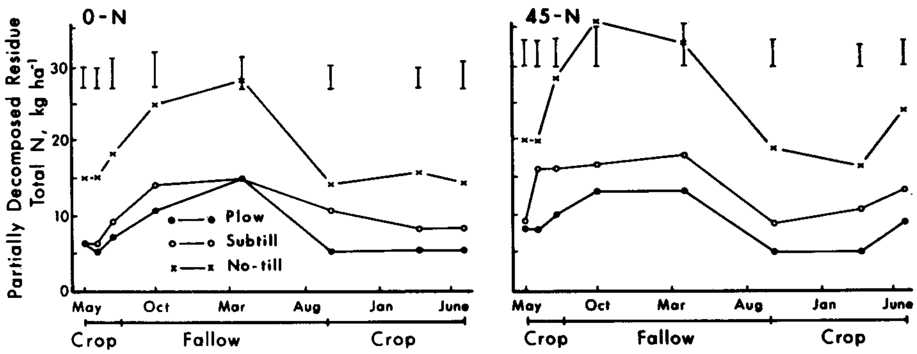

Fig. 4. Total N in partially decomposed wheat residues as affected by fallow method and N fertilization. ($LSD_{0.05}$ values indicated by bars at top of figure.)

fertilizer N is kept in the upper 100 mm of soil with no-till than with other fallow methods. Broder et al. (1984) and Linn and Doran (1984) arrived at the same conclusion from various data on mass and activity of soil microorganisms, collected from these same plots. It is of interest to note that about 20% of the labeled N was removed in harvested grain for all fallow methods.

The results of this study suggest that fallow methods significantly altered size and distribution of the various N pools associated with the N cycle, probably because of differences in microbial activity and resulting N transformations (Broder et al., 1984; Paul and Juma, 1981; Rice and Smith, 1983). More N was retained in the surface soil with no-till than with plowing (Broder et al., 1984), but below 75 mm, microbial biomass and potentially mineralizable N were often greater for plow than no-till so that, for the 0- to 150-mm depth, little or no differences in tillage methods existed. While tillage effects in this study were significant, differences were relatively small and plant uptake and removal of N in the grain were not greatly affected by fallow method. Thus, under the conditions of this experiment, there is little evidence that lack of crop response to the additional water conserved with no-till can be directly attributed to the N supply available to the crop.

Table 4. Percent of labeled N added in fertilizer found in various pools of the N cycle as affected by fallow method.

	First crop			Fallow		Second crop		
N pool	May	June	July	Oct.	April	Oct.	April	July
	% of applied labeled N							
	Plowed fallow							
Plant uptake†	15	28	12	0	0	0	4	1
Grain removed	0	0	16	16	16	16	16	21
Soil inorganic	42	16	7	4	2	0	0	0
Visible residues	0	4	4	3	4	1	2	0
Partially decomposed	0	0	2	2	2	0	0	0
Total	57	48	41	25	24	17	22	22
	Stubble-mulched fallow							
Plant uptake†	17	30	5	0	0	0	7	2
Grain removed	0	0	16	16	16	16	16	19
Soil inorganic	38	11	7	4	1	2	2	0
Visible residues	1	4	4	4	4	2	2	1
Partially decomposed	0	0	2	2	2	2	2	0
Total	56	45	33	26	23	22	29	22
	No-till fallow							
Plant uptake†	20	28	7	0	0	0	8	4
Grain removed	0	0	18	18	18	18	18	22
Soil inorganic	33	9	4	7	4	2	2	2
Visible residues	3	7	7	13	7	4	4	2
Partially decomposed	2	2	9	6	4	4	2	0
Total	58	46	45	44	33	28	34	30

† Excluding mature grain.

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