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Carbon and Nitrogen Stable Isotope Ratios
Measurement of Anionic Polyacrylamide Degradation in Soil

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1 **Abstract**

2 Water soluble anionic polyacrylamide (PAM) is a highly effective erosion-preventing and
3 infiltration-enhancing polymer, when applied at rates of 1 to 10 g m⁻³ in furrow irrigation water.
4 PAM degradation has not directly been measured in soil or water. Natural abundance of the
5 carbon (¹³C/¹²C) isotope ratios correlated with anionic PAM concentration in positive curvilinear
6 relationships in Xeric Haplocalcid and Typic Torripsamment soils (r² = 0.98 and 0.99
7 respectively) but not Typic Kandiudult or Xeric Argialboll soils (r² = 0.26 and 0.32 respectively).
8 Natural abundance of the nitrogen (¹⁵N/¹⁴N) isotope ratios correlated with anionic PAM
9 concentration in positive curvilinear relationships in Durinodic Xeric Haplocalcid and Typic
10 Torripsamment soils and (r² = 0.85 and 0.92 respectively) but not in Typic Kandiudult or Xeric
11 Argialbolls soils (r² = 0.55 and 0.45 respectively). When 2691 kg PAM ha⁻¹ was applied to the
12 Xeric Haplocalcid soil, we measured 1317 kg ai PAM ha⁻¹ in 2000 indicating 49% was degraded
13 after 4 years and in 2006 we measured 691 kg ai PAM ha⁻¹ indicating 74% of the PAM was
14 degraded after 7 years. When 5382 kg ai PAM ha⁻¹ was applied to the Xeric Haplocalcid soil, we
15 measured 4675 kg ai PAM ha⁻¹ in 2000 indicating 13% was degraded after 6 years and in 2006
16 we measured 1466 kg ai PAM ha⁻¹ indicating 73% of the PAM was degraded after 12 years
17 We calculated PAM degradation rates based on δ¹³C to be 9.8% yr⁻¹. Further testing using ¹⁴C or
18 ¹³C labeled anionic polyacrylamide is necessary to determine what portion of the ¹³C released
19 from decomposing PAM is incorporated into soil organic matter or living microbial biomass and
20 being detected in the isotope ratio analysis and interpreted as PAM in remaining in soil.

1 **1. Introduction**

2 Water-soluble anionic polyacrylamide (PAM) is a highly effective erosion-preventing and
3 infiltration-enhancing polymer, when applied at rates of 1 to 10 g m⁻³ in furrow irrigation water
4 (Lentz et al., 1992; Lentz and Sojka, 1994; McCutchan et al., 1994; Trout et al., 1995; Sojka and
5 Lentz, 1997; Sojka et al., 1998a,b). Coulombic and Van der Waals forces attract soil particles to
6 PAM (Orts et al., 1999, 2000). These surface attractions stabilize soil structure by enhancing
7 particle cohesion, thus increasing resistance to shear-induced detachment and preventing
8 transport in runoff. The few particles that detach are quickly flocculated by PAM, settling them
9 out of the transport stream. Modest amounts of Ca⁺⁺ in the water shrink the electrical double
10 layer surrounding soil particles and bridge the anionic surfaces of soil particles and PAM
11 molecules, enabling flocculation (Orts, et al., 2001; Wallace and Wallace, 1996).

12 PAM delivery via irrigation water is very efficient, because it needs only to stabilize the thin
13 veneer of soil directly active in the erosion process. In furrow irrigation, PAM treats only about
14 25% of the field surface area to a few millimeters depth, thus only 1-2 kg ha⁻¹ of PAM per
15 irrigation is required to halt erosion and improve infiltration. PAM achieves its result by
16 stabilizing soil surface structure and pore continuity. In 1995, the United States Natural
17 Resource Conservation Service (NRCS) published a PAM-use conservation practice standard
18 (Anonymous, 1995) that was revised in 2000. PAMs were first sold for erosion control in the
19 US in 1995, and by 1999 about 400,000 ha were PAM-treated in the U.S. The U.S. market is
20 expected to continue to grow as water quality improvements are mandated by new Federal
21 legislation and court action, and since PAM use is one of the most effective, economical and
22 least intrusive management approaches recently identified that can meet the needed water quality
23 improvement. PAM reduced sediment in furrow irrigation runoff by 94% in three years of
24 studies in Idaho (Lentz and Sojka, 1994). The original 1995 NRCS PAM application method
25 called for dissolving 10 g m⁻³ PAM in furrow inflow water as it first crosses a field (i.e. water
26 advance, which is, typically the first 10 to 25% of an irrigation duration). Using this method,
27 PAM dosing is halted when runoff begins. The PAM applied during water advance generally
28 prevents erosion throughout a 24 hr irrigation. Application amounts dissolved in the advancing
29 stream usually total 1-2 kg ha⁻¹ per irrigation. For freshly formed furrows, Lentz and Sojka

1 (1999) reported that on 1-2% slopes, the effectiveness of applying PAM at a uniformly dosed
2 inflow concentration varied with inflow rate, PAM concentration, duration of furrow exposure,
3 and total amount of PAM applied. Erosion control with PAM was similar for three application
4 methods: 1) application of 10 kg ML⁻¹ dissolved in the advance, 2) application of 5 kg ML⁻¹
5 during advance, followed by 5 to 10 minutes of 5 kg ML⁻¹ re-application every few hours, or 3)
6 continuous application of 1 to 2 kg ML⁻¹ for the entire irrigation period. Continuous application
7 of 0.25 kg ML⁻¹ controlled erosion about one third less effectively.

8 Stable isotope ratios of organisms reflect the source ratios, with adjustment for
9 discrimination during assimilation, of the molecules they assimilate. (DeNiro and Epstein, 1978;
10 1981). Stable isotope ratios have been used to determine degradation of a variety of polyaromatic
11 hydrocarbons (Somsamak et al., 2006; Smernik, 2005; Boschake and Middleber, 2002). The
12 stable isotope ratios of light elements (e.g. C, N, O, H and S) are measured on isotope ratio
13 mass spectrometers with fixed magnets and Faraday cups positioned to detect a small number of
14 masses (Kreuzer-Martin, 2006). The configuration generates high sensitivity and precision,
15 enabling accurate measurement of isotope ratios. Isotope ratios can be determined quadrupole
16 mass spectrometers and require a higher concentration of the rare isotope than isotope ratio mass
17 spectrometers (IRMS) (Kreuzer-Martin, 2006). IRMS measure isotope ratios in comparison to
18 reference materials, which are analyzed in parallel with the samples. In natural abundance
19 studies, the isotope ratios are expressed in relation to international standards as delta values (δ)
20 in parts per thousand (‰) (Kreuzer-Martin, 2006). Combustion is used for carbon analysis as
21 CO₂, nitrogen as N₂ and sulfur as SO₂. Pyrolysis in the presence of glassy carbon is often used
22 for oxygen analysis as carbon monoxide (CO) and hydrogen (H₂) from organic materials
23 (DeGroot, 2004; Kreuzer-Martin, 2006).

24 PAM degradation has not directly been measured in soil or water. Indirect measurement
25 of PAM degradation in soil estimated that PAM degrades at approximately 10% year⁻¹ (Tolstikh,
26 et al., 1992). The acrylamide monomer (AMD) of PAM degrades fairly rapidly (Kay-Shoemake
27 et al., 1998a; Shanker et al., 1990; Lande et al., 1979). AMD was completely degraded within 5
28 days after applying 500 mg PAM kg⁻¹ garden soil (Shanker et al., 1990). Lande et al. (1979)
29 applied 25 mg PAM kg⁻¹ soil and reported that half life of an AMD in agricultural soils was 18-

1 45 hr. The existing information on degradation rates of PAM in soil and water is insufficient to
2 accurately predict the residence time of the compound in various ecosystems. This lack of
3 reliable information has repeatedly subjected PAM users to safety questions from environmental
4 watch groups and government regulators. This has been one of the most persistent and difficult
5 obstacles in most situations to garnering full public sector endorsement of PAM technology for
6 environmental protection. The objective of our research was to determine the efficacy of natural
7 abundance of the carbon ($^{13}\text{C}/^{12}\text{C}$) and nitrogen stable isotope ratio ($^{15}\text{N}/^{14}\text{N}$) to measure the
8 concentration of anionic PAM in four different soils and to measure PAM degradation rates.

10 **2.0 Materials and Methods**

11 **Experiment 1. Relationship between polyacrylamide concentrations in soils and carbon and** 12 **nitrogen stable isotope ratios**

14 *2.1 Soils*

15 To determine the relationship of anionic PAM concentration to the C and N stable isotope
16 ratios in soils we mixed increasing amounts of PAM in four soils sampled from agricultural sites.
17 Soil samples were collected from the top 5.0 cm of mineral soil in three separate 1- m² areas of
18 each soil type described above and in the high PAM application plots. Soil was collected and
19 stored in air tight and moisture tight plastic freezer bags at 4 °C and at moisture conditions
20 similar to those in the field.

21 The Kimberly soil was sampled from the 0-5 cm of the USDA Agricultural Research
22 Service's Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho research site.
23 The soil has been characterized as Portneuf silt loam (coarse-silty, mixed, super active, mesic
24 Durinodic Xeric Haplocalcid), with 10-21 g kg⁻¹ clay and 60-75 g kg⁻¹ silt, and organic matter of
25 approximately 13 g kg⁻¹. Saturated paste extract electrical conductivity (EC) of these calcareous
26 soils range from 0.7 to 1.3 dS m⁻¹, with exchangeable sodium percentage (ESP) of 1.4 to 1.7, and
27 pH of 7.6-8.0, and a CaCO₃ equivalent of 2-8%. Soil carbon and nutrient and microbial
28 characteristics are described in (Entry and Sojka, 2003; Sojka et al., 2006).

1 The New Mexico soil was sampled from the 0-5 cm of a series near Sandoval County, New
2 Mexico. The soil is a Bluepoint-Kokan series (pale brown fine sandy Typic Torripsamment) that
3 formed in a sandy alluvium. Vegetation on the soil was short grasses and broom snakeweed.
4 Mean annual precipitation varies from 16-25 cm per year. The soil has 10-21 g kg⁻¹ clay and 60-
5 75 g kg⁻¹ silt, and organic matter of approximately 13 g kg⁻¹. Saturated paste extract electrical
6 conductivity (EC) of these basic soils range from 0.7 to 1.0 dS m⁻¹, with exchangeable sodium
7 percentage (ESP) of 1.0 to 147 and pH of 7.6-7.8.

8 The Palouse soil was sampled from the 0-5 cm of a Latachco series, which is classified as
9 a fine-silty, mixed, superactive, frigid Argiaquic Xeric Argialbolls. The Latahco series consists of
10 very deep loess soils that formed in alluvium from the surrounding uplands. The soil is
11 approximately 20 g kg⁻¹ sand, 20 g kg⁻¹ clay and 60 g kg⁻¹ silt with a pH of 5.9 (Bea and
12 Knudsen, 2001). The average annual precipitation is about 45 cm and the average annual
13 temperature is 17 °C.

14 The Florence soil was sampled from the 0-5 cm (Ap horizon) from a long-term research
15 site that had conventional (disked) and conservation (non-disked) tillage plots established in
16 1978 on a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Kandiodult) near Florence,
17 South Carolina. The Norfolk soil was a sandy loam that formed in coastal marine sediments. It
18 has an Ap horizon that had been tilled over the years to a depth of about 20 cm. Below the tilled
19 layer, it had an eluviated E horizon that typically varies in depth from 30 to 100 cm and when re-
20 compacted developed penetration resistance that restricts root growth. Both the Ap and E
21 horizons had less than 5 to 6 g kg⁻¹ soil organic matter, 1 to 4 cmol kg⁻¹ cation exchange capacity,
22 and 20 to 80 g kg⁻¹ clay content. The Ap and E horizons overlaid a sandy clay loam Bt horizon
23 that extended beyond 60 cm depth. The Bt horizon typically had less than 5 g kg⁻¹ organic matter,
24 2 to 5 cmol kg⁻¹ cation exchange capacity, and 200 to 400 g kg⁻¹ clay content (Soil Survey Staff,
25 2005). The field was planted with corn (*Zea mays* L.) from 2002 through 2005 years and
26 fertilized with 110 N ha⁻¹ as NH₄NO₃.

27 28 *2.2 Experimental design*

29 The experiment was arranged in a completely randomized design (Kirk 1982). Soil samples were

1 taken from four different soils types; Portneuf silt loam from Kimberly, Idaho, a Typic
2 Torripsamment from Rio Rancho, New Mexico, a Typic Kandiuult from Florence, South
3 Carolina and a Xeric Argialbolls from Pullman, Washington. Anionic PAM was added to each
4 soil at 0, 10, 100, 1000 and 10,000 mg PAM kg⁻¹ soil. There were four soils x five PAM
5 concentrations x three replicates for a total of 60 samples, which were analyzed by two separate
6 laboratories.

7 8 *2.3 Sampling Procedures and PAM Application*

9 Soil samples were collected from the top 5.0 cm of mineral soil in three separate 1- m²
10 areas of each soil type described above. Soil was collected and stored in air tight and moisture
11 tight plastic freezer bags at 4 °C and at moisture conditions similar to those in the field. We air
12 dried the soils to a water content of 25 g kg⁻¹ by placing the soil in a drying oven at 70 °C for 48
13 hrs.

14 We mixed the following amounts of PAM in 100 ml reverse osmosis water and added the
15 mixture to 100 g soil. The concentrations of PAM mixed in soils were:

16 0 mg PAM kg ⁻¹ soil	0.000000 g No PAM, 100 ml water only (control)
17 10 mg PAM kg ⁻¹ soil	0.000055 g PAM dissolved in 100 ml water
18 100 mg PAM kg ⁻¹ soil	0.00055 g PAM dissolved in 100 ml water
19 1,000 mg PAM kg ⁻¹ soil	0.0055 g PAM dissolved in 100 ml water
20 10,000 mg PAM kg ⁻¹ soil	0.055 g PAM dissolved in 100 ml water

21
22 One hundred g of each soil was placed in a 150 ml french square bottle and water containing the
23 above stated amounts of PAM and soil was added. Soil and PAM was thoroughly mixed, placing
24 the bottles on a shaker for 30 min. Water content of soils were adjusted to 25 g kg⁻¹ by placing
25 the soil in a drying oven at 70 °C for 48 hrs and mixed by placing them in a shaker for 30 min. A
26 2 mg sub-sample from each sample was analyzed for carbon (¹³C/¹²C) and nitrogen (¹⁵N/¹⁴N)
27 stable isotope ratios.

2.4 Stable Isotope Ratio Analysis

Stable isotope ratios are measured relative to internationally recognized standards. Isotope ratios are expressed in “delta” notation as δ values in parts per thousand (‰), where δ ‰ = $(R_A/R_{Std} - 1) * 1000$ and $R_A/$ and R_{Std} are the molar ratios of the rare to abundant isotope (e.g. $^{13}\text{C}/^{12}\text{C}$) in the sample (R_A) and the standard (R_{Std}). The standard for carbon is Peedee belemnite (Coplen, 1996), a fossil limestone from South Carolina. The standard for nitrogen is air.

For isotope ratio analysis, $2 \text{ mg} \pm 10\%$ soil samples were weighed and placed into tin capsules. Carbon and nitrogen isotope ratios of each sample were determined on a Finnigan-MAT Delta S isotope ratio mass spectrometer (IRMS, Bremen, Germany) interfaced with an Elemental Analyzer (Model 1108; Carlo Erba, Milan Italy). The SIRFER facility calibrates its own internal laboratory standards relative to the international standards and includes multiple samples of the internal standard in each set of unknown samples to be analyzed. Instrument precision, based on repeated measurements of these internal laboratory standards, was 0.2 ‰ for both carbon and nitrogen isotope ratios. Stable isotope ratios for anionic polyacrylamide were 29.3 for ^{13}C and -13.1 for ^{15}N .

Experiment 2. Polyacrylamide Degradation Rates

The PAM degradation study was conducted on a site that had large accumulative additions of PAM over 3-6 year periods. There was little if any effect on microbial diversity and effects on soil microbial biomass, though measurable, were inconsistent and small considering the massive amounts of PAM added (Sojka et al., 2006). Anionic PAM is composed of 51% C and 20% N by weight and there are 3 C atoms for each N atom in the molecule. We used the same $\delta^{13}\text{C}$ to determine the amount of anionic PAM remaining in the Xeric Haplocalcid soil because we obtained the best correlation with the amount of anionic PAM in soil with the $\delta^{13}\text{C}$ in that soil, the site had large quantities of the chemical applied over a six year period, and the soil microbiological community had been characterized.

2.5 Field Study Site

The study was conducted at the USDA Agricultural Research Service's Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho. The soil in the test area was Portneuf silt loam (coarse-silty, mixed, superactive mesic Durinodic Xeric Haplocalcid) described above. Slope on this site was approximately 1.5%. Soil physical and chemical parameters on these treatments are described in detail in Sojka et al. (2006).

2.6 Experimental Design

The experimental design was a randomized complete block with three replications. Treatments were: 5382 kg active ingredient (ai) PAM ha⁻¹, 2691 kg ai PAM ha⁻¹ and a control (no PAM applied) with 3 replications (plots) of each treatment. Plots were treated five years prior to sampling. We took three samples in June, July and August, 2000 and 2006 from each plot. Plots were 40 m long x 4 m wide. We took a total of 54 samples (3 treatments x 3 replicated plots x 3 separate samples taken within each plot x 2 sampling years)

2.7 Polyacrylamide Application

The polyacrylamide copolymer used was a dry granular material having an approximate molecular weight of 12-15 Mg mole⁻¹, with an 18% negative charge density. PAM application involved the spread of granular PAM on the surface of an approximately 0.1 m² area in the furrow, corresponding to the first meter of furrow below inflow spigots. Successive application amounts were 35, 35, and 15 g of material (approximately 28, 28, and 12 g of active ingredient, which is referred to as the "patch" PAM application method as described in the USDA National Resource Conservation Service manual (Sojka et al., 1998c). In addition we applied 897 kg ai PAM ha⁻¹ in the spring every year for three years to plots receiving 2691 kg PAM ha⁻¹ (Table 1). We applied 897 kg kg PAM ha⁻¹ in the spring every year for six years to plots receiving 5382 kg PAM ha⁻¹. Since the PAM contains 41.5% C and 17.7 % N PAM treatments received 465 kg C ha⁻¹ and 199 kg N ha⁻¹ each year while receiving PAM 897 kg PAM (Table 2). Since it has been reported that anionic polyacrylamide degrades at approximately 10% y⁻¹ in soil (Tolstikh, et al. 1992), we estimated the amount of PAM remaining in the soil for each year. Fertilizer, pesticide

1 and water application are described in Sojka et al. (2006).

2 3 2.8 Sampling Procedures

4 Three separate 2.5 cm diameter soil cores were collected from the top 30 cm of mineral
5 soil from the above different locations in each plot in June, July and August, 2000 and 2006 .
6 Samples of mineral soil collected from each plot were as described above.

7 8 3.0 Results

9 In experiment 1, anionic PAM concentration correlated with in positive curvilinear relationships
10 with $\delta^{13}\text{C}$ in the Xeric Haplocalcid and Typic Torripsamment soils ($r^2 = 0.98$ and 0.99
11 respectively) but not Typic Kandiodult or Xeric Argialboll soils ($r^2 = 0.26$ and 0.32 , respectively)
12 (Table 2). Similarly, anionic PAM concentration correlated with in positive curvilinear
13 relationships with $\delta^{15}\text{N}$ in Durinodic Xeric Haplocalcid and Typic Torripsamment soils and (r^2
14 = 0.85 and 0.92 respectively) but not the Typic Kandiodult or Xeric Argialbolls soils ($r^2 = 0.55$
15 and 0.45 respectively).

16 In experiment 2, we applied $897 \text{ kg ai PAM ha}^{-1}$ in the spring annually for 3 years to plots
17 receiving 2691 kg PAM and $897 \text{ kg ai PAM ha}^{-1}$ in the spring annually for 6 years to plots
18 receiving $5382 \text{ kg PAM ha}^{-1}$ (Table 3). When $2691 \text{ kg PAM ha}^{-1}$ was applied to the soil, we
19 measured $1317 \text{ kg ai PAM ha}^{-1}$ in 2000, indicating 49% was degraded after 4 years and in 2006
20 we measured $691 \text{ kg ai PAM ha}^{-1}$, indicating 74% of the PAM was degraded after 7 years. When
21 $5382 \text{ kg ai PAM ha}^{-1}$ was applied to the soil in 1995 to 2000, we measured $4675 \text{ kg ai PAM ha}^{-1}$
22 in 2000 indicating 13% was degraded after 6 years and in 2006 we measured 1466 kg ai PAM
23 ha^{-1} indicating 73% of the PAM was degraded after 12 years. We calculated PAM degradation
24 rates based on $\delta^{13}\text{C}$ to be $9.8\% \text{ yr}^{-1}$.

25 26 4.0 Discussion

27 Anionic polyacrylamide concentration estimated by $\delta^{13}\text{C}$ values closely related to PAM
28 enriched standards when added to the Xeric Haplocalcid and Typic Torripsamment soils but not
29 Xeric Haplocalcid and Typic Torripsamment soils. The Xeric Haplocalcid and Typic

1 Torripsamment soils formed in xeric environments; they are basic soils with a high concentration
2 of base cations. A modest amount of Ca^{++} in the water shrinks the electrical double layer
3 surrounding soil particles and bridges the anionic surfaces of soil particles and PAM molecules,
4 enabling flocculation (Orts, et al., 2001; Wallace and Wallace, 1996). Calcium ions act as a
5 bridge between anionic soil surfaces and the anionic PAM macromolecule. Calcium has a
6 double charge and small hydrated radius which favors flocculation. By contrast, Na ions have a
7 large hydrated radius which impairs ion bridging, generally leading to dispersion rather than
8 flocculation of solids. The higher concentration of base cations, particularly Ca, may have
9 increased bonding of anionic polyacrylamide to soil particles and promoted a more thorough
10 mixing of polyacrylamide in the Xeric Haplocalcid and Typic Torripsamment soils compared to
11 the Typic Kandiudult or Xeric Argialbolls soils.

12 Anionic polyacrylamide may affect microbial growth by binding microorganisms to soil
13 particles or to one another, restricting their mobility and access to C and nutrients or reducing N-
14 fixing bacteria via nitrogen additions. The anionic PAM used in this study is to nontoxic most
15 soil organisms (Barvenik, 1994; Seybold, 1994; Bologna et al., 1999). Sojka et al. (2006) found
16 that active microbial biomass in these plots was 27-48 % greater in these same untreated controls
17 than soil treated with 2691 or 5382 kg ai PAM ha^{-1} . In addition whole soil fatty acid (FAME)
18 profiles showed no discernible change in the soil microbial community due to either of the PAM
19 treatments.

20 Earlier work estimated that anionic polyacrylamide degrades at rates of approximately
21 10% per year as a result of physical, chemical, biological and photochemical processes and
22 reactions (Tolstikh, et al.1992). When anionic PAM degradation rates were based on $\delta^{13}\text{C}$, we
23 found that PAM degraded at a rate of 9.8% yr^{-1} . Our data agrees with results of Tolstikh, et
24 al.(1992). Since the $\delta^{13}\text{C}$ measures all C with the specific $\delta^{13}\text{C}$ in the sample, some of which may
25 not be in the form of PAM, our degradation rates may be low because the measurement would
26 also include mineralized C reincorporated into soil microorganisms and soil organic matter.
27 Entry et al. (1992) found that as para-hydroxybenzoic acid and catechol was degraded, 15-21% of
28 the ^{14}C labeled carbon was incorporated into soil fungal tissue. Further testing using ^{14}C or ^{13}C
29 labeled anionic polyacrylamide is necessary to confirm this discrepancy.

1 The anionic polyacrylamide product used here contains <0.05% acrylamide monomer
2 (AMD). AMD is a neurotoxin, but PAM products below these AMD contents are considered
3 safe for PAM applications to water (Barvenik,1994). AMD is easily metabolized by
4 microorganisms in soil and biologically active waters, with a half life in tens of hours (Lande et
5 al, 1979; Shanker et al., 1990). Bologna et al. (1999) showed that AMD does not accumulate in
6 harvested plant tissues and apparently breaks down rapidly even when injected directly into
7 living plant tissue. PAM does not revert to AMD in the natural environment upon degradation
8 (MacWilliams, 1978). Because PAM is highly susceptible to UV degradation, its breakdown rate
9 when applied at the soil surface for erosion control may be faster than the 10% per year estimated
10 by Tolstikh, et al.(1992), which was for biological degradation of PAM mixed into a large soil
11 volume.
12

13 **5.0 Conclusions**

14 Natural abundance of ¹³C is a viable techniques for estimating the PAM concentrations in
15 some soils because its calibration and reliability are soil dependant. The technique provides an
16 analytical tool which can be used to estimate PAM degradation under various soil management
17 regimes. This cabability should be helpful in providing data to address environmental concerns
18 regarding PAM accumulation and degradation in soil.
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1 Table 1. Amount of carbon (C) and nitrogen (N) contained in polyacrylamide (PAM) treatments over a six year period from 1995 to 2000.

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4 Treatment	5 ----- 1995 -----			6 ----- 1996 -----			7 ----- 1997 -----			8 ----- 1998 -----			9 ----- 1999 -----			10 ----- 2000 -----		
	PAM	C	N	PAM	C	N												
11 Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 No PAM																		
13 2691 kg ai PAM 14 ha ⁻¹ applied.	0	0	0	0	0	0	0	0	0	897	465	199	897	465	199	897	465	199
15 Total kg ai PAM 16 ha ⁻¹ in soil ‡	0	0	0	0	0	0	0	0	0	897	465	199	1704	465	199	2430	465	199
17 5382 kg ai PAM 18 ha ⁻¹ applied	897	465	199	897	465	199	897	465	199	897	465	199	897	465	199	897	465	199
19 Total kg ai PAM 20 ha ⁻¹ in soil ‡	897	465	199	1704	465	199	2430	465	199	3085	465	199	3673	465	199	4230	465	199

21 † ai = active ingredient.

22 ‡ The amount of anionic polyacrylamide calculated to be remaining in soil at a 10% year degradation rate (Tolstikh, et al.1992).

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1 Table 2. Regressions between anionic polyacrylamide concentration in soils relative to $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in four soils

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3 ----- $\delta^{13}\text{C}$ ----- ----- $\delta^{15}\text{N}$ -----

4 Soil Location	r^2	Regression Equation	r^2	Regression Equation
5 Kimberly, ID	0.98	PAM = 315044 - (63021 * ^{13}C) + (3970.31 * $^{13}\text{C}^2$) - 6 (75.71 * $^{13}\text{C}^3$).	0.85	PAM = 2404.98 - (1511.96 * ^{15}N) + 7 (855.94 * $^{15}\text{N}^2$) - (21.04 * $^{15}\text{N}^3$).
8 Albuquerque, NM ≤ 1000 ppm	0.99	PAM = 20786 - (451203 * ^{13}C) - (311483409 * $^{13}\text{C}^2$) - 9 (669281207 * $^{13}\text{C}^3$).	0.92	PAM = 286234 - (2129041 * ^{15}N) + 10 (523435 * $^{15}\text{N}^2$) - (4247282 * $^{15}\text{N}^3$).
11 Florence, SC	0.26	PAM = 69389825 - (430725 * ^{13}C) - (397 * $^{13}\text{C}^2$).	0.55	PAM = -18862 + (13326 * ^{15}N) + 12 (2847 * $^{15}\text{N}^2$) + (44 * $^{15}\text{N}^3$)
13 Pullman, WA	0.32	PAM = -4846983 + (5050604 * ^{13}C) - (* $^{13}\text{C}^2$) + 14 (1314424 * $^{13}\text{C}^3$).	0.45	PAM = 2681646 - (978476 * ^{15}N) + 15 (99452 * $^{15}\text{N}^2$) - (298 * $^{15}\text{N}^3$)

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Table 3. Concentration of anionic polyacrylamide (PAM) in a Portnuef Silt loam soil in Kimberly, Idaho as measured by $\delta^{13}\text{C}$ values.

-----kg ai PAM ha⁻¹-----

1995-2000	0	2691 ²	5382 ²
2000	0 e	1317 c	4675 a
2006	0 e	691 d	1466 b

¹In each column, and row values followed by the same letter are not significantly different as determined by the least square means test ($p \leq 0.05$, $n=9$).

² Amount of anionic polyacrylamide added to soil annually from 1995 to 20000. Polyacrylamide was not added to control treatments.