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Water quality effectiveness of ditch fencing and culvert crossing in the Lake Okeechobee basin, southern Florida, USA

S. Shukla[a,*], D. Goswami[a], W.D. Graham[b], A.W. Hodges[c], M.C. Christman[d], J.M. Knowles[a]

[a] Agricultural and Biological Engineering (ABE) Department, Southwest Florida Research and Education Center, University of Florida (UF), 2685 State Road 29N, Immokalee, FL 34142, United States
[b] ABE Department, UF, P.O. Box 110570, Gainesville, FL 32611, United States
[c] Food and Resources Economics Department, UF, P.O. Box 110240, Gainesville, FL 32611, United States
[d] Statistics Department, UF, P.O. Box 110339, Gainesville, FL 32611, United States

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ABSTRACT

Ditch fencing and culvert cattle crossing Best Management Practice (BMP) was evaluated in this study with regard to phosphorus (P) and nitrogen (N) load reductions and economic feasibility in the Lake Okeechobee (LO) basin. The BMP was implemented at a 170 m section of a drainage ditch within a ranch in the LO basin and flow and concentration (N and P) data at the upstream and downstream of the ditch were collected for one pre-BMP (June–October, 2005) and three post-BMP (June–October, 2006–2008) periods. During the pre-BMP period, downstream total P (TP) load was 20% (67.0 kg) higher than the upstream, indicating the cattle crossing to be a source of P. Downstream loads of TP in 2006 and 2008 (post-BMP periods) became 26% (14.7 kg) and 11% (85.9 kg) lower than the upstream loads, respectively indicating that the BMP reduced the P loads. The site was a sink for N for all periods except the 2007. Unusual dry conditions during 2007 resulted in the addition of P and N at the BMP site, probably due to the release of P and N from soil and plants. Average of three post-BMP period load showed a 10% reduction of TP loads at the downstream (251.8 kg) compared to the upstream (281.0 kg) location. To consider potential P contributions from the soil and plant, two scenarios, conservative and liberal, were considered to estimate P load reductions due to the BMP. For the conservative scenario, P contribution from soil and plant was considered, while for liberal it was not. Reductions in P loads for conservative and liberal scenarios were 0.35 and 0.44 kg/day, respectively. Phosphorus removal cost for the conservative scenario was $12.61/kg of P, which is considerably less than the cost of other P reduction strategies in the basin. Overall, results show that the BMP can reduce P concentration and loads from ranches without causing adverse impact on cattle production.

1. Introduction

Lake Okeechobee (LO) is a large, multi-functional lake located at the center of the Kissimmee–Okeechobee–Everglades aquatic ecosystem in south-central Florida. Excessive phosphorus (P) loading is one of the problems facing the lake (Bottcher et al., 1995; Nair et al., 2007; Tweel and Bohlen, 2008). Cow–calf operations, the single largest land use in the Lake Okeechobee watershed, are the most important source of external P loadings to the lake (Capece et al., 2007). The Florida Cattlemen's Association (FCA) in cooperation with the University of Florida (UF), Florida Department of Agriculture and Consumer Services (FDACS), Florida Department of Environmental Protection (FDEP), and South Florida Water Management District (SFWMD) has developed a variety of Best management Practices (BMPs) to control the P discharges from the cow–calf operations (FDACS, 2008). Water quality benefits of most of the BMPs in the manual have not yet been quantified. There is a need to quantify the effects of these BMPs for making basin-wide plans for achieving the Total Maximum Daily Load (TMDL) for the lake. Keeping cattle out of waterways with ditch fencing and culvert crossing within a ranch is one such BMP which is promising with regard to reducing P and nitrogen (N) loads. The term 'cattle exclusion' has been used in the literature to refer to a variety of management practices including the ditch fencing and culvert crossing (DFCC) BMP and/or providing alternate drinking water source for cattle to avoid/eliminate the direct deposition of cattle feces and urine into ditches, streams, creeks, or rivers.

Grazing cattle in pastures with unfenced streams and drainage ditches contributes significant loads of P and N to surface waters (Byers et al., 2005). Several studies (Sheffield et al., 1997; Line

* Corresponding author. Tel.: +1 239 658 3425; fax: +1 239 658 3469.
E-mail address: sshukla@ufl.edu (S. Shukla).

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et al., 2000; Galeone et al., 2006) have been conducted to study the effects of cattle exclusion from waterways on water quality. Sheffield et al. (1997) evaluated alternative water source as an option to reduce cattle entry to a stream in Virginia by comparing the pre-BMP (August, 1994–April, 1995) and post-BMP (April, 1995–October, 1995) monitoring data. They concluded that providing off-stream water source reduced the in-stream cattle traffic which eventually reduced Total Suspended Solids (TSS), Total nitrogen (TN), and Total Phosphorus (TP) concentrations by 90, 54, and 81%, respectively. Line et al. (2000) evaluated effects of fencing a 335 m long riparian corridor in North Carolina by comparing the pre-BMP (81 weeks) and post-BMP (137 weeks) P and N loads and found that post-BMP mean weekly loadings of Total Kjeldahl Nitrogen (TKN), TP, TSS, and Total Solids (TS) were reduced by 79, 76, 82, and 83%, respectively. A study was conducted by Meals (2001) to evaluate the combined effectiveness of livestock exclusion along with stream bank restoration, and riparian zone protection in Vermont. Results indicated reductions in TP concentration (25%) and load (42%) in the treated watershed compared to a control watershed. In a paired-watershed study, Galeone et al. (2006) evaluated the effects of stream bank fencing in Pennsylvania and found reductions in Nitrate (NO_3–N), Nitrite (NO_2–N), Ammonia (NH_3–N), TKN, and TP loads.

In a review of cattle exclusion studies, Dillaha (2007) noted several limitations in some studies. For example, in the study conducted by Sheffield et al. (1997), the pre-BMP period included winter, while the post-BMP period included summer. The post-BMP rainfall was 54% higher than the pre-BMP rainfall which might have introduced bias in the BMP results. For the Galeone et al. (2006) study, Dillaha (2007) noted that several factors other than the BMP might have resulted in reductions in flows and P concentrations: P and N fertilizer applications decreased by 27–30% during the post-BMP period; number of livestock decreased by 50% during the post-BMP period; and the pre-BMP rainfall was 11% higher than post-BMP rainfall which may have resulted in reduced post-BMP stream flows. In the Line et al. (2000) study, there were four major storms during the pre-BMP period while no similar storms occurred during the post-BMP period. The larger storms during the pre-BMP period were expected to produce larger nutrient loads. Variability in factors such as climate, fertilizer, and cattle density observed in these studies has limited the ability to attribute the water quality improvements to cattle exclusion.

In light of the above limitations of cattle exclusion studies and regional differences in weather, soil, topographic, and hydrologic factors, conclusions drawn from one soil-hydrologic region may not be applicable to another region. For example, soils, topography, and hydrology of south Florida are quite different from other regions within U.S. due to poorly drained sandy soils, shallow water table and nearly flat topography (NRCS, 2003). Furthermore, as opposed to natural streams passing through the ranchland in other states, most of the ranches in south Florida have drainage ditches that drain the area to make it suitable for improved pasture and cattle production. Due to relatively flat topography, flow rates in the ditches are slow. The flows in the ditches mainly occur during the wet period (June–October) which receives 70% of the total annual rainfall in this region (Shukla et al., 2010). Given such differences in soils, climate, hydrology, and landscape, cattle exclusion studies conducted elsewhere in the U.S. have limited applicability to south Florida. Moreover, no study till date has incorporated economic analysis as part of cattle exclusion BMP evaluation. Economic analysis is an important component of the BMP effectiveness for facilitating basin-wide BMP implementation. The goal of this study was to evaluate the effectiveness of DFCC BMP in a ranch located within the LO basin in south Florida with regard to P and N loadings and economic effects.

2. Materials and methods

2.1. Site description

The study site is a commercial 250 ha cow–calf ranch located in south-west Okeechobee County. Soils in the area are typically poorly drained and highly sandy (NRCS, 2003). The ranch is dominated by improved pastures laced with shallow ditches for drainage. The three major forage types in the ranch are Bahia (*Paspalum notatum*), Floralta (*Hemarthria altissima*), and Stargrass (*Cynodon nlemfuensis*). The surface flow (drainage and runoff) from the ranch moves in a southerly direction and is discharged to the Kissimmee River which eventually empties into the lake. The ranch can be divided into two sub-watersheds, termed as 1 and 2. Discharges from the two sub-watersheds (Flume 1 and Flume 2) combine and flow through a main drainage ditch (length = 170 m) before exiting the ranch (Flume 3) (Fig. 1). The DFCC BMP was evaluated at the main drainage ditch.

2.2. Ditch fencing and culvert crossing BMP

A pre- and post-BMP monitoring design was used to evaluate the DFCC BMP at the main drainage ditch (Fig. 1). The BMP involved installation of a culvert crossing and fencing in January 2006 to route the cattle over the ditch instead of through it (Fig. 1). Before BMP implementation, there was a cattle crossing pathway almost midway in the ditch, which over the years resulted in erosion of the ditch bank and resulted in an elevated patch of land in the middle of the ditch. The average depth of the drainage ditch is 1.40 m which results in the availability of water in the ditch for most of the year due to shallow groundwater in the region. The ditch served as the drinking water source as well as an area for cooling off for cattle.

2.3. Hydrologic and water quality monitoring

Three trapezoidal flumes (Flumes 1, 2, and 3) equipped with the digital shaft encoders (to monitor the hydraulic head), were installed at the inflow (Flumes 1 and 2) and outflow (ranch outlet, Flume 3) locations of the selected ditch to measure the flows till August 2007 and afterwards using Acoustic Doppler Velocimeters. By comparing P and N loadings at inflow and outflow, P and N addition/removal at the BMP site were quantified. The wet season (June–October) of 2005 was the pre-BMP period. The wet seasons (June–October) of 2006, 2007, and 2008 were the three post-BMP periods (post-BMP 1, post-BMP 2, and post-BMP 3, respectively).

Auto-samplers were installed at each flume site to collect surface water samples to determine TP, TKN, NH_3–N, and NO_3–N (nitrate–nitrite) concentrations. Nutrient concentration data were combined with the flows to estimate the N and P loads using the linear interpolation (between two consecutive samples) method (Kronvang and Bruhn, 1996). A weather station was installed near Flume 2 to collect rainfall and other climatic data.

2.4. Land use management

Ranch management data were collected to evaluate the effects of pre and post-BMP ranch management activities on water quality. The data on ranch management included pasture type and improvement, fertilizer rates, and cattle stocking rate. Equal amounts (392 kg/ha) of NPK fertilizer (20-5-5) were applied at the site each year during the study period. The average cattle weight is about 527 kg. The age of the cattle ranges from less than a year to over two years. The cattle density is about 1.5 cows per ha of pasture which is typical for beef–cattle ranches in Florida (Tweel and Bohlen, 2008). The cattle are grazed on rotational basis in the pas-