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Publisher: Taylor & Francis

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Special Issue: Agriculture and stream water quality – future challenges for monitoring
Guest Editors: Brian Koozang and Marianne Bechmann

The official journal of the
Soil Science Society of America



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Acta Agriculturae Scandinavica, Section B – Soil & Plant Science

Publication details, including instructions for authors and subscription information:
<http://www.tandfonline.com/loi/sagb20>

Arkansas Discovery Farms: documenting water quality benefits of on-farm conservation management and empowering farmers

Andrew Sharpley^a, Mike Daniels^b, Lawrence Berry^a, Cory Hallmark^b & Josh Hesselbein^b

^a Department of Crop, Soil and Environmental Sciences, Division of Agriculture, University of Arkansas System, Fayetteville, AR, USA

^b Department of Crop, Soil and Environmental Sciences, Cooperative Extension Service, Division of Agriculture, University of Arkansas System, Little Rock, AR, USA

Published online: 15 Apr 2015.

To cite this article: Andrew Sharpley, Mike Daniels, Lawrence Berry, Cory Hallmark & Josh Hesselbein (2015) Arkansas Discovery Farms: documenting water quality benefits of on-farm conservation management and empowering farmers, Acta Agriculturae Scandinavica, Section B – Soil & Plant Science, 65:sup2, 186-198, DOI: [10.1080/09064710.2014.960444](https://doi.org/10.1080/09064710.2014.960444)

To link to this article: <http://dx.doi.org/10.1080/09064710.2014.960444>

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ORIGINAL ARTICLE

Arkansas Discovery Farms: documenting water quality benefits of on-farm conservation management and empowering farmers

Andrew Sharpley^{a*}, Mike Daniels^b, Lawrence Berry^a, Cory Hallmark^b and Josh Hesselbein^b

^aDepartment of Crop, Soil and Environmental Sciences, Division of Agriculture, University of Arkansas System, Fayetteville, AR, USA; ^bDepartment of Crop, Soil and Environmental Sciences, Cooperative Extension Service, Division of Agriculture, University of Arkansas System, Little Rock, AR, USA

(Received 5 June 2014; accepted 27 August 2014)

Arkansas Discovery Farms (ADFs) are private farms that collaborate with on-farm research, verification, and demonstration of farming's impact on the environment. We have nine ADFs representing livestock (broiler poultry and pasture grazed beef and sheep) and row crop agriculture (corn, cotton, rice, soybean, and wheat), where we collect water use and water quality data as a function of conservation management, using autosamplers equipped with edge-of-field H-flumes or weir flow structures, which measure and collect surface runoff. On the poultry farms, we are monitoring nutrient and sediment runoff originating immediately near poultry houses due to concerns with spillage of litter during bird removal and house clean out, as well as dust from tunnel ventilation. On a nearby farm we are assessing the impact of rotational grazing on water quality, soil organic matter, and soil health metrics. On the row crop farms we are assessing the impacts of conservation tillage and cover crops on soybean–corn rotations and cotton on nutrient and sediment runoff and the benefits of water harvesting and reuse of water conservation and quality. The information in this paper while preliminary, demonstrates how a state-wide on-farm demonstration program operates. Elevated nutrient and sediment runoff from around poultry production areas are decreased three-fold by directing runoff into ponds or through grassed waterways. While conservation tillage and cover crops do decrease nutrient and sediment runoff, no significant difference between conventional and conservation operations is yet to be realized. Importantly, ADF empowers farmers to proactively address environmental concerns. This paper discusses the development, guidance, principals, and goals of ADF and contrasts this with other farm monitoring projects, where the sources of nutrient impairment are the subject of ongoing litigation. Monitoring in divisive and transparent situations presents unique challenges with data ownership and release of findings, which can hinder productive outcomes of such monitoring.

Keywords: phosphorus; nitrogen; agricultural runoff; nutrient management; manure management; eutrophication; water quality; surface runoff; mitigation

Introduction

Nutrient enrichment remains a major impairment to the designated uses of fresh and coastal waters of the USA (Schindler et al. 2008). While there are many sources of nutrients, the contribution of agriculture, in particular intensive livestock and crop production, has received increased attention to reduce nutrient losses (U.S. Environmental Protection Agency 2010). This attention has been fueled by recent modeling efforts and surveys that have suggested that agriculture remains a major contributor of nutrients to surface

waters and thereby to their impairment. For instance, recent model estimates suggest that up to 85% of the phosphorus (P) and nitrogen (N) entering the Gulf of Mexico originates from agriculture (Alexander et al. 2008). While these estimates are based on large-scale modeling within the Mississippi River Basin, there have been few farm-scale studies of P and N loss from agricultural production systems in the Basin, particularly the Lower Mississippi Alluvial Valley, containing large agricultural areas in Arkansas and Mississippi (Dale et al. 2010; Kröger et al. 2012).

*Corresponding author. Email: sharples@uark.edu

This has resulted in growing pressures being placed on agricultural producers to minimize nutrient and sediment associated water quality concerns globally (Boesch et al. 2001; Rabalais et al. 2001; Richards et al. 2009, 2010). Local water quality issues in Arkansas have placed additional pressures on farmers to defend their practices and to document the benefits of their conservation practices already in place. The pressure over potential water quality impacts originating from agricultural operations has prompted controversy and created an emotional issue among agricultural producers who feel they have been unfairly targeted. Because of this pressure, the Discovery Farm Program was developed in Wisconsin some 10 years ago (Stuntebeck et al. 2011 and <http://www.uwdiscoveryfarms.org/Home.aspx>). There are now four states in the USA, with similar programs based on the Wisconsin model that include Arkansas, Iowa, Minnesota, and North Dakota.

The Arkansas Discovery Farm Program (ADFP) is an effective stakeholder-driven environmental research and demonstration program, where extensive water quality monitoring systems, equipment, and protocol are installed on real, working farms to document environmental impact, and to research the potential of alternative practices to reduce off-farm impacts. The overall goal of the program is to document sustainable and viable farming systems that remain cost-effective in an environmentally sound manner, with the following objectives:

- (1) Conduct on-farm research and monitoring to assess the need for and effectiveness of best management practices (BMPs).
- (2) Provide on-farm verification and documentation of nutrient and sediment loss reductions and water conservation in support of nutrient management planning (NMP) and sound environmental farm stewardship.
- (3) Develop and deliver educational programs from on-farm data that will assist producers in achieving both production and environmental goals in support of sustainable farming.

Documenting environmental impacts of farming systems, as well as evaluating the efficacy and cost-effectiveness of alternative practices, will bridge a knowledge gap that now keeps farmers, natural resource managers, and decision-makers from confidently taking effective actions that ensure both economic and environmental sustainability. The ADFP, as well as the formation of strong partnerships, has the potential to affect millions of agricultural acres across the Mississippi River Basin.

Concurrent with this environmental pressure for farmers to practice environmental stewardship, is the

need to intensify agricultural production and maximize yields, in efforts to feed an ever-increasing global population. This has led to the intensification and expansion of livestock operations in particular. One such farm, a swine breeding operation was recently permitted to operate in the watershed of a National Scenic River in the USA (NPDES 2012). Similarly, the rapid growth of poultry broiler operations in northwest Arkansas and northeast Oklahoma have led to lawsuits between downstream water users (City of Tulsa and Lakes Eufaula, Spavinaw, and Tahlequah in Oklahoma) and poultry integrators in the area, who are perceived to be the source of excess nutrients that eutrophy waters (DeLaune et al. 2006). This has drawn attention from pro-farming and pro-environmental groups and has led to a closer scrutiny of monitoring of the impact of the farms on area water quality. The unique monitoring issues arising from voluntary on-farm monitoring will be compared with those associated with a highly contentious and closely scrutinized farm operation.

In this paper, we will describe how the ADFP was developed in Arkansas, how stakeholders were involved in the program and given ownership, how participating farmers can be an effective mouthpiece to widespread adoption of conservation practices, and how results to date have influenced local and regional nutrient management and water quality policy. We will compare how monitoring under the framework of ADFP activity differs from that where compliance with nutrient management and water quality standards is required by regulation.

Monitoring under the ADFP

Field methodology

Only operations reflective of typical farming systems are used where edge-of-field monitoring will determine runoff volume as well as nutrient and sediment loss from a minimum of three sites where specific conservation practices are installed and with a fourth untreated site acting as a control. Thus, we typically equip three to four sites (fields) with monitoring stations which allows us to conduct field by field comparisons or compare two to three scenarios with a control site. Because we conduct this research on real-working farms at a field scale, we cannot usually predetermine what specific factors to investigate without first meeting with the farmer and conducting a thorough farm reconnaissance. Furthermore, a control site may not always be available for the length of the study (five years minimum) on a commercial farm, and in these cases time after implementation of a BMP is used to evaluate nutrient reduction potentials.

The BMPs that are evaluated are specific to the particular farm and the needs of the farmer. As field, farm, and watershed level response to conservation practice implementation can take several years to be fully manifested, site monitoring occurs for a minimum of five years to ensure that reliable water quality response changes can be documented.

Specifically, monitoring at each site is comprised of runoff and water flow measured by strategically located gauged flumes or weirs, along with auto-samplers to collect water samples for analysis of nutrients and sediments during flow – runoff events. At each field site, surface runoff water leaving a field is measured at existing discharge points, such as outlets or standpipes already in place as part of the field management and drainage operation. These pipes accumulate runoff water leaving a field to one point where we can continuously measure flow volume and rate by automatic stage height and transducers. Where no such outlet exists, we construct berms at predetermined positions to direct surface runoff to a single collection point where we install a flume or weir, depending on the size of the field, drainage area, and potential receiving water volumes, to continuously measure flow volume and rate as above.

At each field outlet site, an automatic water sampler is installed to collect runoff samples at predetermined intervals during a discharge event. For example, each sampler is programmed to collect 100, 100 mL samples integrated across various stages of the flow hydrograph, or up to a total of 10 L during each runoff event. Each sample is collected and analyzed following protocol set forth by the U.S. Environmental Protection Agency for suspended solids, sediment, N, and P. A sample is collected on a unit flow basis, such that a composite flow-weighted sample for the whole discharge event is obtained. This sample is collected from the autosampler within 24 hours of collection for determination of N, P, and sediment concentration, as described below.

For row crop situations where irrigation is utilized, irrigation inflow will be measured with in-pipe flow meters to determine application rates and cumulative irrigation volume. Irrigation water use is monitored with turbine-based, inline flow meters outfitted with data loggers. In some situations, evapotranspiration (ET) gauges are utilized to estimate daily ET losses and soil moisture sensors are utilized to estimate change in soil water volume while the monitoring stations at the drainage outlet of the field allows for the determination of tail water losses from irrigation.

Program governance and oversight

While the University of Arkansas – Division of Agriculture provides leadership and expertise to ensure that data are collected in a scientifically rigorous and valid manner, the program is led by ADFP Stakeholders and Technical Committees (Table 1) consisting of leaders from agricultural organizations and one reserved for environmental organizations. Currently, the Nature Conservancy and Arkansas Department of Environmental Quality serve on our Stakeholder and Technical Advisory Committees to ensure transparency among all stakeholders.

In addressing water resource issues, partnerships are essential. Our partners include both public and private entities. One interesting aspect of our partnership is the participation of the Arkansas Discovery Farms (ADFs) in the Mississippi Healthy River Basin Initiative (MRBI) program (U.S. Department of Agriculture – Natural Resources Conservation Service 2009). The Natural Resource Conservation Service (NRCS) administers this financial incentive program (\$320 million) for agriculture in 13 states along the Mississippi River Corridor. One of the unique aspects of this program is that NRCS provides financial incentives to farmers to conduct edge-of-field monitoring.

Table 1. Members of the ADF Committees.

Technical	Stakeholder involvement
Arkansas Natural Resources Commission	Arkansas Dairy Producer
Arkansas Association of Conservation Districts	Arkansas Association of Conservation Districts
Arkansas Department of Environmental Quality	Arkansas Farm Bureau
NRCS	U.S. Rice Federation
Arkansas State Plant Board	Arkansas Cattlemen's Association
Arkansas Livestock And Poultry Commission	Arkansas Nature Conservancy
Arkansas Game and Fish Commission	Poultry Producers
International Plant Nutrition Institute	Arkansas Rural Water Association
Arkansas Forestry Commission	Arkansas Pork Producers Association
U.S. Geological Survey	Arkansas Soybean Association
Arkansas Farm Bureau	Arkansas Forestry Association
	Agricultural Council of Arkansas

The Arkansas Discovery Farms

Nine ADFs in four distinct physiographic farming regions around the state constitute the present program (Figure 1 and Table 2). Dominant Arkansas farming systems are represented and include livestock (broiler poultry along with beef and sheep grazing) in northwest Arkansas and crop production enterprises in eastern and southern Arkansas.

Atkins – Maus Farm

The Maus Farm is a 400-ha row crop farm in the MRBI focus watershed of Point Remove – Lake Conway, in Pope County. There are about 80 ha of wheat (*Triticum aestivum*), 100 ha of rice (*Oryza sativa*), 80 ha of corn (*Zea mays*), and 160 ha of soybean (*Glycine max*). We are monitoring runoff from three fields that have management ranging from cover crop, no cover crop, conservation tillage, and conventional tillage under a rotation of corn and soybean.

Cherry Valley – Clements' Farm

The Matt and Danny Clements' Farm (about 650 ha) east of the L'Anguille River immediately across

from the Woods' Farm. It is a row crop operation, which rotates soybeans, rice, and occasionally wheat and is in the L'Anguille Watershed in Cross County. This area was recently declared a critical groundwater area by Arkansas Natural Resources Commission (ANRC).

The Clements' use conventional tillage and water management and offers a contrast in conservation practices with the Woods' Farm, which has planted switchgrass (*Panicum virgatum*) buffers between the river and his fields via Conservation Reserve Practice or set aside from production agriculture and generally uses no-till cultivation practices.

Because fields in this area are not candidates for land-leveling (due to cost and the risk of exposing underlying soil horizons that are detrimental to crop production), flood irrigation is still the preferred irrigation method for soybeans. The Clements' Farm uses ground water as an irrigation source. We are monitoring runoff, nutrients, and sediment from one field under traditional tillage management on the Clements' Farm. Information from this farm will provide baseline information on current and generally more commonly practiced management. Runoff will eventually be captured by a new tail water recovery system and a new reservoir. In April each

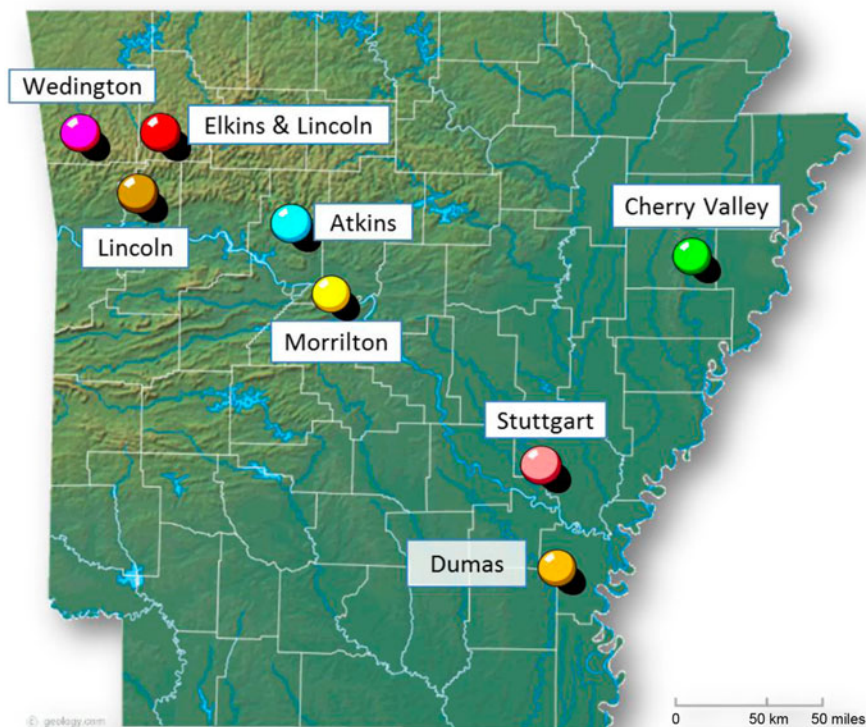


Figure 1. Map of ADFs.

Table 2. ADFs.

Location	Farm	Size (ha)	Farm operation	Measures assessed
Atkins	Maus	400	Corn, soybean, and rice	Cover crops
Cherry Valley	Clements	650	Rice and soybean	Conventional tillage
Cherry Valley	Wood	1100	Rice and soybean	No-tillage edge-of-field buffers
Elkins	Marley	900	Broiler poultry (250,000 birds) and beef grazing (250 head)	Runoff from production area
Lincoln	Moore	250	Broiler poultry (200,000) and corn	Runoff from production area
Morrilton	Willow Bend	1050	Irrigated Bermuda pasture, beef (300 head), and corn	Nutrient management and wetland capture of runoff
Stuttgart	Dabbs	600	Corn, rice, and soybean	Water harvesting and reuse and conservation tillage
Dumas	Stephens	600	Cotton and corn	Cover crops and conservation tillage
Wedington	Morrow	100	Beef and sheep grazing	Rotational grazing

year, 40 kg N and 25 kg P ha⁻¹ are broadcast prior to planting.

Cherry Valley – Woods' Farm

The Woods' Farm (about 1100 ha) is on the west side of the L'Anguille River, Cross County, immediately across from the Clements' Farm. This area was recently declared a critical groundwater area by ANRC, and this and the Clements' Farm offer a contrast in conservation practices.

The Woods' Farm uses a combination of surface sources (relief from the L'Anguille) and wells to irrigate mostly conservation tillage (no-till) rice and soybean rotations, which drain through a switchgrass border and/or Conservation Reserve Program (CRP) lands. Another field we are monitoring uses furrow irrigation for soybeans. As with the Clements' Farm, 40 kg N and 25 kg P ha⁻¹ are broadcast prior to no-till planting of soybean each year.

Runoff, nutrients, and sediment are monitored from conservation tillage management of soybeans and rice. Information from this farm and the adjacent Clements' Farm will provide a good comparison of the conservation and conventional tillage management on nutrient and sediment runoff in this region.

Dumas – Stephens' Farm

The Stephens' Farm is a row crop operation (about 600 ha), concentrating on cotton (*Gossypium spp.*) and corn and is located in the Bayou Macon Watershed in Desha County. The Bayou Macon Watershed, located in southeastern Arkansas and northeastern Louisiana appeared on the 2006 State of Arkansas' 303d list as being impaired for aquatic habitat by turbidity caused by sediment/siltation from intensive row crop agriculture. The Bayou

Macon Watershed was one of the seven watersheds approved by NRCS as a MRBI project area.

On the Stephens' Farm, we are evaluating the benefits of conservation tillage, cover crops and irrigation water management on nutrient and sediment runoff. Three cotton fields, Shopcot (9 ha), East Weaver (15 ha), and Homeplace (16 ha), were selected for monitoring the quantity and quality of both inflow (precipitation and irrigation) and outflow (runoff). All three fields were planted to cotton in late May. Stale seed bed with minimum tillage was utilized in the East Weaver and Homeplace fields. However due to the residue from the cover crop, the middles in the Shopcot were plowed to ensure that water would move freely down the field. In June 2013, fertilizer was broadcast at the rates of 44 kg N ha⁻¹ and 11 kg P ha⁻¹ on all fields.

Elkins – Marley Farm

The Marley Farm is a poultry–beef grazing operation in the Beaver Lake – Upper White River Watershed, in Washington County. There are 10 poultry houses (approximate 25,000 bird capacity), with 500 ha of pasture and about 400 ha of woodland.

We are monitoring runoff from four poultry houses that flow into a 1.5 ha pond (Flume 1) and from two houses (Flume 2) where runoff flows through a pasture (cut for hay) into an ephemeral creek (Flume 3), connected to the White River. Monitoring stations quantify nutrient and sediment loadings entering the pond and pasture before reaching the creek. These data are used to determine quantities of nutrients and sediment that may be lost from around the poultry houses and to quantify nutrient and sediment trapping efficiencies of the pond and pasture. A tall fescue (*Lolium arundinaceum*) and Bermudagrass (*Cynodon dactylon*) pasture between Flumes 2 and 3 was fenced to exclude grazing cattle. The pasture is designed to operate as grassed waterway

that might mitigate any N and P loss from around the poultry houses before entering the ephemeral creek. The distance of pasture from Flumes 2–3 is approximately 200 m and has a slope of 2%.

Lincoln – Moore Farm

The Moore Farm is a poultry – row crop operation (about 250 ha) in the Illinois River Watershed. There are currently four poultry houses (approximately 25,000 bird capacity), with four new houses being constructed. Here we are working with the farmer to design and construct the new houses in a way that they have a minimal water and nutrient footprint. We are monitoring runoff from around the new houses to demonstrate that a low-nutrient footprint design for poultry houses can cost-effectively mitigate nutrient runoff.

We will establish BMPs around the newly constructed poultry houses, at minimal cost to the farmer, with little water quality impact and monitor runoff onto and off the site to document water quality benefits. On the same farm, we will also retro-fit older poultry houses with BMPs and assess their similar effectiveness. The BMPs considered are:

- (1) French drains under the roofline to carry roof runoff from the site underground, minimizing erosion.
- (2) Larger concrete pads at the front of the house, with a gutter around it. This would make it easier for a farmer to clean any unavoidable spillage of litter following bird or litter removal.
- (3) Backfill any French drain with locally sourced P sorbing materials, such as by-products from the nearby Beaver Water District drinking water treatment.
- (4) Use of an existing farm pond to collect any runoff and trap nutrients.
- (5) Establish forage cover around the houses to minimize runoff and erosion.
- (6) Divert any concentrated flowing water away from the houses where possible.

Morrilton – Willow Bend Farm

Willow Bend Farm is a beef (about 550 ha) and row crop (about 500 ha) operation managed by Ruth Spillar. The farm is in the Point Remove Watershed in Conway County and pastures beef immediately adjacent to Point Remove Creek and the Arkansas River. These pastures are fertilized with litter that is purchased from other farms.

Many of the pastures are irrigated to produce high quality Bermudagrass hay and others are underlain

by poorly drained soils that stay wet for a large part of the winter and are prone to intermittent flooding. In one pasture, runoff drains into a natural wetland.

We are determining the effect of poultry litter management (e.g., application rate, timing, and placement) on nutrient runoff from the pasture. This runoff enters a wetland and we are monitoring runoff entering and exiting the wetland to quantify nutrient and sediment storage in the wetland. Plans are currently underway to construct a levee near the wetland for use as a cattle crossing during the winter when the ground is normally very wet.

Stuttgart – Dabbs' Farm

The Dabbs' Farm is a row crop operation (about 600 ha), concentrating on rice, soybean, and corn rotations and is located in the Bayou Meto Watershed in Arkansas County. The Dabbs' Farm has been in a critical groundwater area for more than a decade.

In contrast to water management at the Cross County site, this farm has nearly all fields land-leveled, and a tail water recovery system collects all runoff water from this farm and returns it to the irrigation reservoir for reuse. This farm uses only surface water for irrigation as opposed to the Cross County site.

We are monitoring water use and water quality (nutrients and sediment) on four fields with different cropping rotations and management, which include rice grown on zero grade, rice grown on unlevelled ground (control), rice grown on a precision-leveled field, and corn grown on a precision-leveled field. This combination of treatments allows us to compare different water management schemes, as well as compare water use of rice and corn at a field scale. We are also monitoring the quantity and quality of recovery water immediately before it reenters the reservoir.

Wedington – Morrow Farm

The Morrow Farm is a rotationally grazed beef and sheep operation (about 100 ha) with about 200 head of beef cows, as well as approximately 150 sheep. The farm is in the Illinois River Watershed in Washington County. The farm has currently been rotationally grazed pastures for about five years (since 2007) and limited fertilizer and no manure has been applied in that time. The strategic plan for the farm is to carefully manage pasture by rotating cows and redistributing nutrients across the pastures (Franzleubbers et al. 2000; Contant et al. 2003; Sanderson et al. 2010).

Soil health is monitored by grid-soil sampling, surface runoff from rotationally grazed pasture and the water quality of a stream entering and leaving the farm is continuously monitored. The overall goal of this farm is to raise soil organic matter from 1–2% to over 4% in the coming years, simply through careful pasture management and rotational grazing. We are monitoring the changes in soil physical, chemical, and biological properties influencing soil health, associated pasture productivity, and surface runoff quantity, and quality.

There is a great interest among the farming community in documenting the benefits of rotational compared with continuous grazing on soil health and overall soil and water quality. Additionally, there is renewed interest among the scientific community on developing robust metrics to more accurately and reliably, yet simply define soil health. This interest is fueled by NRCS's Soil Health Initiative focused on improving or maintaining soil health and providing cost share to farmers will to adopt such conservation practices (see <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/>). The overall benefits of improved soil health are diverse and will affect a wide range of ecosystem services (Karlen et al. 2003; Letey et al. 2003; Rainford 2008). Information gathered on this farm will be used to demonstrate the benefits of rotational compared with continuous grazing on beef cattle weight gains and profitability as well as on pasture production and water quality.

Monitoring nutrient runoff under a litigated scenario

The Big Creek monitoring project evaluates the sustainable management of nutrients from a Concentrated Animal Feeding Operation that has recently been permitted to operate with the Buffalo River Watershed. As the Buffalo River was the first National Scenic River designated in the USA in 1973, there has been wide public concern over the environmental impacts of the farm operation on area water quality. The project includes the following major tasks:

- (1) Monitor the fate and transport of nutrients and bacteria from land-applied swine effluent to pastures.
- (2) Assess the impact of farming operations (effluent holding ponds and land application of effluent) on the quality of critical water features on and surrounding the farm.
- (3) Determine the effectiveness and sustainability of alternative manure management techniques, including solid separation.

To address the long-term sustainability of the farm, the project is measuring soil fertility levels of all permitted fields at frequent intervals. This combined with nutrient levels in monitored wells will help guide adaptive manure management decisions to address field and environmental sustainability concerns. The project also assesses the feasibility of manure treatment, which is regarded as addressing nutrient imbalance concerns and has the potential to provide the farm with cost-beneficial alternatives for the sustainable use and export of treated manures.

Second, we describe the impacts of legislation governing the land application of P in the Eucha-Spavinaw Watershed (ESW) in northeast Oklahoma and northwest Arkansas, USA. The ESW is the main source of water for Tulsa, Oklahoma, and this watershed, legislation now governs the land application of poultry litter. In 2003, the City of Tulsa and Tulsa Metropolitan Utility Authority agreed to a settlement with several poultry companies and the City of Decatur wastewater treatment plant, Arkansas. The agreement provided measures to reduce P discharge from the Decatur wastewater treatment plant and in runoff from pastures fertilized with poultry litter, which were contributing to accelerated algae growth, causing taste, and odor problems in downstream drinking water sources for several municipalities in northeast Oklahoma. The settlement required poultry farmers to have a NMP that determined appropriate rates of poultry litter application based on the potential for P loss in runoff (i.e., P-based management) using the Eucha-Spavinaw P Index (ESPI), developed specifically for land use (pastures), topography, and climate of ESW (DeLaune et al. 2006).

Similar indices have been adopted by 47 of 50 states in the USA as a component of required NMP strategies (Sharpley et al. 2003, Sharpley, Beegle et al. 2012; Sharpley, Richards et al. 2012). The settlement further stipulated that no litter could be applied to soils which exceeded a 300 mg kg⁻¹ Mehlich-3 soil test P (STP) concentration and that no more than two-thirds of the litter produced in ESW could be land applied within ESW. As a result of ESPI and the STP threshold, this watershed is subject to stricter P-based manure management than most states (Osmond et al. 2006). These NMP requirements are enforced in the watershed by the States of Arkansas and Oklahoma and strict record keeping and accountability checks are in place to ensure adherence to the litigation agreements.

The ESW drains 1076 km² of the Ozark Plateau in northeast Oklahoma and northwest Arkansas, feeding Lakes Eucha and Spavinaw, which serve as the water supply for the cities of Jay, Tulsa, and several surrounding rural communities in Oklahoma

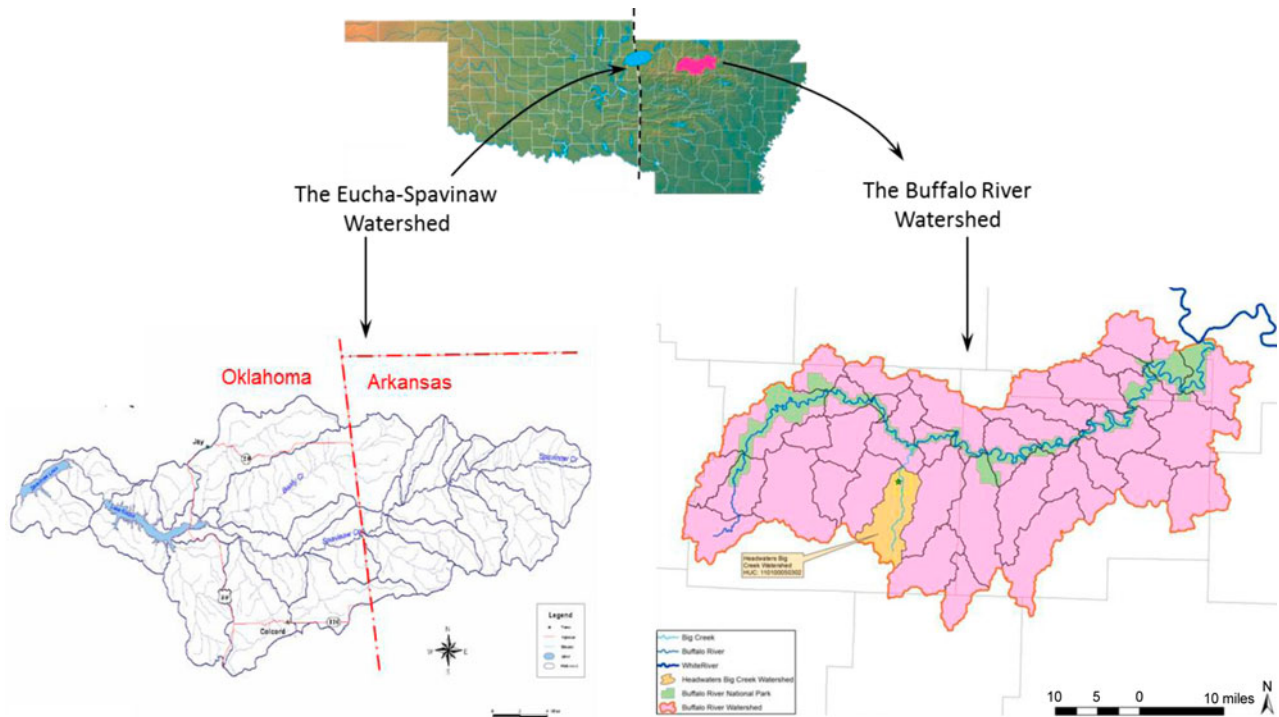


Figure 2. Location of the Eucha-Spavinaw and Buffalo River Watersheds.

(Figure 2). Land use is forest (51%), pasture (43%), with little row crop (3%), and urban land (1%). The watershed is home to an intensive and highly productive synergistic poultry–beef cattle operations, which use poultry litter as a fertilizer source for pastures dominated by Bermuda grass and tall fescue. In fact, the portion of northwest Arkansas, in which ESW is located, is the top producing area for beef cattle in Arkansas and second in the nation for broiler production behind Georgia (U.S. Department of Agriculture – Economic Research Service 2011).

Analytical methodology

Soil sampling

Soil samples are collected at a depth of 10 cm each spring according to the University of Arkansas – Division of Agriculture recommendations (Daniels et al. 2005); or if need dictates, grid-soil sampling at a resolution of 10 samples ha^{-1} (i.e., 0.1 ha grid). A subsample is taken for analysis. Samples can be held indefinitely once thoroughly mixed and air-dried. The samples are delivered to the University of Arkansas Soil Testing Laboratory where they are analyzed. Analyzes include Mehlich-3 STP at the standard 1:10 extraction ratio. Mehlich-3 extractable P is determined by shaking 1 g soil samples with 10 mL of 0.2 M CH_3COOH , 0.25 M NH_4NO_3 , 0.015 M NH_4F , 0.013 M HNO_3 , and 0.001 M EDTA for

five minutes (Mehlich 1984), filtering, and analysing the extract for P by inductively coupled plasma.

Runoff water samples

At the lower end of each field, automated, runoff water quality monitoring stations were established to: (1) measure runoff flow volume, (2) collect water quality samples of runoff for water quality analysis, and (3) measure precipitation. The automated portable water sampler was utilized to interface and integrate all components of the flow station. Runoff flow volume (discharge) was collected with a trapezoidal flume especially designed to measure flow in agricultural drainage channels. Discharge data were utilized to trigger flow-paced, automated collection of up to 100, 100 mL sub-samples, which were composited into a single 10 L sample.

Runoff water samples are placed in clean, acid-washed polyethylene bottles with caps and labeled with site number, date, time, and collector's name and immediately transferred for initial sample filtration within 24 hours of collection by the certified laboratory. Samples for dissolved P, nitrate–N and ammonium–N are filtered through a 0.45 μm membrane into a sterile glass vial and stored at 4°C in the dark along with unfiltered samples. Dissolved P, nitrate–N, and ammonium–N are determined colorimetrically by standard U.S. Environmental Protection Agency methods. Total N and P will be determined by the same colorimetric methods after

Kjeldahl digestion of an unfiltered water sample. Particulate P is calculated as the difference between total and total dissolved P. The suspended sediment concentration of collected runoff water samples is determined gravimetrically, as the difference in weights between oven-dried (105°C), unfiltered and filtered samples.

Results and discussion

ADFs Monitoring

Below, we present preliminary findings of five of the nine ADFs that span no more than two years of monitoring on any one farm. As ADF has been operating for only two years, this short length of monitoring is not adequate to define current management impacts on water quality or quantify the benefits of implemented BMPs. The information is presented, however, to demonstrate the potential of an on-farm monitoring program on nutrient and sediment runoff and water-use efficiency.

Cherry Valley Farm

Over the last the first two years of monitoring N, P, and sediment concentration in runoff from both the

Clements' and Woods' Farm fields were similar (Table 3). Over the two years of monitoring at this site, it is clear that implementation of conservation measures on the Woods' Farm had little effect to lower nutrient concentrations of runoff. However, the limited data suggest that suspended sediment concentrations were slightly higher from the conventionally tilled fields (Clements) than from conservation fields (Woods; Table 3). It is expected that with time the effects of conservation tillage and edge-of-field buffers will result in lower nutrient and sediment runoff from the Woods' Farm.

Dumas – Stephens' Farm

Runoff from precipitation during the growing season ranged from 29% to 63% of the precipitation total received while runoff from irrigation ranged from 23% to 54% of the irrigation total applied (Table 4). These data indicate that runoff losses and trends from irrigation are similar to those of precipitation, which may indicate that field and soil features exhibit much influence on runoff and infiltration as opposed to the source of input. Cumulative runoff from all three fields exhibit similar trends even though the magnitude of runoff was different. Cumulative

Table 3. Mean annual nutrient and sediment concentrations in runoff from soybeans under conventional (moldboard plowed) and conservation (no-till) for 2012 and 2013 at the Cherry Valley Farm.

Sampling location	Dissolved P	Total P	Nitrate-N	Total N	Total solids
	mg L ⁻¹				
<i>Clements' Farm</i>					
Well water	0.010	0.038	0.05	0.19	500
Field 1	0.071	0.353	0.21	2.18	762
Field 2	0.027	0.285	0.66	3.33	565
<i>Woods' Farm</i>					
Well water	0.023	0.064	0.10	0.20	437
Field 1	0.081	0.344	0.40	2.67	532
Field 2	0.095	0.429	0.75	3.78	428

Table 4. Precipitation, irrigation, and runoff from selected cotton fields from the Stephens' Farm, Dumas.

Field	Precipitation			Irrigation			Precipitation and irrigation		
	Total	Runoff	Percent as runoff	Total	Runoff	Percent as runoff	Total	Runoff	Percent as runoff
	cm	cm	%	cm	cm	%	cm	cm	%
Homeplace	32.0	13.1	41	27.0	14.7	54	59.1	27.8	47
Shopcot	32.0	20.1	63	46.9	22.7	48	78.9	42.8	54
East Weaver	32.0	9.3	29	34.5	8.0	23	66.5	17.3	26

Table 5. Seasonal total N and P loss in runoff compared to N and P applied for the Stephens' Farm, Dumas.

Field	N or P applied	N or P loss	Percent loss	Total loss
	kg ha ⁻¹		%	kg
<i>Nitrogen</i>				
Homeplace	44	4.62	10.5	114.0
Shopcot	44	0.28	0.7	12.3
East Weaver	44	0.73	1.7	31.8
<i>Phosphorus</i>				
Homeplace	11	0.89	8.1	21.8
Shopcot	11	0.20	1.9	8.6
East Weaver	11	0.32	3.0	14.1

runoff from the East Weaver field increased much slower with time than the cumulative inputs once irrigation commenced in early July, which most likely reflects the increase in ET rate of the rapid development of the cotton biomass.

Total N losses in runoff from each field were very low compared to the N applied as fertilizer (Table 5). This study was not designed to do a mass balance of N applied as change in soil N levels were not measured, however, losses in runoff were compared to the N applied as a way to put losses in runoff in perspective in terms of management. Nitrogen loss from the Shopcot field was an order of magnitude greater than in the other fields. However, much of this N loss occurred during rainfall events in May before N was applied in June. Two possible explanations include the facts that a cover crop was established in Shopcot and that cotton followed corn in this field while cotton followed cotton in the other fields. Nitrogen mineralization from the decaying cover crop may have acted as a source of N during May or residual soil N left from the previous corn crop may have been a source. Either way, it appeared that very little of the applied N was lost in runoff. Total P losses were also very low in runoff and were also very low compared to P applied (Table 5).

The data collected during this first year indicate typical hydrological variability among fields, runoff events and in time as it relates to cotton development. Studies and data such as this are important to understanding the impact of cotton production on water use and water efficiency, which are becoming increasingly important considerations for row crop agriculture in Arkansas in light of declining groundwater levels. The data collected during this first year also indicate low nutrient losses in runoff to off-farm water bodies, which provides encouragement that our cotton production systems are efficient in terms of nutrient loss to runoff. It is still preliminary as it is generally accepted by the scientific community that runoff studies should be conducted for a minimum of five years to account for climatic and hydrological response variability.

Elkins – Marley Farm

Flumes 1 and 2 collect runoff draining directly from around the poultry houses, and concentrations of N and P are elevated compared with runoff from unfertilized pastures (dissolved P was 0.05, total P was 0.1, and nitrate-N was 0.5 mg L⁻¹; Sharpley et al. 2007). However, the concentrations of N and P decrease between Flumes 2 and 3 by approximately three-fold due to the combination of dilution with additional rainfall-runoff and by uptake and deposition. Even so, the concentration of P in field runoff at Flume 3 entering the adjacent creek was elevated compared with ecological thresholds set for the adjacent Illinois River as it crosses from Arkansas to Oklahoma (0.037 mg L⁻¹; U.S. Environmental Protection Agency 2001; DeLaune et al. 2006). Sediment concentrations between Flumes 2 and 3 also decreased by nearly a half (Table 6). Loads will be calculated when flow at each flume is determined. Further the concentrations of N and P in the pond were appreciably less than that entering into the pond (Table 6). This decrease can be attributed to P sorption by suspended and deposited sediment, dilution, as well as by algal and macrophyte uptake.

Table 6. Mean annual nutrient and sediment concentrations in runoff from around poultry houses (Flumes 1 and 2), 300 m grassed waterway (Flume 3), and pond receiving runoff from Flume 1 for 2011 to 2013 at the Marley Farm, Elkins.

Farm location	Dissolved P	Total P	Nitrate-N	Total N	Total solids
	mg L ⁻¹				
Flume 1	1.59	1.96	5.38	9.38	200
Flume 2	1.80	2.19	8.69	10.93	276
Flume 3	0.64	0.82	3.59	3.86	157
Pond	0.22	0.44	0.19	2.79	292

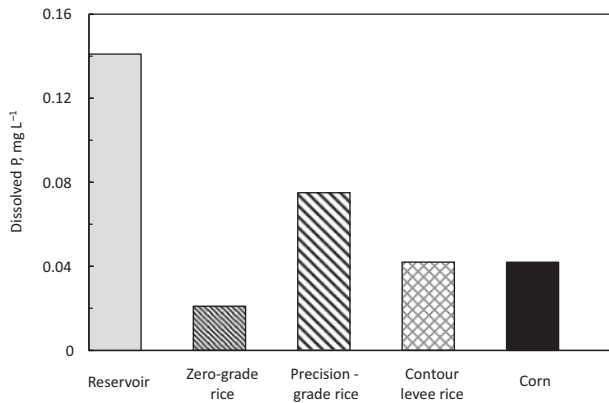


Figure 3. Dissolved P in runoff as a function of field management for 2013 at the Dabbs' Farm, Stuttgart.

After an additional year of runoff data, it is planned to treat the pasture between Flumes 2 and 3 to enhance P reduction efficiency.

Stuttgart – Dabbs' Farm

A decrease in dissolved P between irrigation water added to several fields and concentrations in surface runoff water were observed for rice and corn fields on the Dabbs' Farm (Figure 3). Approximately 30 kg P ha⁻¹ was added to each of the fields prior to rice and corn planting. In addition to storm water runoff, runoff from adjacent property, all the runoff and rainfall on the Dabbs' Farm is captured as part of their water harvesting and conservation program, due to the depletion of groundwater levels to increased depths that have become uneconomical to remove water from.

Litigated monitoring

Buffalo River Watershed Monitoring

Monitoring in the Buffalo River Watershed on Big Creek began in late 2013 and insufficient data has been collected to present here. However, there is no significant difference in N and P concentrations (at $p > 0.001$) in Big Creek above and below the farm,

where average dissolved P is below 0.01 mg L⁻¹, total P below 0.02 mg L⁻¹, nitrate-N below 0.50 mg L⁻¹, and total N below 1.00 mg L⁻¹, which are typical of unimpacted watershed in this area of the USA (U.S. Environmental Protection Agency 2001, 2002). Although little slurry from the hog facility has been land applied to date, it is expected that landscape processing of applied N and P may delay any significant impacts on area stream water quality. Monitoring of springs, wells, and ephemeral streams in this karst region will determine if land applied nutrients are starting to move through the karst terrain (Sharpley et al. 2013; Jarvie et al. 2014).

Because of the public scrutiny this farm is receiving, fields which are permitted to receive slurry are monitored for surface runoff by previously mentioned H-flumes and autosamplers along with leaching by piezometers.

Eucha-Spavinaw Watershed Monitoring

While there has been no consistent change in STP concentrations measured since 2004, averaging 178 mg kg⁻¹, the majority of the soils tested were below the 300 mg kg⁻¹ threshold (89–95%; Table 7). Most of the fields sampled in ESW for which STP concentrations are below 300 mg kg⁻¹ (the court designated threshold above which no P can be applied).

Each year since 2004, the litigated nutrient management guidelines and restrictions have had a direct impact on the land application of poultry litter, which decreased from 3.3 to 2.4 tonnes ha⁻¹, a 20% decrease in four years (2004–2008; Table 7). Following 2008, litter application rates have been consistently at 2.4 tonnes ha⁻¹ or 40 kg P ha⁻¹. These rates of poultry litter application in 2009 are 40–60% less than N-based rates prior to the settlement agreement, which were 4.5 tonnes ha⁻¹ year⁻¹ (75 kg P ha⁻¹ year⁻¹) for cool and 6.7 tonnes ha⁻¹ year⁻¹ (110 kg P ha⁻¹ year⁻¹) for warm season grasses (Slaton et al. 2004). Offtake of P in harvested forage is approximately 30 kg P ha⁻¹ year⁻¹.

Even though litter application rates have decreased by about 50% since 2004, this has not been translated

Table 7. Summary findings of P-based NMP in the ESW, from 2004 to 2007.

Parameter	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Average STP, mg kg ⁻¹	165	186	178	170	175	196	170	185	176	182
Fields with <300 mg kg ⁻¹ (%)	95	91	90	95	95	89	91	90	85	92
Average poultry litter rate, tonnes ha ⁻¹	3.3	3.2	2.9	2.6	2.5	2.5	2.4	2.5	2.4	2.4
Area of watershed receiving litter (%)	7	6	7	6	7	6	6	6	7	6
Litter exported (%)	69	75	74	77	80	82	85	86	88	92

Source: Updated from Sharpley et al. (2009).

into a consistent decline in STP concentrations (Table 7). For example, the average STP concentration of soils sampled during the NMP process was 165 mg kg^{-1} in 2004 and 196 mg kg^{-1} in 2009. This is not unexpected given the slow decline in STP, even when no P is applied, due to the slow release of sorbed P and offtake with harvested forage (Sharpley et al. 2007, 2009). The lag time between management change and STP response will likely exceed 10 years (McCollum 1991; Sharpley et al. 2013). However, based on data collected by the planning team, the number of fields receiving poultry litter declined from 900 in 2004 to 700 in 2013, which cover only 7–6% of the whole ESW (Table 7).

Approximately 82,000 tonnes of poultry litter are produced within ESW annually. From amounts of litter applied determined by NMPs, it was calculated that a gradually increasing amount of the litter produced in ESW has been exported out of the watershed each year since the litigated settlement was enforced in 2004 (69–92%; Table 7). Thus, ESPI-based NMPs more than met guidelines set forth in the court agreement (i.e., at least one-third the litter produced be exported out of ESW), each year since its enactment.

Conclusions

Monitoring and documenting environmental impacts of Arkansas farming systems, as well as evaluating the efficacy and cost-effectiveness of alternative practices, will bridge a knowledge gap that now keeps farmers, natural resource managers and decision-makers alike from confidently taking effective actions that ensure both economic and environmental sustainability. The ADF Program, as well as the formation of strong partnerships, has the potential to affect millions of agricultural acres across the state. Program results will also give all of us the confidence that we are doing our part to maintain safe and affordable food supplies while protecting our natural resources for future generations in the State.

Implementation of standard water quality monitoring methods on private working farms across the state will document the true impacts of Arkansas agriculture on environmental quality and efficiency of current conservation measures. As this monitoring is being conducted on private property, the results will have greater impact and resonate with the farming community more than that conducted on University property. In fact, we are already seeing farmer ownership of the ADF Program and runoff data by requesting that they present data at farmer meetings. Also, in some cases, farmers are voluntarily introducing additional conservation practices to further reduce nutrient runoff after seeing the results.

Implications of the court-mandated NMP in ESW have resulted in a decrease in poultry litter application rates and less than a quarter of the litter produced is applied in ESW some 10 years earlier, with the remainder being exported out of the watershed. These changes in litter management have affected the beef cattle farmers most, to whom litter is an inexpensive source of N (and to an increasing extent P and K). In order to maintain the economic viability of all farming enterprises, the NMP process must go beyond addressing poultry litter application rates and environmental risk and include educational efforts to help farmers develop sustainable whole-farm operations.

Monitoring in a highly visible public setting such as the Big Creek, Buffalo River, and Illinois River Watersheds provides the public with real-time information on the concentrations of nutrients and sediment in runoff, leachate, and streams. This information can be very powerful in the context of farm management and watershed planning strategies. Limited background management information and/or the use of few data observations has the potential to be grossly misused and lead to misinterpreted nutrient flux estimates. However undesirable and misleading this may appear, freedom of information laws dictate immediate transparency of all monitoring data. Because of the visibility and sensitivity of these monitoring programs, there is an inevitable rush to judgment by a concerned public.

Even given these concerns, this should not limit these types of studies. With all monitoring, whether it be voluntary-, research-, regulatory-, or litigatory-based program managers have a moral obligation to ensure that the information and sound science only determines outcomes and future conservation and mitigation strategies.

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