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CARBON AND PHOSPHORUS LOSSES FROM DECOMPOSING CROP RESIDUES IN NO-TILL AND CONVENTIONAL TILL AGROECOSYSTEMS

by

Marc Buchanan* and Larry D. King

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*Assistant Professor, Board of Environmental Studies, University of California, Santa Cruz, CA. 95064 and Professor, Department of Soil Science, North Carolina State University, Raleigh, NC. 27695

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ABSTRACT

An increased knowledge of crop residue decomposition characteristics is a critical component for nutrient cycling studies in agroecosystems. Carbon and P losses from shoot residues of maize (*Zea mays* L.), wheat (*Triticum vulagare* L.), soybean (*Glycine max* L.), and shoot and root residues of crimson clover (*Trifolium incarnatum* L.) were compared in no-till and conventional till systems. Grain crop residues were generally collected from senescent plants following harvest and placed in fiberglass mesh litter bags. However, soybean leaf residues were sampled following pre-harvest abscission, while crimson clover residues were collected at spring anthesis and buried only in a conventional till system. Generally, the changes in C and P content of residues were best described by exponential and/or logarithmic functions. Losses of C and P from crop residues were consistently greater, and more rapid when residues were buried versus left on the soil surface. Crimson clover shoots lost C and P more rapidly than root residues. Generally, greater initial losses of P occurred in comparison to C in most residues. The lack of correlation between C and P losses is believed to be due to an initial but likely variable inorganic P content, which is readily leached prior to the decomposition and mineralization losses of C. Differences in the rate and magnitude of C losses were related to seasonal effects, the initial N and P content, and/or the proportional amount of lignin in the plant residues. Tillage is clearly an important regulator or driving variable for element cycling in agroecosystems.

The study of nutrient cycling in agroecosystems may lead to more efficient nutrient use by crops and reduce negative impacts on the environment. Residue decomposition is an important driving variable of nutrient cycling processes in terrestrial ecosystems. Therefore, an increased knowledge of crop residue decomposition characteristics is a critical component for nutrient cycling studies in agroecosystems. There has been renewed interest in the management of legume cover crop residues for the supply of N to crops (Ebelhar et al., 1984; Wilson and Hargrove, 1986; Wagger, 1989), and crop residue management for soil erosion control and moisture conservation (Gallaher, 1977; Sojka et al., 1985). However few studies, particularly in field environments, have observed mass loss and the release of P from decaying agricultural residues.

Decomposition of residues is regulated by a number of variables, including the residue's physical and chemical properties, climate, and the interactions between soil microflora and fauna. Perhaps most important are climatic variables and the susceptibility of the residue to colonization by decomposers (Meentemeyer, 1978; Swift et al., 1979). Soil disturbance from tillage operations alters the microclimatic variables and is an important regulator of decomposition in agroecosystems (House et al., 1984; Wilson and Hargrove, 1986; Hendrix et al., 1986). Previous investigations have demonstrated that lignin and N concentrations and the C:N ratio in the residue are important chemical characteristics affecting decomposition rates (Mellilo et al., 1982; Muller et al., 1988; Wagger, 1989).

A large amount of P is recycled annually through above-ground and below-ground plant residues. The P contained in crop residues, or in a legume green manure that is incorporated in soil, can increase available soil P (Fuller, 1956; Dalal, 1979). However, results in many of the studies have been conflicting. Fuller et al. (1956) concluded that microbial immobilization of P would not occur if residue P concentrations were > 2 g kg^{-1}. Other studies have attempted to establish C:P ratios as an index for decomposition rates, P mineralization, and/or plant uptake of released residue P (Enwezor, 1967; Blair and Boland, 1978; White and Ayoub, 1983) with inconsistent results. Blair and Boland (1978) concluded that P turnover dynamics observed in laboratory investigations may be significantly altered by the presence or absence of active plant roots. Varying magnitudes of chemical and biological immobilization inherent in differing soils rather than P concentrations or C:P ratios in residues are more likely the cause of conflicting results. Another important factor influencing the release patterns and fate of residue P may be the variable and significant inorganic P in the original plant materials (Bieleski, 1973; Dalal, 1979; Stewart, 1984).

Jones and Bromfield (1969) found that inorganic P was readily leached from residues when microbial colonization and, therefore immobilization of P was inhibited. This effect may be the dominant mechanism contributing to differences in P release patterns from surface applied and soil incorporated residues. Soluble inorganic P concentrations in runoff or leaching waters are higher in conservation tillage systems in comparison to conventional till (McDowell and McGregor, 1984; Sharpley and Stewart, 1989).

Hendrix and Parmelee (1985) reported changes in the P concentration of weed residue as affected by herbicide applications using mesh litter bags. However, it appears that no other work has been done to estimate the release of P from agricultural residues under no-till and conventional tillage practices using this method. Additionally, we are not aware of studies that have examined P release from the shoot and root residues of winter legume cover crops. Therefore, the objective of this study was to measure loss of mass, C and P from residues of three field crops under no-till and conventional till management, and from shoot and roots of a winter legume.

MATERIALS AND METHODS

The crop residues used in this study came from plants grown in a long-term cropping systems experiment at the North Carolina State University Agricultural Research Unit 9 at Raleigh. Each system was managed with conventional tillage (CT) and no tillage (NT). The site, which is in a typical Southern Piedmont landscape, is rolling with maximum slopes not exceeding 10%. Temperatures in the area range between a mean of 26° C in July to 6° C in January, while mean annual precipitation is 1168 mm. Each cropping system is replicated four times in a randomized complete block design. The plots are 7.7 m wide by 30.5 m long, which allows for the use of full size equipment for all field operations. The plot width accomodates eight maize or soybean crop rows spaced at 0.96 m. All sampling occurred within the four inner rows.

Additional details of the management systems are shown in Table 1. Conventional tillage practices utilized fall chisel plow, spring disk, and disk-sweep cultivation for weed control. In all cases, with the exception of crimson clover, only above-ground material was collected. The decomposition of crimson clover shoots and roots was observed only in the CT continuous maize system which incorporates a winter crimson clover cover crop .

Residue sampling

All residues, except crimson clover, were sampled from four 0.25 m^2 quadrates chosen at random in each of four plot replicates (n=4). All samples were dried at 60° C and then weighed. Dry residue samples were subsampled and weighed before placing them in 20 by 20-cm fiberglass mesh bags (1.3 mm square openings). No size reduction (cutting or grinding) of residues was performed prior to placement in the bags. It was assumed that the use of fiberglass mesh with 1.3 mm openings would give results reasonably comparable to changes occurring in unconfined residue.

Sample weights were equivalent to field estimates (kg ha^{-1}) of standing residues of each crop type. Duplicate litter bags were prepared for each anticipated sample date in each of the four plot replicates. Residues were placed on the soil surface (with underside contact with soil) in NT plots or buried vertically in the 0- to 20-cm depth in CT plots to best represent full distribution within that profile interval. The mesh bags in CT systems were removed and replaced during each tillage operation. A total of eight litter bags were sampled at each date for each residue type and tillage system.

Residues became available and were placed in the plots at different times. The residue types, time of field placement, and the sample intervals are given in Table 3. Additional details or deviations from procedures mentioned above are provided in the following:

Maize - Residues were collected from NT and CT systems (both continuous and rotation) following harvest and rotary mowing of the standing stover. Data provided is from the NT rotation system and CT continuous system.

Wheat - Residues were placed on the surface in NT plots or partially buried in CT plots to simulate residue incorporation by disc harrowing.

Soybean - Leaves were sampled after complete leaf drop. Stem and stalks were collected following harvest. Residues were initially placed on the soil surface in CT plots, as no tillage operations occurred until the following spring. The previously surface-placed residue was buried in the CT plots after the first tillage operation in spring.

Crimson Clover - Crimson clover residues were not sampled from field plots. Rather in the fall, crimson clover was seeded into two free standing cylindrical enclosures located adjacent to the field site which measured 0.75 m in diameter and 0.40 m high. This was done to facilitate the collection of root material in the spring. The steel cylinders had previously been filled in layers with subsoil and topsoil which was tamped to approximate field conditions. The walls of the enclosures were insulated with hay and soil.

In the following spring, shoots were sampled from 0.25 m^2 quadrates in each cylinder by clipping live plants level with the soil. Roots were then removed from within the 0.5 by 0.5 by 0.4-m volume of soil. Blocks of soil were first soaked, then gently washed with a stream of water through a nest of sieves. Losses of root material appeared to be minimal. Immediately after sampling, ten subsamples were weighed, then dried to constant weight at 65° C for a mean dry matter determination. Samples were stored fresh at 4° C for 32 hours before subsampling and placing in litter bags. Fresh residue samples were placed in the mesh bags to mimic the actual field conditions. The mean dry matter percentage was used to convert fresh weight to dry weight during the filling of mesh bags.

Mass loss estimates and C and P analysis

The initial total C and P in all crop residues was determined from subsamples. All materials were ground with a Wiley mill to pass a 1-mm screen. Two replicate 100-mg samples were analyzed for C using a hybrid of the Walkley-Black and Mebius wet digestion procedures (Nelson and Sommers, 1982). Phosphorus was determined from two replicate 200-mg samples following micro-Kjeldahl digestion (Bremner and Mulvaney, 1982) with a molybdate-ascorbic acid method (Olsen and Sommers, 1982) which includes an alkalai addition step to neutralize the acid digest sample. Two replicate 1-g samples of residues were analyzed for lignin content using a permanganate reduction procedure (Goering and Van Soest, 1970).

After removal from the field, the remaining residue was removed from mesh bags and weighed. Samples were dried at 60° C, then ground to < 500 µm for quantitative analysis. A 1-g subsample was ashed at 550° C for 12 hrs to correct for soil contamination and, thus, express changes on an ash-free basis. The C and P determinations of residues were corrected to an ash-free basis. It was assumed that all of the ash content was from soil, trusting that the ash content of the residues themselves had declined to minimal levels due to leach losses. A previously determined estimate of total soil P was subtracted for calculations of ash-free P.

In most cases, the decomposition of plant materials have been described by linear and exponential functions. Wieder and Lang (1982) suggested that mass loss and elemental release might best be described, after log transformation, by double-exponential decay functions. In this study equations describing mass loss versus time were calculated with linear and non-linear regression analysis options on PC-SAS.

RESULTS

Initial chemical composition of the residues is presented in Table 2. Total C did not vary greatly among residue types, but all other constituents varied substantially. Initial total P concentrations were in the order of clover shoots > soybean leaves > soybean stems > maize > clover roots > wheat. Initial lignin (L) and total N concentration and, in some cases L:N ratios within the same crop residue, differed due to differing management. Initial L:N ratios were in the order of wheat > soybean stems > maize > clover roots > soybean leaves > clover shoots.

Maize

The patterns of total C and P losses from maize residues are shown in Figure 1. This data is for the rotation maize system only, as results in all systems were quite similar. The C and P remaining in the residue at each sampling date is represented as a percentage of the elements in the residue at the time of placement. The decline in residue C and P in both cropping systems is best described by exponential functions.

Carbon losses were greater at all sample dates for maize buried in soil. However, at the first sample date (4 weeks), P losses were identical in NT and CT systems. After this date P losses were consistently greater for residue in the CT system. After 44 weeks (1988 maize harvest), only 11% of the original P remained under CT, whereas 29% of the original P remained in residues under NT. In comparison, the C remaining at 44 weeks was 21% and 39% for CT and NT respectively. At 100 weeks following placement (1989 maize harvest), the C remaining was 5% and 25% for CT and NT, while the P remaining was 3% and 18% for CT and NT respectively.

The greater proportional P losses from maize residues under CT resulted in consistently wider C:P ratios in comparison to NT after the 4 week sample date (Figure 1).

Wheat

The decline in C and P in wheat residue in both CT and NT was best described by exponential functions (Figure 2). Following the 3-week sample date, the C loss from wheat residues was greater under CT. However, P losses were consistently greater at all dates for residue under CT. After 9 weeks, only 53% of the original P remained in wheat under CT, whereas 79% of the original P remained in residue under NT. In comparison, the C remaining at 9 weeks was 70% and 80% for CT and NT, respectively. After 72 weeks in the field (1989 maize harvest), the C remaining was 23% and 36% for CT and NT, while the P remaining was 20% and 23% respectively. The greater proportional P losses from wheat residue under CT resulted in consistently larger C:P ratios after the 9-week sample date (Figure 2). It is interesting to note that C:P ratios decreased with time under NT, but generally increased under CT.

Soybean

The decline in C and P in soybean leaf and stem-stalk residue under CT and NT could be described by exponential functions (Figure 3). However, slightly more of the variation in C and P losses from leaves under CT could be accounted for with linear regression equations than with exponential functions.

Carbon losses from leaf residue under CT and NT were generally similar until 33 weeks. At this time, the residue was buried in soil in the CT treatments. The effect of that incorporation is evident in the data at 45 weeks where a marked increase in C and P loss is apparent. The C:P ratios were identical under CT and NT through the 33-week sampling date (Figure 3). Subsequently, the C:P ratio became much greater under CT than under NT. At 45 weeks (1989 maize harvest), the C remaining was 18% and 32% for CT and NT, while the P remaining was 9% and 21% for CT and NT respectively.

At 16 weeks, C and P losses from stem-stalk residue became greater under CT. However, P losses were greater under NT at 8 weeks. After 16 weeks, P losses became proportionately greater than C losses in both cropping systems. Mesh bags were buried at 30 weeks in the CT system. The effect of that incorporation is evident in a comparison of the C and P losses at 32 and 40 weeks. At 40 weeks (1989 maize harvest), the C remaining in the residue was 35% and 53% under CT and NT, while the P remaining was 20% and 34% under CT and NT respectively. The C:P ratios were identical under CT and NT until the final sample date, when the ratio was greater in CT than NT.

Crimson clover

The decline in C and P in clover root residue under CT and NT could be described by exponential functions (Figure 4.). However, the decline in C and P in shoots was described more accurately with logarithmic functions. After 2 weeks, C and P losses were consistently greater for shoots than roots. Note that the regression curves for root samples which extend beyond the final sample date are based on the regression model and not actual data.

Phosphorus declines were very rapid in shoots, such that 73% of the original P was lost after only 2 weeks. The loss of P from roots was not as great, but still surprisingly large, as 44% of the original P was lost at 2 weeks. After 16 weeks (1988 maize harvest), the P remaining in the residues was 4% and 17% for shoots and roots, while the C remaining was 10% and 32% for shoots and roots, respectively. Little C and P was lost between the 16- and 48-week (1989 maize planting) sampling dates, i.e., 7% of the initial C and 2% of the initial P remained. Generally, the C:P ratios of shoot and root residues increased with time.

Climate

It should be noted that the years 1987 and 1988 were dryer and warmer than normal for the Central Piedmont region of North Carolina. Conversely, the spring of 1989 (when field sampling ended) was wetter and cooler than normal. These climatic variants must be acknowledged as important regulators of our observed decomposition and nutrient release patterns. Rainfall and mean surface soil temperatures during the study period are given in Figures 5 and 6, respectively.

DISCUSSION

This study has observed crop residue decomposition under field conditions starting at the actual time of crop harvest, senescence, or plowdown. These results comparing C and P losses from residues under CT and NT are consistent with studies evaluating N release patterns from residues (House et al., 1984; Wilson and Hargrove, 1986). Generally, C and P loss from all residues, independent of season effects, was faster and greater under CT. The effect of soil incorporation was evident in the data for soybean residues as C and P losses were accelerated following the burial of mesh bags at 30 weeks (Figure 3).

We acknowledge that the use of mesh bags may alter the decomposition process. Some workers have been concerned with experimental artifacts due to the exclusion of predatory and saprophytic microarthropods (Hagvar and Kjondal, 1981; Seastedt, 1984). St. John (1980) demonstrated that nylon mesh material interfered with the contact of fungal vegetative structures with confined litter. Christensen (1985) identified problems with losses and gains of organic particles in large mesh size bags. Wilson and Hargrove (1986) minimized this effect by using very small (53 μm) nylon mesh. House et al. (1987) found that decomposition of wheat straw was not altered by mesh openings ranging from 0.05 to 5.0 mm. However, nylon or fiberglass mesh bags have been used extensively in natural ecosystem investigations, and have been employed in mass loss and N release studies in agroecosystems (Bocock and Gilbert, 1957; Douglas et al., 1980; House et al., 1984; Wilson and Hargrove, 1986; Wagger, 1989). This method has been useful in comparisons of placement and management effects on mass loss from crop residues (Holland and Coleman, 1987) and also facilitates the estimation of decomposition rate equations for use in simulation model development (Meentemeyer, 1978).

After 100 weeks in the field almost 95% of the initial C in maize residues under CT was lost. In comparison approximately 75% of the initial C was lost under NT in the same time period. This suggests that during repeated cropping, accumulation of surface residues would continue for some time under NT. A parallel assumption could be made for P, as the difference between NT and CT was 6-fold. We observed a similar pattern in wheat and soybean. However, the differences in wheat residue C and P loss under CT and NT after 72 weeks were not as dramatic as for maize. It is clear that with repeated cropping the NT systems will continue to accumulate significant C and P pools in surface residues over time.

There were very good fits ($R^2 > 0.90$) of the decomposition data to simple exponential functions. However, as was mentioned, soybean leaf C and P loss was more adequately described by linear functions ($R^2 = 0.98$, in both cases) and loss from clover shoots by logarithmic functions ($R^2 = 0.96$-0.98). An exponential or logarithmic decomposition behaviour is likely related to the various chemical constituents of differing resistance to decomposition contained in the materials. The differences in the release patterns of C and P among residues is most likely related to seasonal effects, initial N and P content, and the proportional amount of lignin in the residues. The higher the initial L:N ratio the more resistant a given substrate becomes to attack by decomposers *(need citation)*. This effect is well evidenced in the much greater loss of C from soybean leaves (lower L:N ratio) compared to stems and stalks (higher L:N ratio).

While the L:N ratio has been found to be a reliable index for mass loss and N release from decomposing residues, it may not be as effective a predictor of P release. As we noted earlier, previous studies have not always found a consistent effect of C:P ratios on decomposition rates and release of P from plant materials. Enwezor (1967) concluded that the variable and significant quantities of inorganic P present in plant materials could largely affect the early release patterns of P. Jones and Bromfield (1969) found that 40-60% of the P in selected grasses and legumes was present as inorganic P. They concluded that this predominantly water-soluble fraction could be rapidly lost by leaching and microbial uptake. Possibly, such an effect led to the very high P losses that we observed for crimson clover shoots and roots after 2 weeks in the soil. We speculate that similar or possibly greater proportions of inorganic P to total P may have been present in shoots of crimson clover. Martin and Cunningham (1973) found a rapid release of inorganic P from wheat roots in which approximately 55% of the initial total P was water-soluble inorganic P. So we also speculate, though without direct evidence, that the relatively rapid loss of P from clover roots may also be due to a significant inorganic P fraction. However, one cannot assume that this rapidly released P would dramatically increase plant available P as we have not accounted for the rate and magnitude of microbial and chemical immobilization in soil.

The interrelationship of C and P cycles in soils is likely different from that of C and N and C and S cycles (McGill and Cole, 1981; Coleman et al., 1983; Stewart, 1984). It has been proposed that N and part of soil S are stabilized in direct association with C (C-N and C-S bonds) and are mineralized as a result of C oxidation for energy. Conversely, organic P and S are found as esters (C-O-P and C-O-S bonds), which are stabilized by adsorption and precipitation reactions with soil solids and are mineralized by enzymes in response to microbial need. As a result, P turnover from stable organic fractions will generally be slower than N and S. The same constraints should apply for the interrelationship of C and P mineralization from residues.

Based on the above, C and P losses should not be expected to parallel one another during decomposition of plant materials. This is apparent in comparison of the changes in C:P ratios of wheat decomposing under CT and NT. Under NT the ratio decreased with time. Carbon losses were proportionately greater than P losses under NT, while they were often quite similar to P losses under CT. We also observed a consistently increasing C:P ratio with time in decomposing clover residues, thus indicating that P loss proceeded more rapidly than C. Only the early data (winter season) for soybean leaf residues indicated that C:P ratios remained essentially the same as C and P loss occurred. In all other cases, the C:P ratio of residues tended to increase with time in the field.

CONCLUSIONS

This study illustrates that crop and soil management can influence crop residue decomposition and, thus, the turnover rates of plant nutrients such as P. Tillage can be considered to be a regulator or driving variable of elemental cycling in agroecosystems. We have also shown that P release from crimson clover shoots and roots incorporated in soil can be quite rapid. However, without accounting for the fate of released P in soil we cannot determine how crop residue decomposition influences soil P fertility and plant nutrition. The urgent needs for maximizing nutrient use efficiency requires that we improve our understanding of residue dynamics in relation to nutrient turnover in differing crop ecosystems and environments.

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Table 1. Pesticides and commercial fertilizer used in no-till continuous maize and no-till maize-wheat-soybeans, 1987-1989.

Table 2. Selected chemical composition of crop residues prior to decomposition in mesh bags.

Table 3. Residue type, cropping system placement dates, and sampling intervals used for comparisons

Figure 1. Carbon and phosphorus remaining in maize residue and the C:P ratio of the residue in systems with conventional tillage (CT) and no-till (NT).

Figure 2. Carbon and phosphorus remaining in wheat residue and the C:P ratio of the residue in systems with conventional tillage (CT) and no-till (NT).

Figure 3. Carbon and phosphorus remaining in soybean residue and the C:P ratio of the residue in systems with conventional tillage (CT) and no-till (NT).

Figure 4. Carbon and phosphorus remaining in clover residue and C:P ratio of the residue.

Figure 5. Rainfall during the 1987 - 1989 cropping seasons.

Figure 6. Mean weekly soil surface temperatures for 1987 - 1989.

Table 1. Pesticides and commercial fertilizer used in no-till continuous maize and no-till maize-wheat-soybeans, 1987-1989.

Crop	Pesticide		NH_4NO_3 fertilizer N
	Type	Rate	
			— (kg N ha^{-1}) —
Maize			
	Soil insecticide		
	Furadan® with seed	9.0 kg ha^{-1}	140 in continuous
			105 in rotation
	Preplant herbicide		
	alachlor (Lasso®)	7.0 L ha^{-1}	
	atrazine (AAtrex®)	4.7 L ha^{-1}	
	glyphosate (Roundup®)	3.5 L ha^{-1}	
		9.4 L ha^{-1} (1989)	
	Post emergence herbicide		
	Accent®	36.0 g ha^{-1} (1989)	
Wheat			
	Post emergence herbicide		
	glyphosate	4.7 L ha^{-1}	44 in October
			44 in February
Soybeans			
	Preplant herbicide		
	paraquat (Paraquat®)	2.3 L ha^{-1}	No N applied
	alachlor	7.0 L ha^{-1}	
	linuron (Lorox®)	3.4 kg ha^{-1}	
	Post emergence herbicide		
	sethoydim (Poast®)	1.8 L ha^{-1}	

Table 2. Selected chemical composition of crop residues prior to decomposition in mesh bags.

	-------- Total -------					
Crop	C	N	P	Lignin	Ash	L:N ratio
	---------------- mg kg^{-1} tissue				--------------	
Maize (NT)	432000	10854	1382	76400	9100	7.0
Maize (CT)	428000	12155	1359	74800	11900	6.2
Wheat (NT)	454000	7950	704	112200	34320	14.1
Wheat (CT)	446000	4060	801	81700	26400	20.1
Bean lf.* (NT)	413000	20912	2194	88200	7100	4.2
Bean lf. (CT)	422000	24250	2101	103400	88700	4.3
Bean st.* (NT)	453000	9060	1401	116800	8640	13.0
Bean st. (CT)	451000	9750	1400	115200	9260	11.8
Clover shoot	421000	30257	2634	74700	<100	2.5
Clover root	453000	26125	1200	139000	174700	5.3

* lf. = leaf, st. = stems-stalks

Table 3. Residue type, cropping system placement dates, and sampling intervals used for comparisons.

Residue	Crop system	Placement date	Sample interval ---------- weeks ---------
Maize	NT and CT (rotation & continuous)	Sept. 1987	4, 16, 32, 44, 76, 100
Wheat	NT and CT (rotation)	June 1988	3, 9, 18, 36, 54, 72
Soybean			
leaves	NT and CT (rotation)	Nov. 1988	3, 9, 21, 33, 45
stem-stalk	NT and CT (rotation)	Dec. 1988	2, 8, 16, 32, 40
Clover			
shoots	CT (continuous)	Apr. 1988	2, 4, 8, 16, 48
roots	CT (continuous)	Apr. 1988	2, 4, 8, 16

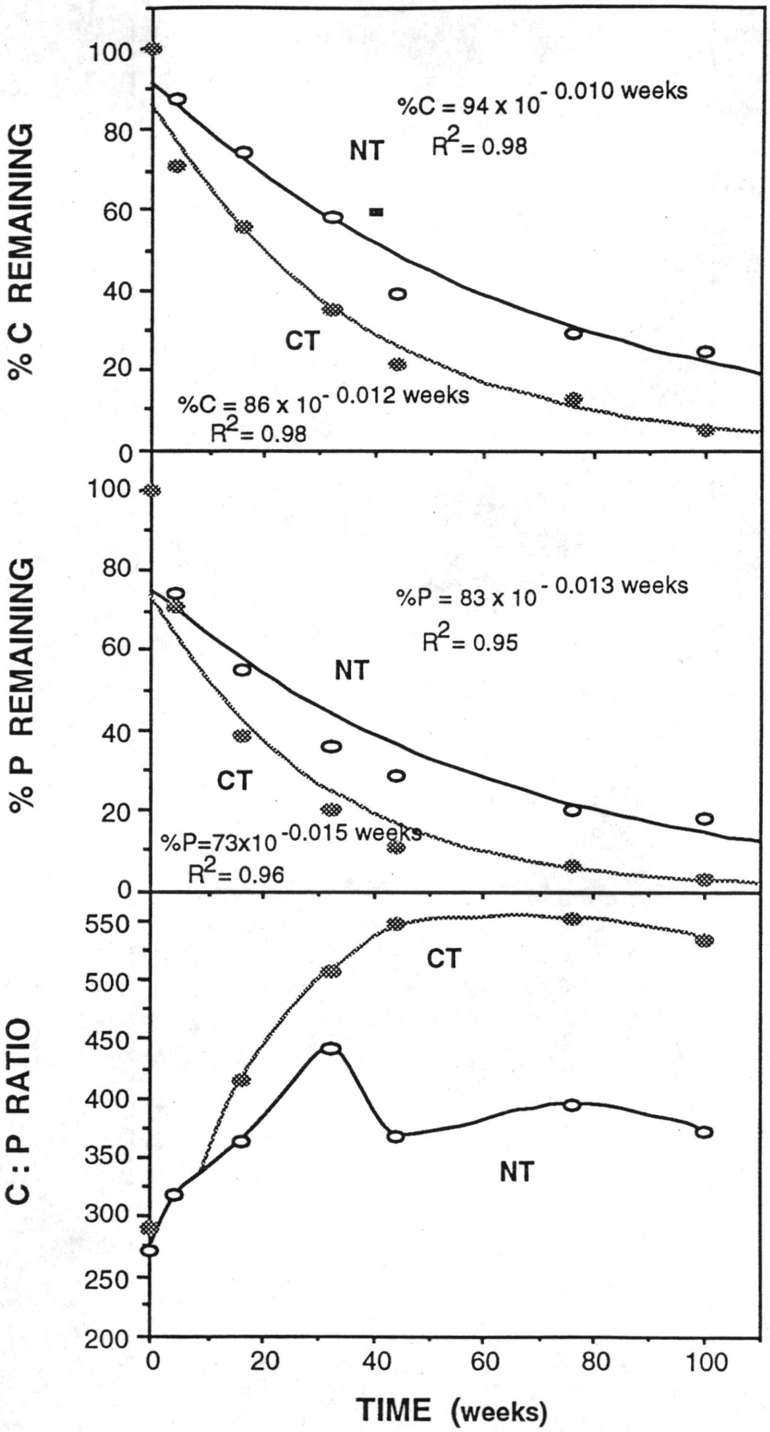

Figure 1. Carbon and phosphorus remaining in maize residue and the C:P ratio of the residue in systems with conventional tillage (CT) and no-till (NT).

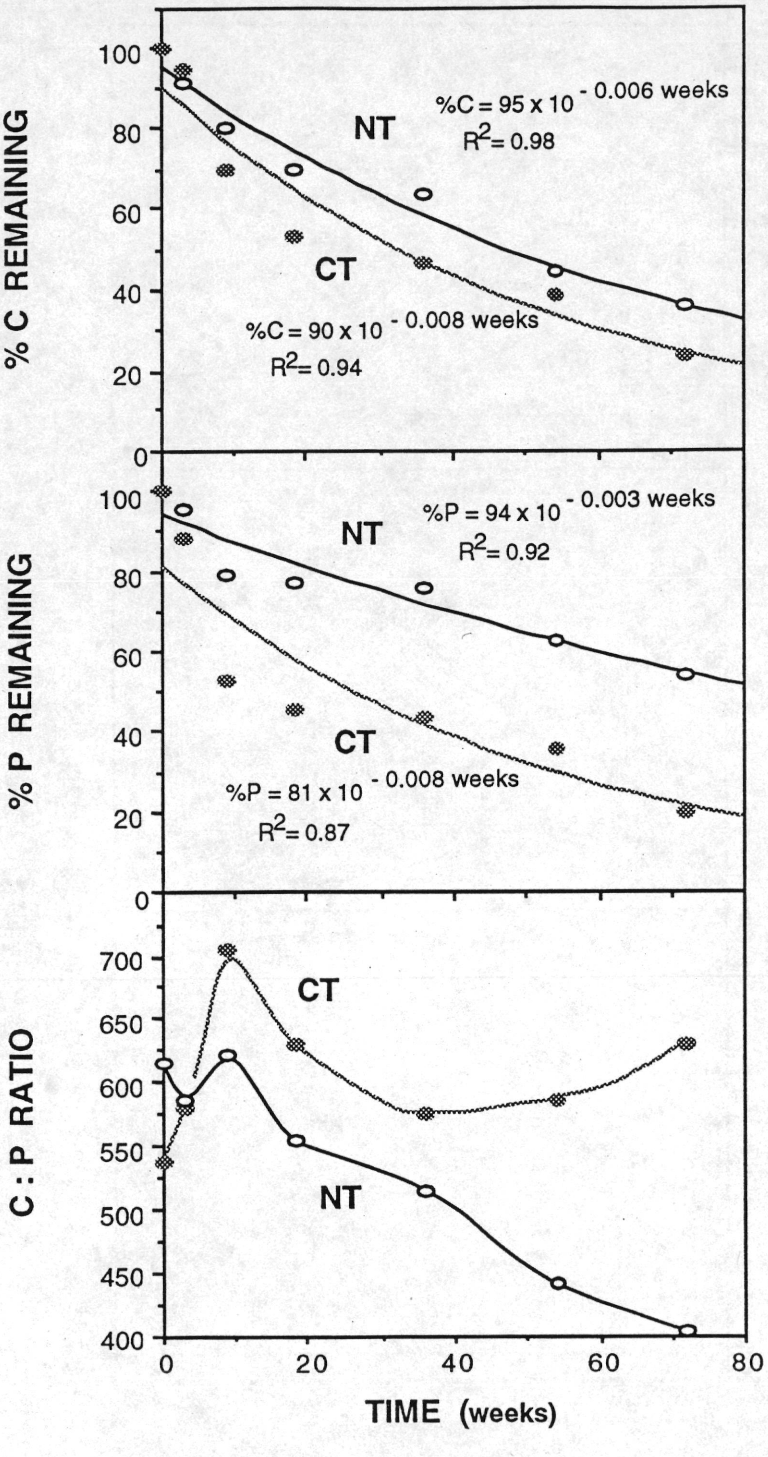

Figure 2. Carbon and phosphorus remaining in wheat residue and the C:P ratio of the residue in systems with conventional tillage (CT) and no-till (NT).

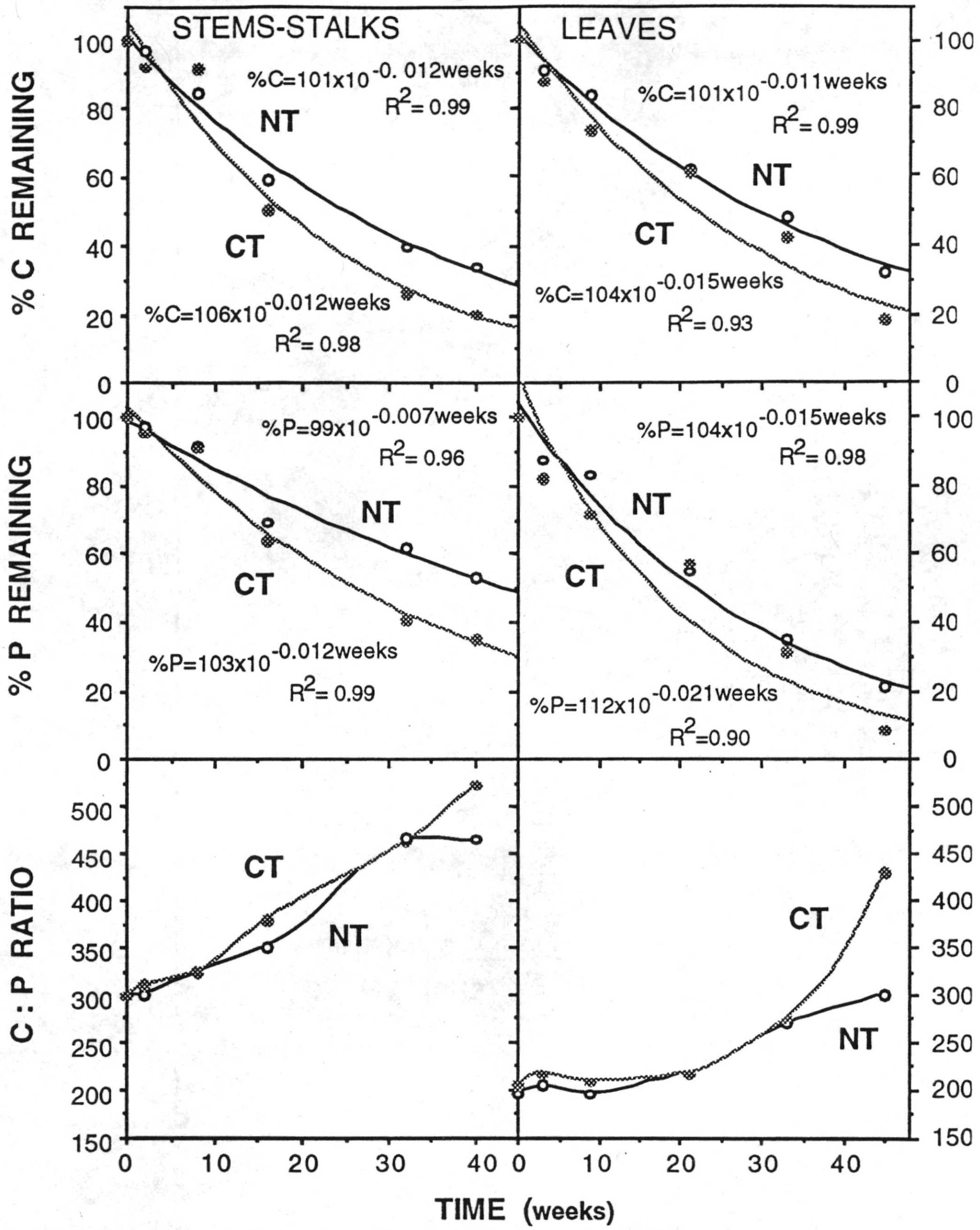

Figure 3. Carbon and phosphorus remaining in soybean residue and the C:P ratio of the residue in systems with conventional tillage (CT) and no-till (NT).

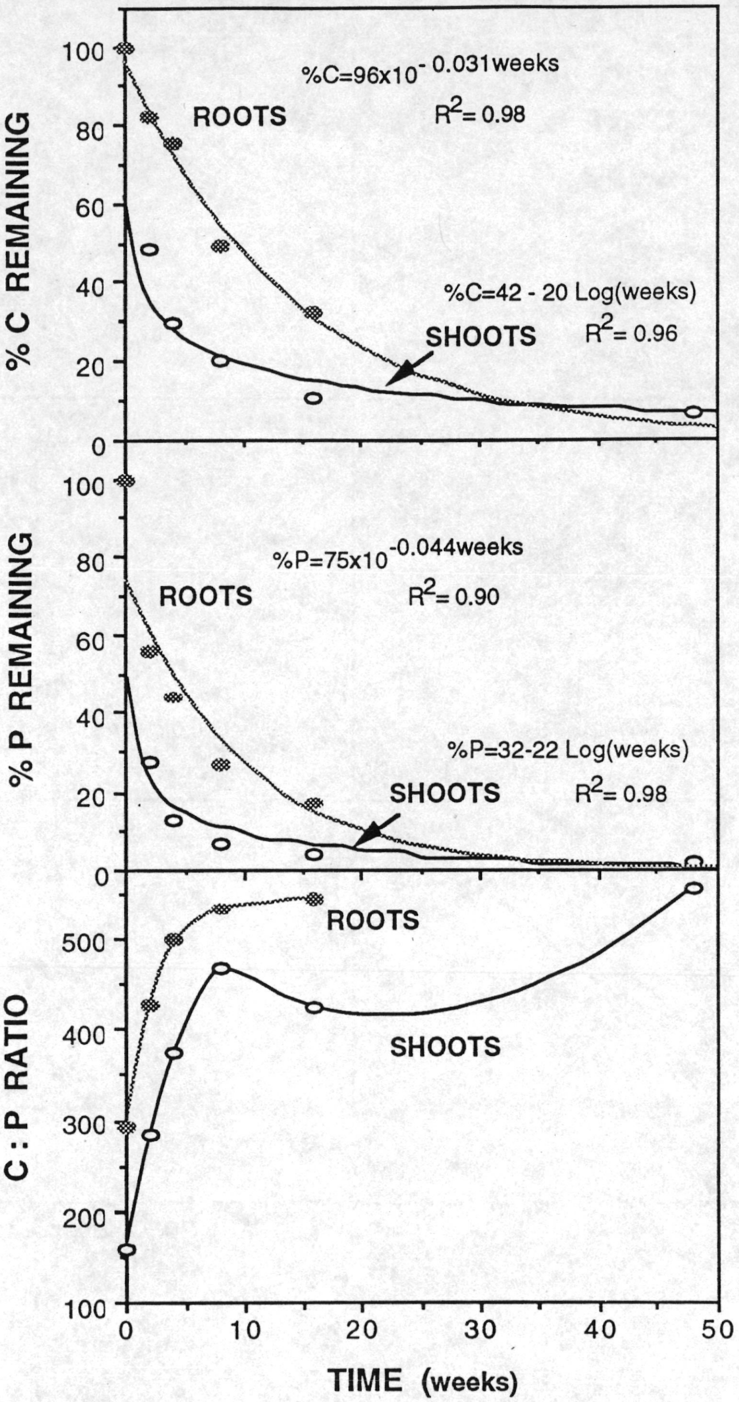

Figure 4. Carbon and phosphorus remaining in clover residue and C:P ratio of the residue.

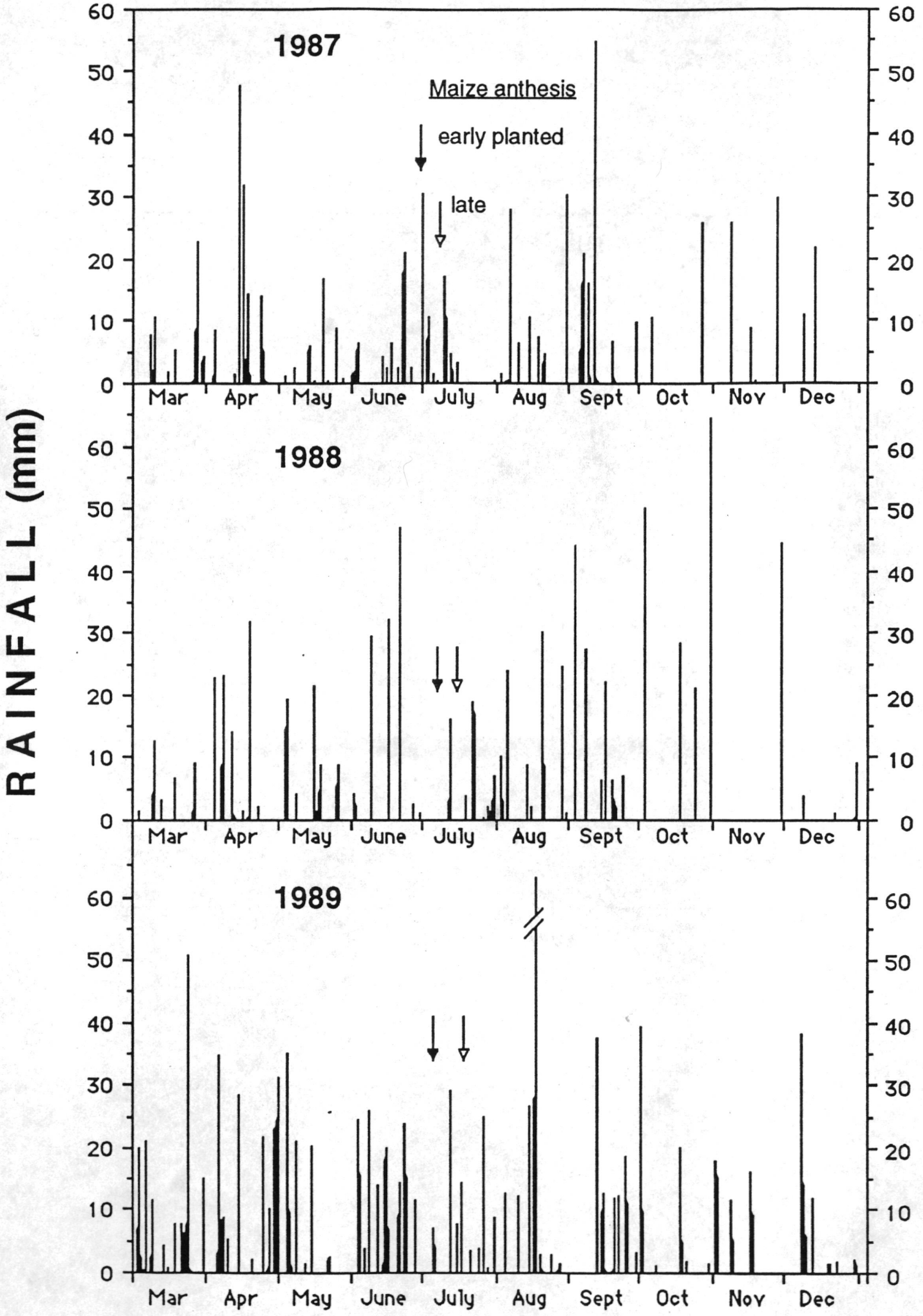

Figure 5. Rainfall during the 1987-1989 cropping seasons

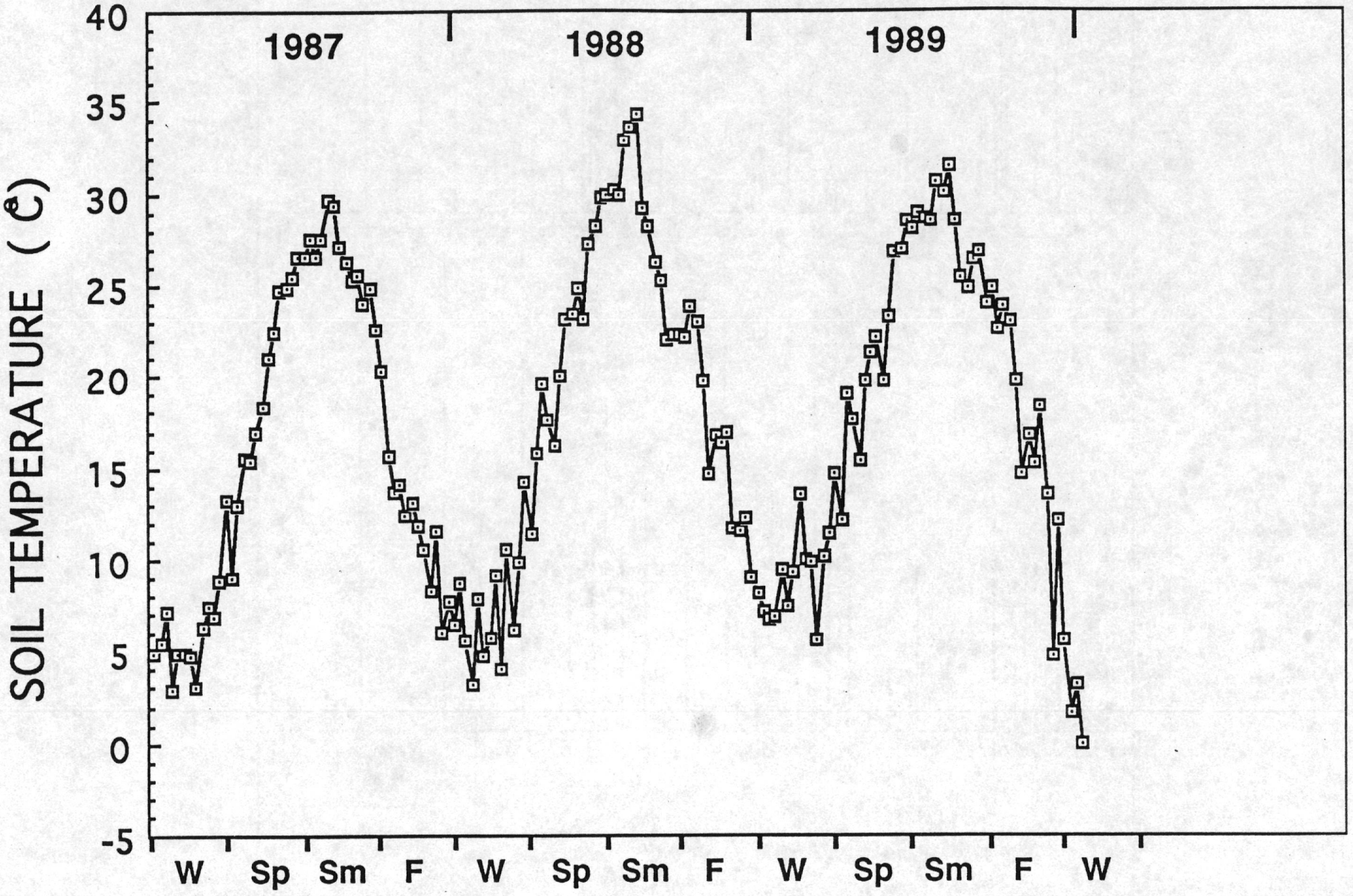

Figure 6. Mean weekly surface soil temperatures during 1987-89