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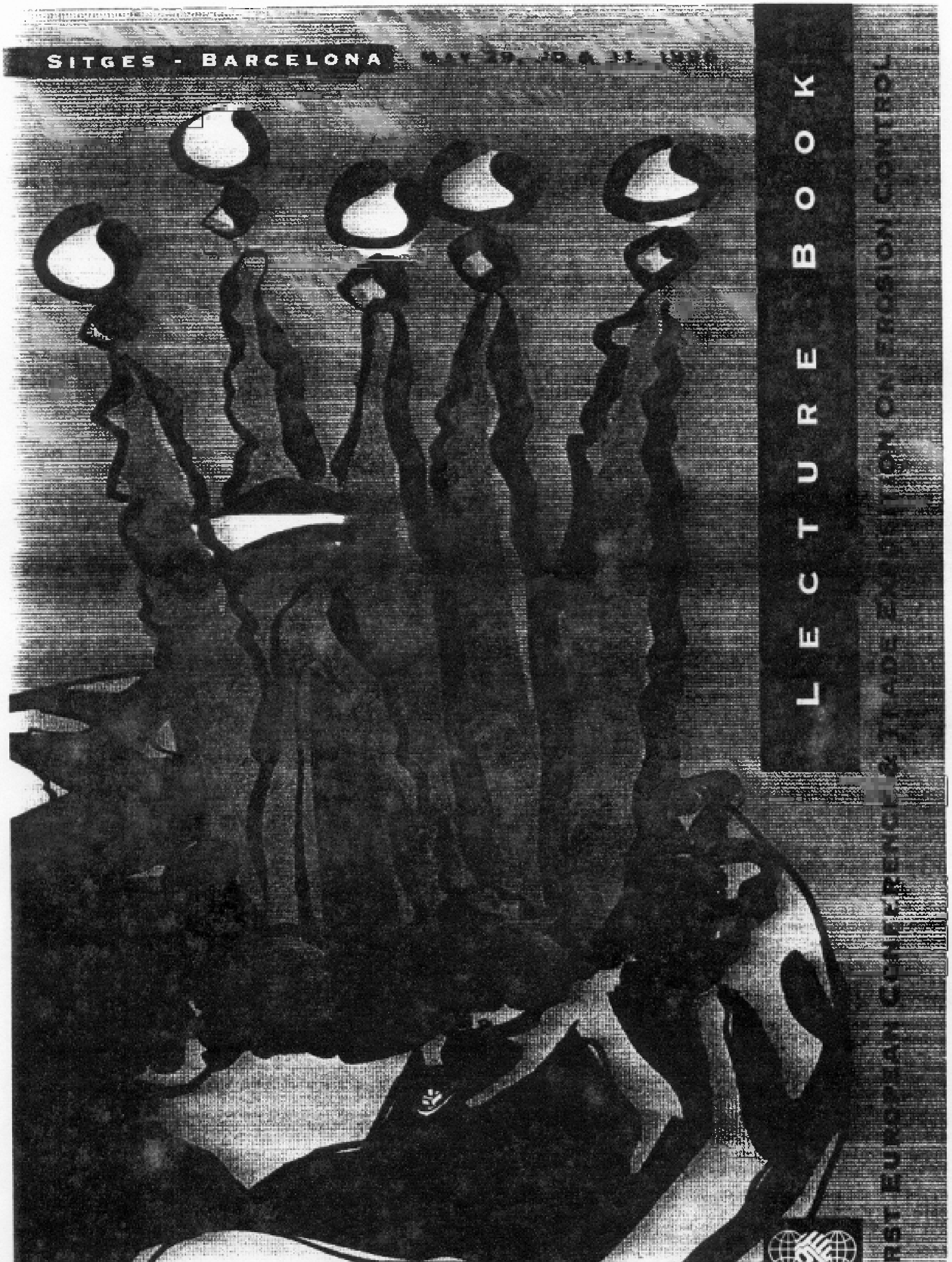

LECTURE BOOK

FIRST EUROPEAN CONFERENCE ON EROSION CONTROL

VOLUME I

LECTURE BOOK

POLYACRYLAMIDE IN FURROW IRRIGATION, AN EROSION CONTROL BREAKTHROUGH

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ABSTRACT

Irrigated crop production is critical to global agricultural output. Surface irrigation, mostly furrow irrigation, accounts for >60% of Earth's 240 million irrigated hectares. Erosion seriously threatens irrigation's ability to sustain its 2X yield advantage over rainfed agriculture and risks serious environmental and food security consequences to earth's mushrooming human population. Furrow irrigation-induced erosion is nearly eliminated by small additions of water-soluble polyacrylamide (PAM) to irrigation water. PAM is an environmentally safe industrial flocculent widely used in municipal water treatment, paper manufacturing, food processing and other sensitive applications. On freshly cultivated furrows, 1 kg/ha·of PAM applied in the irrigation inflow at 10 g/m^3 during water advance (only), reduced sediment in runoff 94% and increased net infiltration 15% in 3 yrs of Agricultural Research Service tests in Idaho on Portneuf silt loam soils (coarse-silty, mixed, mesic Durixerollic Calciorthids). PAM products are now registered throughout the western United States. the Natural Resources Conservation Service published a PAM-use practice standard in January 1995. In 1995, the first year of product commercialization, 20,000 ha of furrow irrigated land used PAM, halting an estimated 0.9 million metric tons of erosion. With PAM-use, irrigation return flows have had reduced sediment, biochemical oxygen demand (BOD), total phosphorus, and various pesticides. Many irrigation farmers who have viewed traditional conservation practices as cumbersome, intrusive, or ineffectual, adopt PAM-use as an attractive inexpensive alternative. The typical \$37-\$88/ha per crop costs, are partially or entirely retrieved by savings in erosion-related field operations, improved infiltration, water conservation, or crop responses. Pam-use in irrigation is expected to expand rapidly in 1996.

INTRODUCTION

Polyacrylamide treatment of irrigation water is one of the fastest growing conservation technologies in irrigated agriculture. PAMs were registered in most states west of the Mississippi River by late 1994, and the Natural Resources Conservation Service (NRCS) published an interim conservation practice standard for PAM-use in January 1995 (Anonymous, 1995). In 1995, its first year of commercial use, about 20,000 ha were PAM-treated, saving as much as 0.9 million metric tons of soil (Sojka and Lentz, 1996). PAM's appeal to irrigators, stems from recognition of irrigated agriculture's value, erosion's threat, and PAM's efficacy and ease of use.

IMPORTANCE OF IRRIGATED AGRICULTURE

Some 240 million (15-17%) of Earth's 1.2 to 1.4 x 10^9 ha of crop land are irrigated, mostly surface irrigated (Hoffman et al., 1990; Gleick, 1993). In the US about 13 million ha (53%) are surface irrigated, mostly by furrow (Anonymous, 1996).

Irrigation occurs mostly in arid climates (Bucks et al., 1990) where photosynthetic rates are high (few clouds), and disease, insect, and weed pressures are low, minimizing fungicide, herbicide, and pesticide inputs. Arid soils need little potassium fertilizer or lime; their neutral to basic pH and low organic matter minimize required rates of soil incorporated herbicides (Ross and Lembi, 1985).

With water, nutrients, and pest control optimized, irrigated commodities attain higher quality than rain-fed. Irrigated yields are twice the average rain-fed yields, accounting for 1/3 of all crop yield, and half of all crop value (Rangeley, 1987; Bucks et al., 1990). About 50 million hectares of Earth's best irrigated land grows 1/3 of her entire *food crop* (Tribe, 1994).

EROSION'S THREAT TO IRRIGATED AGRICULTURE SUSTAINABILITY

Irrigated agriculture's high productivity strategically enables the feeding and clothing of Earth's exploding population, yet, the arid and semi-arid soils supporting it have thin erodible surface horizons. Furrow outflow soil losses of 5-50 tons/ha/yr are common in the US Pacific Northwest, with >3 times the field average loss occurring near inflows (Berg and Carter, 1980; Kemper et al. 1985; Fornstrom and Borelli. 1984; Trout, 1996). Thus, irrigated agriculture's productivity is seriously endangered by arid soil erodibility, and irrigation-induced erosion (Carter, 1993). Some 0.5 x 10^9 ha of grasslands, rain forests, or wetlands would be needed to replace irrigated agriculture's output if irrigation were eliminated.

Many conservation practices for furrow irrigation have been developed since 1970 (Sojka, 1997). Several eliminate >80% of runoff-carried sediment. Yet, few practices are widely accepted, even after decades of promotion and demonstration. This is largely because residue placement, reduced tillage etc. are regarded as inconvenient and intrusive by furrow irrigators, who prefer smooth clear furrows to convey water. Furthermore, practices that reduce sediment loss 60-70% still lose most of the clay-sized solids (Brown et al., 1981), the soil component most critical to sustained soil fertility. These solids also are most linked to BOD, pesticide, and eutrophying nutrient problems in return-flow receiving waters.

PAM-use has proven highly effective for erosion control and infiltration enhancement, and is well received by furrow irrigators. This paper summarizes results and insights obtained over five years of experimentation with small amounts of polyacrylamide (PAM) dissolved in irrigation water.

GENERAL METHODOLOGY

The results discussed were obtained from a series of studies conducted from 1991 through 1995 at or near the USDA Agricultural Research Service's Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho. Soils included Xerollic Haplargids and Haploxerollic Durargids, but most studies were on Portneuf Silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthids). Surface horizons and general physical and chemical characteristics of all soils were similar. Textures were silt loams (10-21% clay, 60-75% silt). Organic matter ranged from 10-13 g/kg. Saturated paste extract EC was 0.7 to 1.3 dS/m, ESP was 1.4 to 1.7, pH was 7.6-8.0 with $CaCO_3$ equivalent of 2-8%. Slopes varied from 0.5 to 3.5%, but unless noted otherwise, data generally reflect slopes of 1 to 1.5%.

Water was applied as furrow irrigation (usually either via spigoted plastic pipe or siphon tubes) to conventionally tilled fields, usually disked in Autumn and Spring, then roller harrowed following incorporation of fertilizer and herbicides prior to planting. Furrows ranged from 175 to 264 meters in length; they varied from 10 to 20 cm in depth, depending on crop grown, and were prepared with weighted 75° shaping tools. Furrow spacing varied with crops, which included edible dry beans (Phaseolus vulgaris) @ 56 cm, Corn (Zea mays) @ 76 cm and Potato (Solanum tuberosa) @ 91.5 cm. Irrigation was normally on every other furrow only, usually in wheel-track furrows. Per hectare sediment-loss and infiltration were calculated based on the spacing between irrigated furrows. Irrigation water was withdrawn from the Twin Falls Canal Company[2] system and had an electrical conductivity (EC) of 0.5 dS/m and a sodium adsorption ratio (SAR) of 0.4 to 0.7. Net infiltration, runoff, and sediment-loss measurements were accomplished by use of periodic flow monitoring and sampling and automated data analysis similar to methods described in detail elsewhere (Sojka et al. 1992 and 1994, Lentz and Sojka, 1994a and 1995). Polyacrylamide (PAM) copolymers used, unless noted otherwise, was a dry granular material having an approximate molecular weight of 12-15 Mg/mole, with an 18% negative charge density, manufactured by CYTEC Industries of Wayne, NJ. It is marketed in the US by American Cyanamid Company under the trade name Superfloc 836A. Numerous similar materials, granular, compressed cakes, and high concentrate liquids are widely available world wide. Unless noted otherwise, our most frequent means of application involved preparation of liquid stock solutions of 1200-2400 g/m^3 concentration which were metered into furrow stream flows to achieve a concentration of 10 g/m^3 in the advancing water flow before runoff began. Typical flow rates ranged 13-38 L/min during advance, reduced to 13-23 L/min at initiation of runoff.

PAM'S CONSERVATION BENEFITS

Polyacrylamide (PAM) has been an effective, economical erosion preventative under a variety of field conditions (Fig. 1) when dissolved at 10 g/m^3 in the advance phase (only) of furrow irrigation inflow streams (Lentz et al., 1992; Lentz and Sojka, 1994b; Lentz, 1996). Polyacrylamide copolymers having molecular weights of 12-15 Mg/mol and charge densities of 8-35% are most effective. Environmental regulation, safety and toxicity issues have been reviewed by Seybold (1994) and Barvenik (1994). In the US, PAMs are used in potable water treatment, food processing and other sensitive applications. No significant negative impacts have been documented for aquatic, edaphic or crop species for PAM applied at recommended concentrations and rates.

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[2] Mention of trademarks, proprietary products, or vendors neither constitutes a guarantee or warranty of the product by the

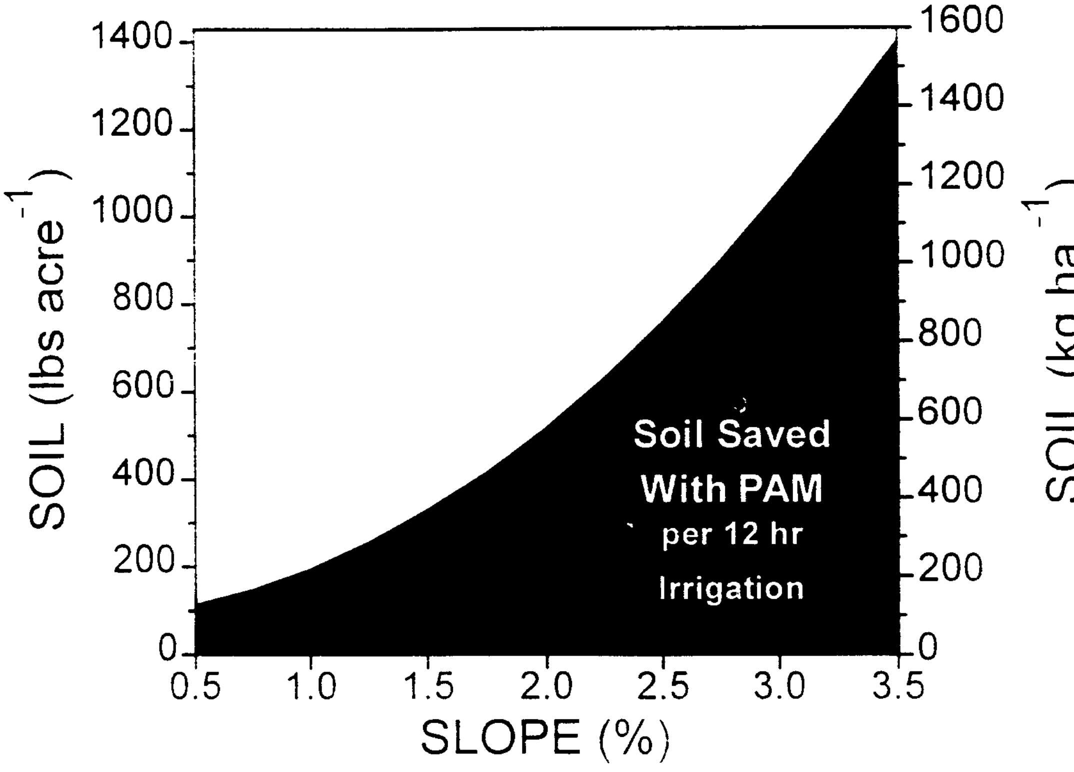

Figure 1. Estimate of soil saved as a function of slope for twelve hour irrigations on Portneuf silt loam using inflows of 23-38 L/min for an approximately 200 meter long field.

Advancing furrow streams containing 10 g/m^3 PAM provided a 94% reduction in runoff-sediment in three years of tests (Lentz et al., 1992; Sojka and Lentz, 1993; Trout and Lentz, 1993; Lentz and Sojka, 1994b, Sojka and Lentz, 1993, 1994a). With PAM-use sediments were retained on fields, even with conventional clean-tillage, using no other conservation practices (Lentz and Sojka, 1994b). PAM is a flocculent that effectively retains nearly all clay-sized material.

PAM used according to the NRCS practice standard (Anonymous, 1995) increased infiltration 15% on Portneuf silt loam (Lentz et al, 1992, Trout and Lentz, 1993; Lentz and Sojka, 1994b; Trout et al., 1995) and up to 50% on finer textured soils (McCutchan et al., 1994). PAM can increase initial infiltration on swelling soils, but may not always affect net infiltration since subsoil swelling blocks water entry as an irrigation proceeds (Mitchell, 1986). Because PAM-treated furrows did not down-cut, water infiltrated in Idaho tests moved 25% further laterally from 10 cm deep furrows between level soil beds (Lentz et al., 1992). Thus PAM-use can save water in early irrigations when only enough needs to be applied to reach planted seeds or young seedlings.

PAM'S MODE OF ACTION

The most effective and environmentally safe PAMs are large negatively charged molecules (Lentz et al., 1993). Divalent cations in water bridge the PAM and soil, increasing soil cohesion and strengthening aggregates contacted in the furrow (De Boodt, 1990; Barvenik, 1994, Sojka and Lentz, 1994b). Soil particles at the furrow's soil-water interface are bound together, preventing detachment and transport of sediments in runoff. Soil erodibility is reduced by improved inter-aggregate bonding and by protecting surface roughness. PAM only penetrates soil a few millimeters in the furrow (Malik et al. 1991) These, however, are the few millimeters critical to the erosion process. And since the wetted perimeter only exposes about 25-30% of the soil surface to flowing water, PAM's properties are effective at very low application rates, typically 1 kg/ha.

PAM is a settling agent. It flocculates (clusters together) dispersed clay and silt particles carried in the flow, enabling them to settle to the furrow bottom. This reduces the amount of suspended fines that plug pores and reduce infiltration compared to sediment-laden water. Pore aperture maintenance was confirmed in treated

furrows by higher infiltration rates under tension compared to controls (Ross et al., 1996). Higher net infiltration decreases runoff rate and amount, further reducing stream force, carrying capacity, and transport volume.
PAM's large molecular size slightly changes the viscosity and surface tension of water. It may also induce laminar flow near the soil-water interface. Further needs to determine the extent to which these changes affect propagation and transfer of shear forces causing detachment of soil particles.

DESCRIPTION OF THE PRACTICE

PAM is used most often as follows (Anonymous, 1995): One of several registered polyacrylamide copolymer products is used. These PAM copolymers are large molecules, containing over 100,000 monomer units per molecule. They typically have 18% negative charge density. US products contain <0.05% free (unreacted) acrylamide monomer by weight (<O.025% in Europe). The negative charge results when one in five amide functional groups is replaced with sodium formate. The sodium cation dissociates in water, leaving a negative charge for each cation dissociated.

These water soluble PAMs are metered into irrigation supply ditches, either as concentrated stock solutions, or as dry granules. If dry granules are metered into the flow, one must also provide turbulence in the head ditch just below the point of addition to promote uniform PAM dissolution and distribution. Supply-ditch PAM concentration is brought to 10 g/m^3 (Lentz et al., 1995). The 10 g/m^3 water is delivered to dry furrows at inflow rates that rapidly advance water across the field.

It is essential that no untreated water wet the furrow ahead of the PAM-treated flow. Untreated water destroys soil structure of erodible soils before PAM-treatment, greatly reducing PAM's affect. Wet furrows also reduce infiltration of PAM-treated water through the soil-water interface, delivering less PAM to the thin layer of soil along the wetted perimeter. This reduced application efficiency may also increase PAM-loss, increasing cost and the risk of delivering PAM to non-targeted waters.

When water reaches the end of the furrow, introduction of PAM into the head ditch is stopped. Untreated water is used for the balance of the irrigation. In most production fields the advance period consists of about the first quarter of a total irrigation period, which typically lasts either 12 or 24 hours. When runoff begins, it is generally recommended that inflows be reduced to the least needed to sustain a minimal runoff rate. In five years of testing in Idaho, this application method has required about 1 kg/ha of PAM per treatment (Lentz and Sojka, 1994b, Lentz and Sojka, 1996). If furrows are undisturbed between irrigations, erosion protection declines about 50% per untreated irrigation (Lentz et al. 1992). Furrows disturbed by traffic or cultivation must be retreated at the 10 g/m^3 rate during inflow advance. Undisturbed furrows typically erode less late in the season (Brown et al., 1995). Vegetation often intrudes into furrow bottoms late in the season (Fig. 2). Shading of furrows slows UV deterioration of PAM and physical destruction of polymer bonds caused by soil shrinking and swelling.

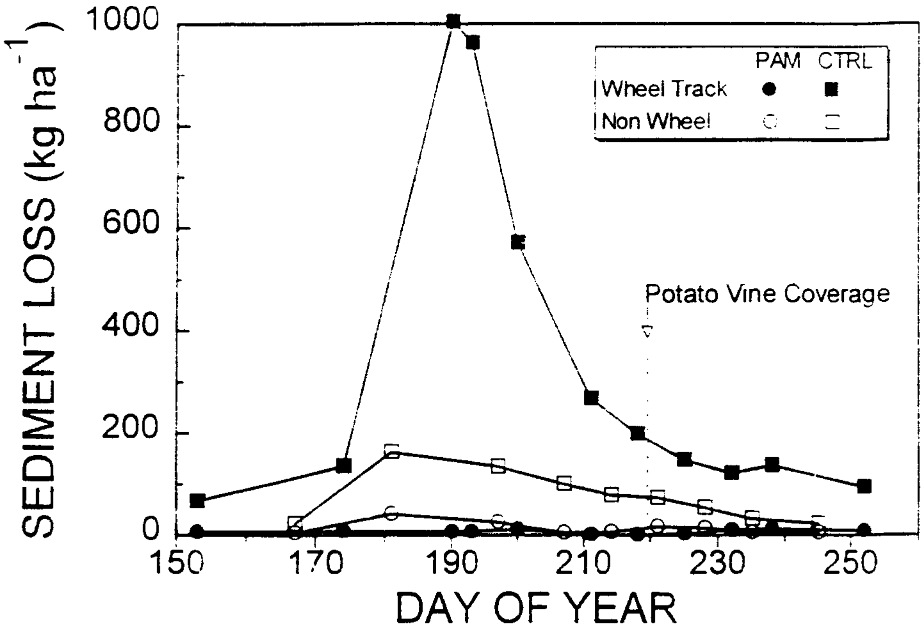

Figure 2. Example of season long reduction in erosion with PAM use in potatoes grown in Portneuf silt loam soils on 1.5% slope, using inflows of 23-46 L/min a 200 meter long field

Season-long application requirement varies with crop, cultural practices, and growing season length (number of irrigations). Typically 3 to 7 treated (@ 1kg/ha) irrigations will provide excellent seasonal erosion reduction. Granular PAM is available to farmers for $9/kg to $12/kg. PAM head ditch applicators can be purchased for a few hundred dollars each. Seasonal costs are low enough to be attractive to most farmers. In addition costs are offset by eliminated need to construct sediment retention basins, or at least, reduced basin maintenance. Furrow reshaping (cultivation), at $9/ha to $18/ha, is often eliminated.

Halting erosion prevents exposure in furrow bottoms of soil not treated with herbicides, thus reducing potential late-season weed problems. Applied pesticide and fertilizer inputs are better retained on the field, with less loss by erosion to receiving waters or riparian areas (Agassi et al., 1995; Singh et al., 1996; Bahr et al., 1996; Bahr and Steiber, 1996). Because virtually no soil is suspended in flowing water, the runoff contains few dissolved organics and nutrients (Lentz and Sojka, 1994b; Bahr et al., 1996).

PAM was used to increase furrow inflows while still controlling erosion (Sojka et al. 1995). This reduced water advance time, allowing more uniform infiltration from upper to lower field ends, improving potato yield and grade and reducing the risk of nitrate leaching from over-irrigation of the upper reaches.

CONCLUSIONS

PAM-use for erosion control can be a potent tool for achieving agricultural sustainability. It provides a potent environmental benefit. It halts furrow irrigation erosion by about 16 kg/g of PAM used. It removes most sediment, phosphorus and pesticides from return flows, and greatly reduces return flow BOD. It increases infiltration, enabling water conservation. Reduced sediment and nutrient loading of riparian areas can ultimately be expected to reduce the frequency and intensity of algal blooms, reduce turbidity and sedimentation of stream bottoms, decelerate reservoir sedimentation and wear on hydropower machinery.

PAM-use allows changes in furrow management that should provide more uniform water application. Coupling PAM-use with improved water management (e.g. accelerated inflow advance to improve field infiltration uniformity) is expected to reduce leaching of applied nitrates and to increase crop quality and net returns.

Detailed cost analyses of PAM-use are not yet available, We do know that expenses related to furrow reshaping and sediment pond or ditch cleaning are reduced. PAM-use also conserves fuel, lessens air pollution, and reduces equipment wear and labor.

Perhaps most importantly, farmers have been enthusiastic to adopt this new practice. Because there is enthusiasm for the practice, its potential for implementation and, hence, erosion and pollution reduction is particularly promising.

REFERENCES

1. Agassi, M, J. Letey, W.J. Farmer, and P. Clark. 1995. Soil erosion contribution to pesticide transport by furrow irrigation. J. Environ. Qual.24:892-895.

2. Anonymous. 1995. Natural Resources Conservation Service West National Technical Center Interim Conservation Practice Standard–Irrigation Erosion Control (Polyacrylamide)–WNTC 201-1. 5 pages.

3. Anonymous. 1996. 1995 Irrigation survey reflects steady growth. Irrig. J. 46:24-39.

4. Bahr, G., T. Steiber and K. Campbell. 1996. Reduction of nutrient and pesticide loss through the application of polyacrylamide in surface irrigated crops. Proc. 6th Annual Nonpoint Source Water Quality Monitoring Results Workshop. Boise State University, Boise ID. Jan. 9, 10 & 11, 1996.

5. Bahr, G., and T. Steiber. 1996. Reduction of nutrient and pesticide loss through the application of polyacrylamide in surface irrigated crops. Proc. Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. College of Southern Idaho, Twin Falls, ID. May 6, 7 & 8, 1996.

6. Barvenik, F.W. 1994. Polyacrylamide Characteristics related to soil applications. Soil Sci. 158:235-243.

7. Berg, R.D., and D.L. Carter. 1980. Furrow erosion and sediment losses on irrigated cropland. J. Soil Water Conserv. 35:367-370.

8. Brown M.J., J.A. Bondurant and C.E. Brockway. 1981 Ponding surface drainage water for sediment and phosphorous removal. Trans. ASAE. 24:1478-1481.

9. Brown. M.J., D.L. Carter. G.A. Lehrsch, and R.E. Sojka. 1995. Seasonal trends in furrow irrigation erosion in southern Idaho. Soil Technology. 8:119-126.

10. Bucks, D.A., T.W. Sammis, and G.L. Dickey. 1990. Irrigation for arid areas. pages 499-548. *In* Management of Farm Irrigation Systems. G.J. Hoffman, T.A. Howell, and K.H. Solomon (eds.). Am. Soc. Ag. Eng. St. Joseph, MI

11. Carter, D.L. 1993. Furrow erosion lowers soil productivity. J. Irrig. Drain. Eng. ASCE. 119:964-974

12. De Boodt. M.F., M.H.B. Hates, and A. Herbillon (eds.). 1990. Soil Colloids and Their Associations in Aggregates. NATO ASI Series B:Physics Vol. 215. 598 pages. Plenum Press. NY

13. Fornstrom. K.J., and J. Borelli. 1984. Design and management procedures for minimizing erosion from furrow irrigated cropland. ASAE Paper 84-2595. ASAE. St. Joseph. MI.

14. Gleick. P.H. 1993. An introduction to global fresh water issues. *In* Gleick. P.H. (ed.) Water in Crisis. Oxford University Press. New York. 473 pages.

15. Hoffman, G.J., T.A. Howell and K.H. Solomon (eds.) 1990. Management of Farm Irrigation Systems. 1040 pages. ASAE. St. Joseph, MI.

16. Kemper, W.D., T.J. Trout. M.J. Brown, and R.C. Rosenau. 1985. Furrow erosion and water and soil management. Trans ASAE 28:1564-1572.

17. Lentz. R.D., I. Shainberg. R.E. Sojka and D.L. Carter 1992 Preventing irrigation furrow erosion with small applications of polymers. Soil Sci. Soc. Am. J. 56:1926-1932.

18. Lentz. R.D., R.E. Sojka. and D.L. Carter. 1993. Influence of polymer charge type and density on polyacrylamide ameliorated irrigated furrow erosion. Proc., 24th Annual International Erosion Control Association Conference. 23-26 Feb., 1993, Indianapolis. IN. pages 159-168.

19. Lentz. R.D. and R.E. Sojka. 1994a. Automated Imhoff cone calibration and soil loss/infiltration analysis for furrow irrigation studies. p. 858-863. *In* D.G. Watson. F.S. Sasueta and T.V. Harrison (eds.) Computers in Agriculture 1994: Proc 5th Internt'l Conf. on Computers in Agriculture. Orlando. FL 5-9 Feb., 1994. ASAE, St. Joseph. MI.

20. Lentz. R.D. and R.E. Sojka. 1994b. Field results using polyacrylamide to manage furrow erosion and infiltration. Soil Science. 158:.274-282

21. Lentz. R.D., T.D. Steiber. and R.E. Sojka. 1995. Applying polyacrylamide (PAM) to reduce erosion and increase infiltration under furrow irrigation. *IN*: Robertson, L.D., Nolte. P., Vodraska. B., King. B., Tindall, T., Romanko. R. and Gallian, J. (eds.) Proc. Winter Commodity Schools—1995. pages 79-92. University of Idaho Cooperative Extension. Moscow, ID.

22. Lentz. R.D. and R.E. Sojka. 1995. Monitoring software for pollutant components in furrow irrigation runoff. p. 123-127. *In* L. Ahuja. J. Leppert. K. Rojas, and E. Seely (eds.) Proc. Workshop on Computer Applications in Water Management. 23-25 May. 1995. Colorado State University Water Resources Research Institute Info. series No 79

23. Lentz. R.D., and R.E. Sojka. 1996 Polyacrylamide application to control furrow irrigation-induced erosion. Proceedings of the 27th International Erosion Control Association meetings. pages 419-430. Seattle Washington. 27 Feb.-1 Mar., 1996

24. Lentz. R.D 1995 Irrigation: Use of water soluble polyacrylamide to control furrow irrigation-induced erosion p. 162-165 *IN* S.P Parker (ed.) Yearbook of Science and Technology 1996. McGraw Hill, Inc. NY.

25. Malik. M. A. Nadler. and J. Letey. 1991. Mobility of polyacrylamide and polysaccharide polymer through soil materials. Soil Technol 4:255-263

26. McCutchan. H. P. Osterli, and J. Letey. 1994 Polymers check furrow erosion. help river life. Calif. Ag. 47:10-1?

27. Mitchell. A.R. 1986 Polyacrylamide application in irrigation water to increase infiltration. Soil Sci. 141:353-358

28. Rangeley. W.R 1987. Irrigation and drainage in the world. p.29-35 *In* Proc. Water and Water Policy in world Food Supplies Conf. W.R. Jordan (ed.). College Station Texas A & M Univ. Press

29. Ross. M.A., and C.A. Lembi. 1985. Applied Weed Science. 340 pages. McMillan and Company New York.

30. Ross. C.W. R.E. Sojka. R.D. Lentz 1996 Polyacrylamide as a tool for controlling sediment runoff and improving infiltration under furrow irrigation. Proceedings Australia & New Zealand National Soils Conference. Melbourne Australia July. 1996 (In Press

31. Seybold, C.A. 1994. Polyacrylamide review: Soil conditioning and environmental fate. Comm. Soil Sci. Plant. Anal. 25:2171-2185.

32. Singh, G., J. Letey, P. Hanson, P. Osterli, and W.F. Spencer. 1996. Soil erosion and pesticide transport from an irrigated field. J. Environ. Sci. Health B31 (1), 25-41.

33. Sojka, R.E., Carter, D.L. and M.J. Brown. 1992. Imhoff cone determination of sediment in irrigation runoff. Soil. Sci. Soc. Am. J. 56:884-890.

34. Sojka, R.E., and R.D. Lentz. 1993. Improving water quality of return flows in furrow-irrigated systems using polymer-amended inflows. Proceedings of the SWCS Conference on Agricultural Research to Protect Water Quality, 21-24 Feb., 1993. Minneapolis, Minn, pp. 395-397.

35. Sojka, R.E. and R.D. Lentz. 1994a. Net infiltration and soil erosion effects of a few ppm polyacrylamide in furrow irrigation water. p. 349-354. *IN*: So, H.B., Smith, G.D., Raine, S.R., Schafer, B.M., and Loch R.J. (eds.) Sealing, Crusting and Hardsetting Soils: Proc. 2nd Internat'l Symposium. 7-11 Feb., 1994. University of Queensland, Brisbane, Australia.

36. Sojka, R.E. and R.D. Lentz. 1994b. Polyacrylamide (PAM): A new weapon in the fight against Irrigation-induced erosion. USDA-ARS Soil and Water Management Research Unit, Station Note #01-94.

37. Sojka, R.E., R.D. Lentz and J.A. Foerster. 1994. Software utilizing Imhoff cone volumes to estimate furrow-irrigation erosion. J. Soil and Water Cons. 49:400-406.

38. Sojka, R.E., R.D. Lentz and D.T. Westermann. 1995. Water and erosion management with PAM in furrow-irrigated potatoes. Agronomy Abstracts

39. Sojka, R.E., R.D. Lentz, and D.T. Westermann. 1995. Water and Erosion Management with PAM in Furrow Irrigated Potatoes. page 284. Agronomy Abstracts 1995.

40. Sojka, R.E., and R.D. Lentz. 1996. Polyacrylamide for furrow-irrigation erosion control. Irrig. J. 46:8-11.

41. Sojka, R.E. 1997. Research contribution to the understanding and management of irrigation-induced erosion. 50th Anniversary Symposium on Soil Conservation Research. J. Soil Water Conserv. Special Pub. F.J. Pierce (ed) (In Press).

42. Tribe, D. 1994. Feeding and Greening the World, the Role of Agricultural Research. 274 pages. CAB International. Wallingford, Oxon, UK.

43. Trout, T.J., R.E. Sojka and R.D. Lentz. 1995. Polyacrylamide effect on furrow erosion and infiltration. Trans. ASAE. 38(3):761-765.

44. Trout, T.J., and R.D. Lentz. 1993. Polyacrylamide decreases furrow erosion. *IN*: R.G. Allen and C.M.U. Neale (eds.) Management of Irrigation and Drainage Systems: Integrated Perspectives. Proceedings of the 1993 Nat'l Conf. on Irrig. and Drainage Engineering. Park City, UT, 21-23 July.

45. Trout, T.J. 1996. Furrow irrigation erosion and sedimentation: on-field distribution. Trans. ASAE (In Press)