Optimization of Best Management Practices (BMPs) for Beef Cattle Ranching in the Lake Okeechobee Basin

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In collaboration with

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Executive Summary

This project was designed to test the effect of cattle stocking rate on nutrient loads in surface runoff from beef cattle pastures in the Lake Okeechobee Basin. The project was the first in a planned series of projects to test and evaluate the efficacy of various Best Management Practices (BMPs) for reducing non-point source nutrient pollution, especially phosphorus loading, from beef cattle ranches in the region. Excessive phosphorus loads in surface runoff have contributed to declines in the water quality of Lake Okeechobee, the major receiving body for surface runoff in the region and the major water supply for south Florida. In 1994, a Memorandum of Understanding (MOU) was established among the South Florida Water Management District (SFWMD), Archbold Expeditions' MacArthur Agro-Ecology Research Center (MAERC), and the University of Florida, Institute of Food and Agricultural Sciences (IFAS) to begin a long-term research affiliation with the goal of providing information on the relationship between beef cattle ranching and water quality, and making recommendations for the development of environmentally and economically sustainable cow/calf practices in the Lake Okeechobee Basin. The Florida Cattlemen's Association (FCA) joined the MOU in an advisory capacity in 1996. The backbone of the MOU is an optimization project, which consists of sixteen field-scale experimental pastures that are 50 to 80 acres in size that are individually fenced and ditched, so that all surface water runoff can be captured and analyzed for water quality parameters. These pastures are located at MAERC's Buck Island Ranch, a 10,300-acre cattle ranch located northwest of Lake Okeechobee in Highlands County.

The SFWMD provided financial support for the project through a series of two contracts (C-13414 and C-8614). Additional support for the project was provided by MAERC, IFAS, the Florida Department of Agriculture and Consumer Services (FDACS) and two contracts with the Stormwater/Nonpoint Source Management Program of the Florida Department of Environmental Protection (FDEP). Additional funding was obtained from the USDA National Research Initiative to support a multidisciplinary research effort investigating the effects of the cattle stocking rate forage on production and utilization, cattle health and productivity, ranch economic performance, soil chemistry and biological indicators. This report focuses on the water quality results of the project but also presents some results pertaining to the impact of cattle stocking rate on ranching operations and economics.

The project design included four cattle stocking rate treatments that were replicated two times in both improved summer pastures and semi-improved winter pastures. Summer pastures consisted of eight 50-acre plots with established bahia grass and were grazed from May-October. Winter pastures consisted of eight 80-acre plots with mixed forages, including bahia grass, and were grazed from November-April. Stocking rate treatments included 0, 15, 20, and 35 cow-calf pairs per pasture to represent non-grazed, low, medium, and high stocking rate treatments, respectively. These stocking rates represented 0, 3.7, 6.5, and 8.6 acres per cow. Summer pastures received spring applications of nitrogen fertilizer (56 kg N ha^{-1}) and winter pastures remained unfertilized. Surface runoff was collected from these pastures from 1998-2003 and was analyzed for various nutrient constituents including total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TKN), nitrate/nitrite (NO_x) and ammonium (NH_4^+).

Cattle stocking rate did not significantly influence concentrations or loads of phosphorus or nitrogen in surface runoff from beef cattle pastures. There were no consistent differences in any year in nutrients in surface runoff between control pastures with no cattle or pastures stocked at the low, medium or high cattle density, indicating that removal of cattle from pastures provides no short-term reduction in nutrient runoff.

Phosphorus loads were 5-7 times greater from summer pastures than from winter pastures. Furthermore, the ratio of soluble-reactive-phosphorus (SRP) to total phosphorus was much greater in summer pasture runoff (0.73) than in winter pasture runoff (0.45). Total nitrogen loads also tended to be greater from improved summer pastures than from semi-improved winter pastures, although the differences were not nearly as great as those for phosphorus. The greater phosphorus loads from summer pastures were related to greater concentrations of total phosphorus and greater proportions of available phosphorus in summer pasture soils relative to winter pasture soils. These differences in soil phosphorus content were likely due to past fertilization practices that included regular additions of phosphorus fertilizer to the summer pastures up until 1987, after which phosphorus fertilizer use was discontinued. The winter pastures have never, to our knowledge, been fertilized.

Cattle stocking rate significantly influenced cattle production and ranch economics. There was no significant decrease in calf weights, pregnancy rates or overall cattle condition with increasing stocking density, and thus there was significantly more weight of calf produced per unit land area at the high stocking density than at the low stocking density. Economic modeling of the entire Buck Island Ranch showed that the high stocking rate gave the best economic return. Total operating costs declined from the highest to lowest stocking rate. However, because fixed costs remain constant, the unit cow costs increased from $167 per cow at the highest stocking rate to $255 per cow at the lowest stocking rate. Assuming a 70 percent calf crop and weaning weights of 450 pounds, break-even prices increased from $53 to $81 per hundred-weight for the high and low stocking rates, respectively.

Based on these results it does not appear that optimizing cattle stocking rate is an effective BMP for reducing nutrient loads in surface runoff from beef cattle pastures in the Lake Okeechobee Basin. Given the lower rate of economic return at the lower stocking rates and the lack of any reduction in nutrient loads, there is little incentive to adopt stocking rate BMPs. The cattle operation during this project was actually a net exporter of phosphorus in calves, with the highest net export occurring in the high stocking density treatment. The stocking rates examined in this project were comparable to regional averages. This project was not designed to address the question of whether very heavily stocked or overstocked pastures could increase nutrient loads relative to typical average stocking rates. The contribution of past phosphorus fertilizer inputs to current nutrient loads suggests that fertilizer phosphorus accumulated in soil can contribute to elevated phosphorus in surface runoff for many years after phosphorus fertilizer use is discontinued. This suggests that water quality BMPs that focus on preventing further phosphorus accumulation, or on decreasing the loss of accumulated phosphorus, could be effective approaches for reducing phosphorus loads in surface runoff from beef cattle operations.

1.0 Introduction

South Florida is faced with significant challenges to protecting water quality and wetland ecosystems in the face of encroaching development and extensive agricultural production (DeAngelis et al., 1997; Harwell, 1998). The region includes extensive grazing lands that contribute to Florida's ranking as one of the leading cattle producing states in the U.S., ranked 12th in beef cows nationally, and third in beef production east of the Mississippi River. About one million head, dominated by beef cow-calf units are supported on over 5 million acres of pasture and rangeland, mostly in south central Florida, mostly privately-owned, and overlapping with some of the most sensitive wetland systems in the state.

Land use changes within this ecosystem have dramatically changed the habitat characteristics and patterns of nutrient flow for uplands, marshes, and lakes resulting in increasing nutrient loads into Lake Okeechobee, which is the main receiving water body of this region and is the heart of south Florida's water supply (Aumen, 1995). The lake's littoral zone provides important fish and wildlife habitat especially for wading birds and waterfowl (Cox, 1994), and it is an important economic resource as a valuable fishery and as water supply for residential and agricultural users. Total phosphorus concentration in Lake Okeechobee has more than doubled since the 1970's and chlorophyll a levels significantly increased between the early 1970's and 2000 (Havens and Schelske, 2001) leading to cultural eutrophication of the lake (Steinman et al., 1999). This serious problem is being addressed by various plans to reduce nutrient inputs to the lake including (a) the Surface Water Improvement Management Plan (b) the Lake Okeechobee Protection Program and (c) the Lake Okeechobee Watershed Project Management Plan as part of the overall Comprehensive Everglades Restoration Plan (CERP). Despite considerable state and federal efforts to reduce nutrient loadings into Lake Okeechobee, the overall pollution load reduction goal has not yet been achieved. The Florida Department of Environmental Protection (FDEP) established a new Total Maximum Daily Load (TMDL) of 140 metric tons of phosphorus per year to reach target phosphorus concentration of 40 ppb in the pelagic zone of the Lake by the year 2015. This will require a substantial reduction from the current 5-year rolling average of 528 metric tons per year.

Beef cattle ranches are being targeted by regulators to achieve a portion of the desired phosphorus load reductions. Although P concentrations associated with beef cow-calf operations are low in comparison with dairy farms, the large area of improved pasture (183,778 ha), unimproved pasture (33,453 ha), and rangeland (46,641 ha) on ranches represents 51% of the Okeechobee Basin, making them a large cumulative contributor to P loads into the lake (Hiscock et al., 2003). The cattle ranching community has identified a variety of potential cattle Best Management Practices (BMPs) for water quality improvements, including modifications to fencing, drainage, feed/water location, and fertilization regimes that are expected to reduce phosphorus runoff if implemented (FCA, 1999), although many of these BMPs have not been tested to ascertain their effectiveness. The Lake Okeechobee Protection Program interagency team is developing voluntary programs that encourage ranchers to adopt water quality BMPs for which they will receive a presumption of compliance with water quality standards.

One proposed BMP to reduce nutrient loadings into Lake Okeechobee that has been of wide interest to regulators for beef cow-calf operations is that of lowering cattle stocking rate. This approach assumes that limiting the numbers of cattle grazing in typical beef cow-calf operations will result in lower nutrient loads in nonpoint runoff, but data concerning nutrient loading from beef cow-calf operations in relation to stocking rate at realistic field or ranch scales have been limited. Most work on the effects of stocking rate, largely in terms of rotational grazing, has focused on vegetation or cattle responses (Taylor et al., 1997; Hart et al., 1988; Heitschmidt et al., 1989; McCollum et al., 1999; Gillen et al., 2000); there appears to be little experimental work on the relationship between stocking rate and water quality. Hence it was not known whether lower cattle stocking rate would result in reduced nutrient loads into receiving water bodies, or how varying stocking rate would affect other parameters such as soil nutrients or biodiversity, or economic productivity. Although stipulating stocking rate as a BMP would be relatively easy from a regulatory perspective, it may have severe economic impacts on producers and should only be implemented if the data are available to support their effectiveness.

In response to this need a major integrated research project to address the effects of stocking rate on nutrient loadings was launched at a full-scale working cattle ranch – the MacArthur Agro-ecology Research Center (MAERC), a 4,168-ha full-scale commercial cattle ranch owned by The John D. and Catherine T. MacArthur Foundation and leased to Archbold Biological Station (Swain, 1998). Three Florida research partners joined in a 1994 Memorandum of Understanding (MOU) to develop this effort; they include Archbold Biological Station (Archbold), the University of Florida, Institute of Food and Agricultural Sciences (UF-IFAS), and the South Florida Water Management District (SFWMD). The Florida Cattlemen's Association (FCA) signed onto the MOU in 1996. Subsequent partners have joined this group including US Department of Agriculture Natural Resources Conservation Service (USDA-NRCS), the USDA Agricultural Research Service (USDA-ARS), and the Florida Department of Agriculture and Consumer Services (FDACS).

The research partners decided to address the effects of cattle stocking rate on nutrient loading using observational, experimental, and modeling techniques to examine not only nutrient loading in relation to stocking density, but also ecological, economic, and physical responses. Two pastures at MAERC totaling approximately 420-ha, and representing two major pasture land-use types in the region, were selected on which to impose different stocking density treatments. The project's core integrated components (Fig. 1) include physical factors, forage analysis, soil fauna, soils processes, nutrient cycling, hydrological flows, wildlife populations, and animal production and economic information. The water quality research was supported by two consecutive contracts awarded to Archbold Biological Station by the SFWMD (Contracts C-8614 and C-13414) and by the FDACS, and two separate contracts with the Stormwater/Nonpoint Source Management Program of FDEP for analyzing the water quality data (WM699 and WM796).

This report provides an overview of water quality results and interprets them in light of the original project goal of developing BMPs for reduced nutrient loads from beef cattle ranches. It also discusses impact of the cattle stocking rate treatments on forage utilization, cattle health and productivity and ranch economics. Some of these results are detailed in other comprehensive reports submitted to FDEP (Capece et al., 1999; 2003) and the raw data for water chemistry,

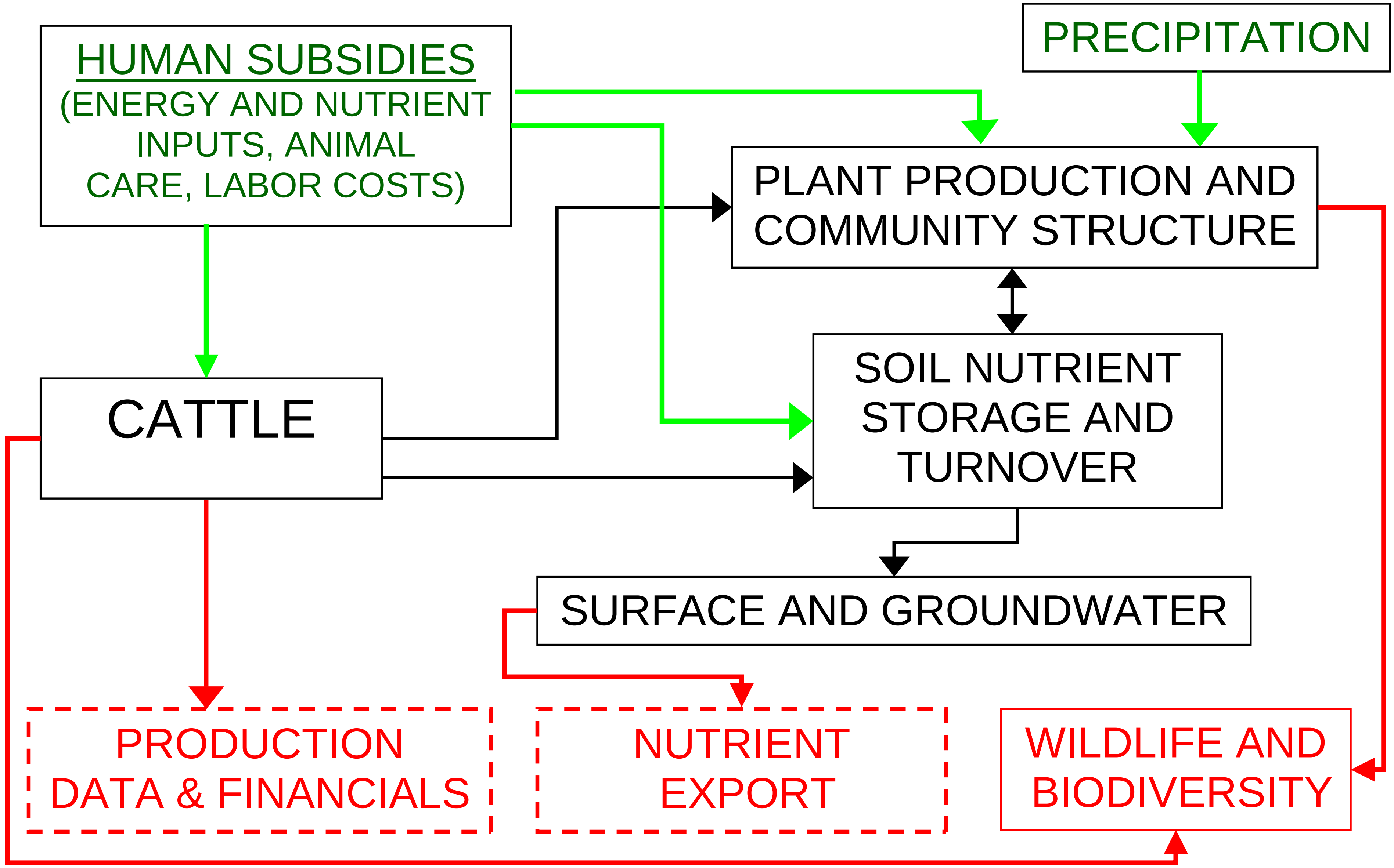

Figure 1. Overall model of the ranch management system showing key components and relationships examined in the water quality BMP project at MAERC. Green text and arrows show inputs to the system, black shows the internal system dynamics, and red shows the key outputs of interest in the project. This report focuses on nutrient export in surface runoff and production values (dashed red boxes).

surface runoff amounts, and meteorological conditions during the study period were submitted to the SFWMD in a series of quarterly reports from 1998-2003. In addition to these reports, three Master theses on the project were completed by graduate students at the University of Florida, including two on soil phosphorus characteristics (Hill, 2003; Sperry, 2004) and one on hydrologic modeling of the nutrient loads (Hendricks, 2003).

2.0 Experimental design and methodology

This project was located at the MacArthur Agro-ecology Research Center at Buck Island Ranch in Highlands Co., Florida (Fig. 2.1) which is operated by Archbold Expeditions (www.maerc.org, Swain, 1998).

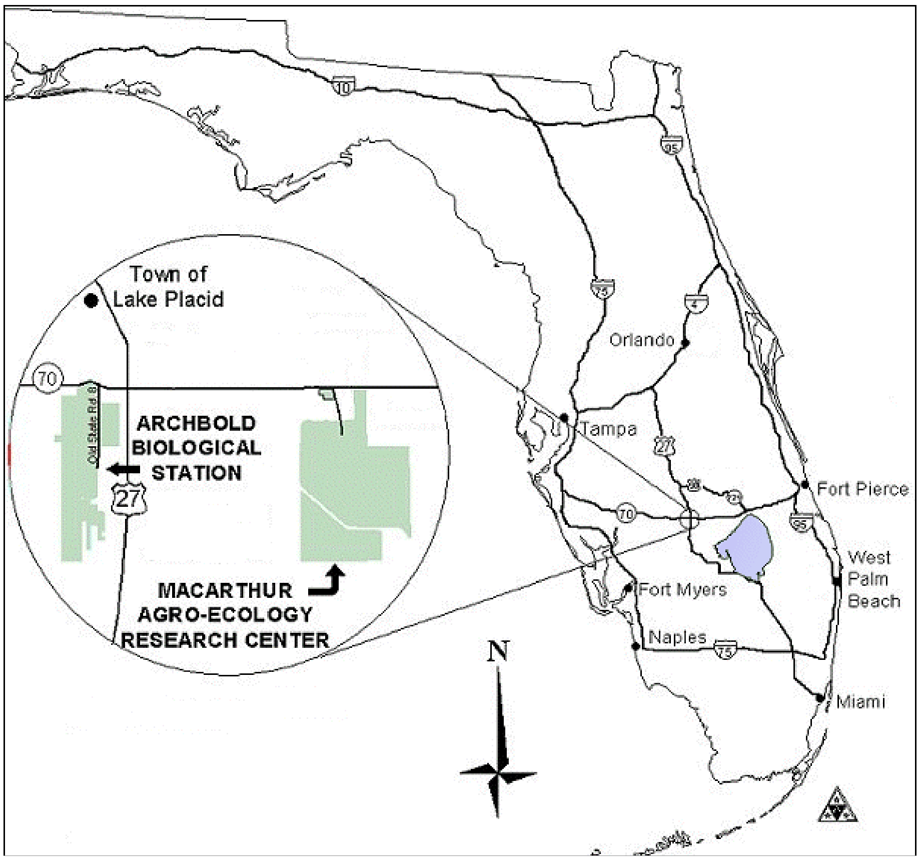

Figure 2.1. Location of the MacArthur Agro-Ecology Research Center.

2.1 MacArthur Agro-ecology Research Center as a representative ranch

Buck Island Ranch consists of a mosaic patchwork of different habitat types, including improved pastures, semi-improved pastures and more native pastures, woodland hammocks and wetlands. The breakdown of acreage of major pasture types on Buck Island Ranch is very similar to that of a typical or average ranch in south-central Florida (Table 2.1).

Table 2.1. The breakdown of acreage on a typical cattle ranch in south-central Florida in comparison to the breakdown of acreage at MAERC.

Type of Pasture	Average ranch[a]	MAERC
	% of total acreage	
Improved	47.1	47.6
Semi-improved and native	49.3	52.4
Hay	3.6	0
Total	100%	100%

[a] The acreage was based on calculation for an average-sized large cow-calf operation of 4,200 acres. The proportion of different pasture types was based on a 1998 Survey of Beef and Forage Practices Used by Beef Cattlemen in South-Central Florida, Range Cattle Research and Education Center, Ona, Florida (Hazen and Sawyer, 2003).

2.2 Pasture layout and instrumentation

The two study sites were selected to represent two typical land uses, improved and unimproved or "semi-improved" pastures (hereafter referred to as summer and winter pastures, respectively) in the south-central region of Florida. A general survey of vegetation and biological conditions in each of the pastures was conducted prior to the start of the cattle stocking experiment to assess any pre-treatment differences (Werner et al., 1998). Soil surveys were conducted at the sites by the USDA-NRCS in June 1997, at 0.5-ha resolution. Soil survey information from USDA was digitized by MAERC to produce an ARC-INFO soils coverage. The location of final pasture boundaries and operational and instrumentation equipment was recorded using a Trimble Pro XR GPS Unit.

Summer pastures - improved pasture study area

An approximately 162-ha study area (27º 8.7′ N, 81º 10.6′ W) was established on improved summer pasture (Fig. 2.2), within what was originally a 320-ha pasture, drained and ditched sometime in the late 1960s/early 1970s, and used for many years typically as summer grazing for beef cow-calf pairs. These pastures were vegetated primarily with bahia grass (*Paspalum notatum)*, and included scattered wetlands, nearly all of which were connected to ditches by the 1970s. Several isolated wetlands, mainly located on the western and eastern edges of this site, are primarily composed of grasses, sedges, and miscellaneous wetland species, with dominants including carpetgrass (*Axonopus affinis)*, maidencane (*Panicum hemitomon)*, soft rush (*Juncus effusus)*, yellow-eyed grass (*Xyris* sp.) and pickerelweed (*Pontederia cordata)*, and some with sawgrass (*Cladium jamaicense)*. Small cabbage palm (*Sabal palmetto*) hammocks are also located on the eastern and western edges of this site. Elevation of the pasture area is ≈ 7.9-8.5 m, sloping gradually to the southeast and draining through a series of ditches into the Harney Pond Canal to the south. From the early 1970s until 1987, this 320-ha pasture was fertilized annually with IFAS recommended amounts of nitrogen, phosphorus, and potassium (D. Childs, personal communication) which was 56 kg N ha^{-1} as $(NH_4)_2SO_4$ or NH_4NO_3, and 34-90 kg of P_2O_5 and K_2O ha^{-1} (F. Pate, personal communication) and then from 1987 until 1995 received only N at 56 kg ha^{-1}, applied between March and May. The site had been periodically limed (every 3-5 years) prior to the study period but was not limed during the study period.

Between 1996 and 1998 the site was subdivided with 5 strand barb wire fence into eight approximately 20-ha experimental pastures (SP1-SP8), each between 180-200 m wide (E-W) by 1.13 km long (N-S) and ranging in size from 19.01 to 22.04 ha (Table 2.3). Each pasture is surrounded by a small berm (4 m wide, 0.5 m above grade) and has a collection ditch (typically 5.5 m wide and 0.6 m below existing grade) along the east and south sides (Fig. 2.2). The original lateral drainage ditches or swales in these pastures, running east-west approximately every 30 m, were connected to two existing N-S ditches (elevations between 7.6 – 7.8 m) and to new collecting ditches, so that the surface water from each pasture runs off separately through one main exit flume on the south end of each pasture. Flume elevation was set at 7.99 m National Geodetic Vertical Datum (NGVD). Access for cattle work, minerals, and feed is through the north end of the pastures. Cattle obtained water from water tanks at the north end of the pastures and from ditches within the pastures. Shade structures were constructed at the north end of all stocked pastures since these lacked significant sources of shade.

Winter pastures - semi-improved pasture study area

An approximately 260-ha study area (27º 7.9′ N, 81º 12.3′ W) was established on an area of unimproved or "semi-improved" pasture (Fig. 2.3), which had extensive bahia grass but was also vegetated with carpetgrass, sedges (*Cyperaceae* spp.), field paspalum (*Paspalum leave)* and bunch grasses such as broomsedge (*Andropogon virginicus)* and bluestem *(Andropogon glomeratus)*. Interspersed throughout the semi-improved pastures are wetlands, nearly all within 30 m of existing ditches, again composed primarily of grasses, sedges, and miscellaneous wetland species, with dominants including carpetgrass, maidencane, red top panicum (*Panicum rigidulum)*, hat pins (*Eriocaulum* sp.), yellow-eyed grass, and with less pickerelweed and soft rush than in the improved pastures. Cabbage palm hammocks occur in the western third of this pasture array where they introduce natural shade. The semi-improved pasture study area was less intensively drained than the summer pasture area, and is regularly flooded or has saturated soils during the rainy season (June-October) and had been used for many years as winter grazing for beef cow-calf pairs. The pasture is at elevation of approximately 8.2 to 8.8 m and drains to the north. Our understanding, obtained through conversation with previous landowners or managers is that this area was never fertilized (D. Childs and D. Durrance, personal communication). Between 1996 and 1998, a 260-ha portion of this pasture was subdivided into eight approximately 32-ha experimental pastures, with a variety of shapes (Fig. 2.3).

Winter pastures (WP1–WP8) vary in size from 30.24 to 34.12 ha (Table 2.3). Existing ditches with elevations between 7.62 - 7.77 m NGVD, and new collecting ditches in these pastures were connected so that the surface water from each experimental pasture runs off separately through one main exit flume, typically at the north end of each pasture, and flows through a main drainage ditch into Harney Pond Canal to the north. Flume elevation was set at 8.08 m NGVD. Access for cattle work, minerals, and feed is through the north end of the pastures. Cattle obtain water from two solar driven groundwater wells, with storage tanks and gravity-fed lines to individual pastures at the south end.

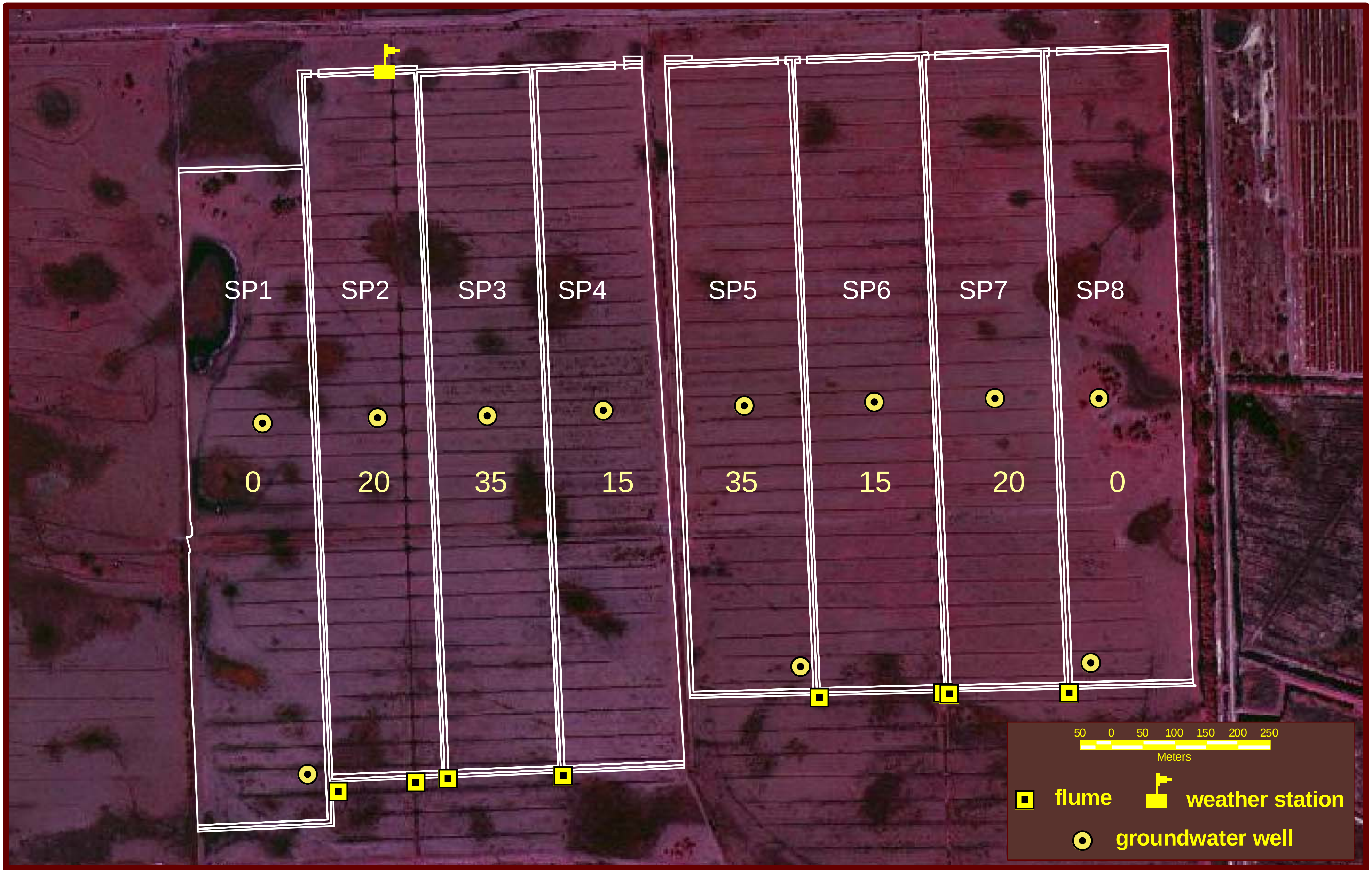

Figure 2.2. Aerial photo showing the layout of the improved "summer" pasture array and location of associated instrumentation. Pasture numbers are SP1-SP8 and stocking rates are indicated by the number of cow-calf pairs per pasture (0, 15, 20, 35).

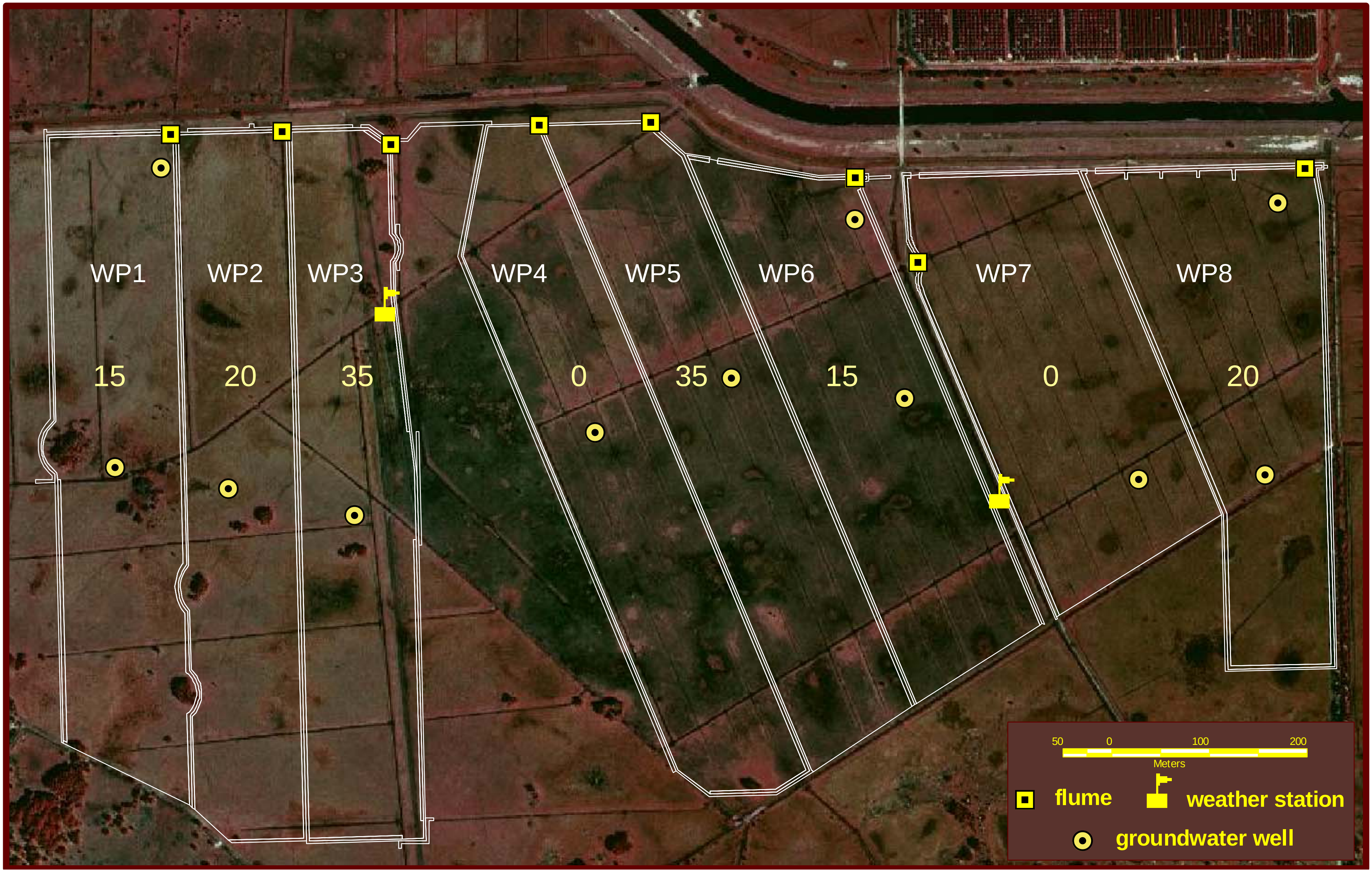

Figure 2.3. Aerial photo showing the layout of the semi-improved "winter" pasture array and location of associated instrumentation. Pasture numbers are WP1-WP8 and stocking rates are indicated by the number of cow-calf pairs per pasture (0, 15, 20, 35).

Equipment and instrumentation

Water draining from the surface ditches in each pasture flows out through a single trapezoidal flume constructed at the exit point from each pasture (Fig. 2.4). Flumes were installed from fall/winter 1997 to spring/summer 1998. The flumes incorporate stilling wells with shaft encoders at the upstream and downstream ports to measure water depth in the flumes and the data were collected by a Campbell CR10 datalogger, powered by a solar panel, and programmed to drive the water quality-sampling regime of an associated ISCO water sampler which samples surface runoff just upstream of the flume. The full details of the design and construction of these flumes and associated instrumentation are provided in Capece et al. (1999; 2003). Data collection started in the summer pastures on 19 May 1998, and in the winter pastures on 21 May 1998, and continued through December 2003, interrupted only by occasional equipment malfunctions. The winter pasture array has two meteorological stations and the summer pasture array has one station; these were installed on 21 May 1998 to record rainfall, wind speed and direction, air temperature, relative humidity, and solar radiation using Campbell Scientific CR10X dataloggers. There are 5 additional tipping buckets installed throughout the pastures to record rainfall. In addition to the meteorological stations at the pasture sites there is a main weather station at the Ranch headquarters, which has operated throughout the experiment, where manual rainfall readings are taken daily and a datalogger records air temperature, relative humidity, wind speed and direction at 3 m and 9.1 m, solar radiation, and soil temperature.

Figure 2.4. Photo of a flume used to collect surface runoff from an experimental pasture.

2.3 Stocking treatments and operation factors

Four stocking densities (no cattle, low, medium, and high) were selected based on input from the FCA and UF-IFAS to reflect typical regional stocking densities, which average one animal unit per 1.42 ha (Gornak and Zhang, 1999). For reference, the entire 4,168-ha ranch is currently stocked at an average density of about one animal unit per 1.34 ha. There were two replicates of each of the four stocking densities in each of the two blocks, the summer and winter pastures, for a total of 16 plots (Table 2.2). The four stocking densities were applied in a randomized design to the 2 x 8 pastures with the exception that the two “outside” summer pastures SP1 and SP8 were allocated as controls, as they differed from the other six pastures by having more wetlands and natural shade. In addition, at the outset of the cattle stocking experiment in the winter pastures, the treatments for WP4 and WP1 were switched, because the solar well pump was unable to supply sufficient water to WP4.

Table 2.2 Design of the cattle stocking rate demonstration project.

Block	Plot ID	Replicates	Treatment		
			Description	Cow-Calf Units	Hectares/Unit
Summer	SP1, SP8	2	Control	0	N/A
	SP4, SP6	2	Low	15	1.3
	SP2, SP7	2	Medium	20	1.0
	SP3, SP5	2	High	35	0.6
Winter	WP4, WP7	2	Control	0	N/A
	WP1, WP6	2	Low	15	2.1
	WP2, WP8	2	Medium	20	1.6
	WP3, WP5	2	High	35	0.9

Cattle stocking treatments were started in the winter pastures on 10 October 1998 and ended 23 October 2003. Cows in the experimental pastures were all worked at approximately the same time as the remainder of the other herds on the ranch. All other management treatments were standard across all pastures, either summer or winter. Cattle and pasture management are summarized in Fig. 2.5. Each of the six experimental cattle "herds" were labeled with different color ear tags and were placed in the summer pastures, largely in the summer months (May-Oct.), and the winter pastures, largely in the winter months (November-April). Movements varied from this schedule depending on prescribed burns, and the ranch management needs. The 140 cows selected for the project were 4–8 year old Brahman cross cows with an initial body condition score of 5 on a scale of 9. Occasionally experimental herds were noted with additional untagged or missing tagged cattle; these problems were rectified as soon as they were reported. All dead cows and calves or cows without calves were replaced with an equivalent cow or cow-calf pair at the first available time. On one occasion cattle other than the experimental herds were placed in summer pastures; 3 herds of 15 bulls each were rotated among the summer pastures SP2, SP3, SP4, SP5, and SP6 between 25 August 2000 and 24 September 2000 (Fig. 2.5). Standard practices were followed for pregnancy checking, deworming, Vibrio. and Lepto. vaccinations and Trich. testing, and external parasite control (26 August 1999, 25 September 2000, 3 September 2001, 11 September 2002, 25 September 2003). Calves were dewormed, castrated, dehorned, implanted, and branded (2 February 1999, 8 - 9 February 2000, 12 February 2001, 25 March 2002, and 18 March 2003). Cows were scored for body condition each time they were worked. Calves were separated from the cows and weighed before shipping (11 August 1999, 23 August 2000, 3 September 2001, 5 September 2002, 18 August 2003); cows were returned to the experimental pastures within 2-4 weeks after separation from calves to allow them to settle (7 October 1999, 9 October 2000, 1 October 2001, 11 September 2002, 25 September 2003). One bull was placed into each pasture with cattle herds in each year for approximately 4-5 months (2 February to 2 June 1999, 29 January to 14 June 2000, 25 January to 1 July 2001, 16 January to 7 June 2002, 15 January to 7-8 June 2003 (it proved impossible to rotate bulls among the pastures as they continually attempted to return to their previous "herd"). Prescribed burning was conducted in the winter pastures at the start (23-24

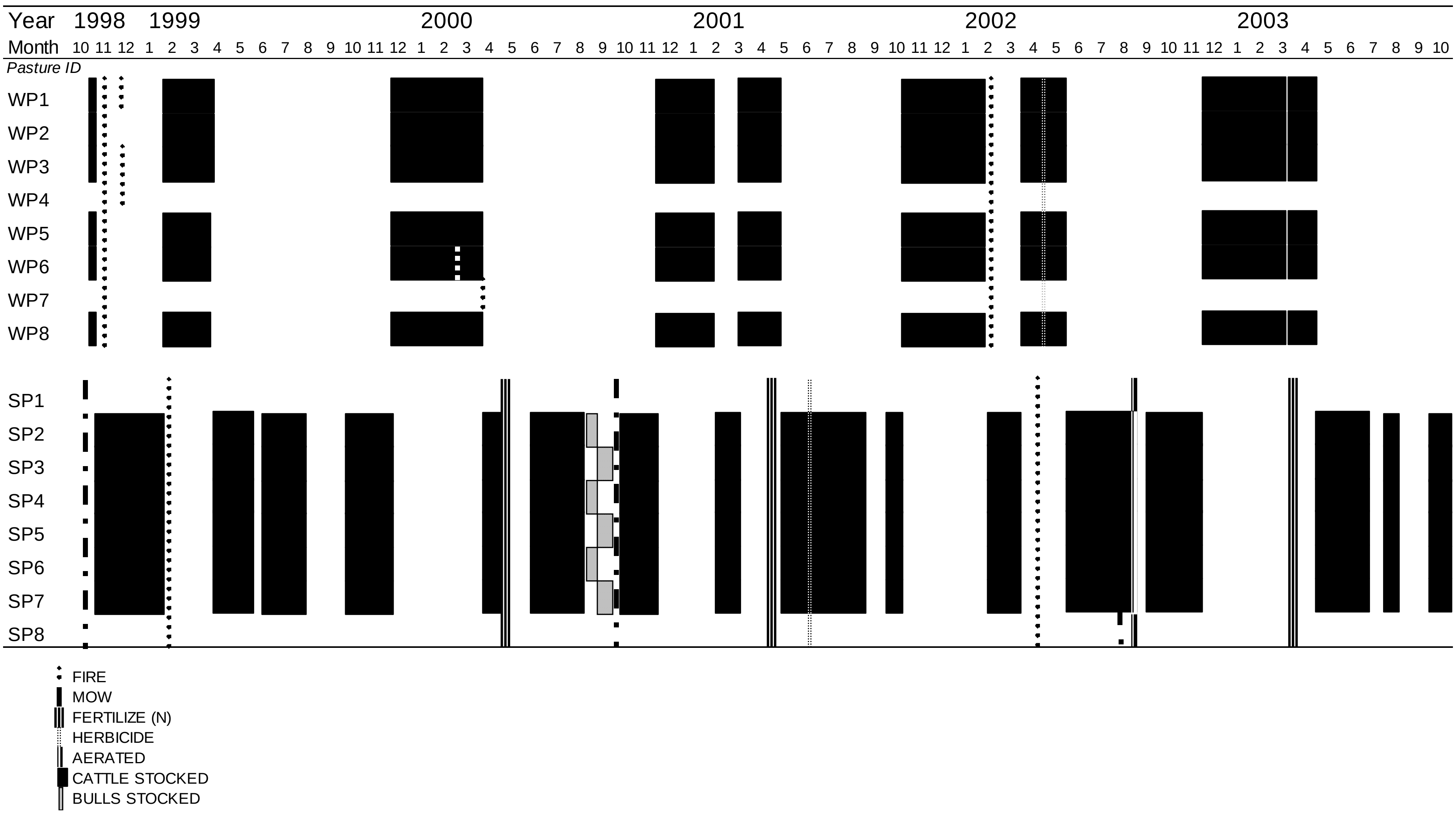

Figure 2.5. Chart showing the timing and duration of various pasture and cattle management practices on the experimental pastures. Please see text for discussion.

November 1998) of the experiment. Missed spots in the winter pastures were burned 10 December 1998; summer pastures were burned 3 February 1999. In 2000 there was no prescribed burning but an accidental fire occurred in WP6 on 1 March 2000 and in WP7 on 5 April 2000. No prescribed burns were conducted in 2001. Winter pastures were burned 11-12 February 2002, and summer pastures 15-18 April 2002. Nitrogen fertilizer was applied as ammonium nitrate or other commercial mix, at 56 kg N/ha to the summer pastures SP1-SP8 1–9 May 2000, 24 April 2001, and 28-29 March 2003, but not in 1999 or 2002. Summer pastures were mowed for brush control in October to November 1998, September to October 2000, and spot mowed August – October 2002. Dog fennel (*Eupatorium capillifolium),* which appeared to establish as a result of drought and disturbance during pasture construction, was treated in the summer pastures on 27-29 June 2001, 19 April to 2 May 2002, and 11 July 2003, with WEEDMASTER® (mixture of dimethylamine salts of dicamba and 2,4-D) at 4.6 L/ha plus 7.5 ml/L of non-ionic surfactant. Summer pastures were aerated August – October 2003. The exit ditches leading from the summer and winter pastures were cleaned out approximately May/June annually to minimize blockage downstream and ensure flow from the experimental pastures.

2.4 Surface runoff sampling and analysis

The experimental pasture plots were fenced and ditched separately from each other, so that all surface water runoff from a given plot could be captured through a single trapezoidal flume and analyzed separately. Stilling wells, floats and digital encoders, which monitored upstream and downstream water depth, served as the basis for real time calculation of flow. Automatic water samplers (Model 3700, ISCO, Inc, Lincoln, NE) were triggered by the data loggers (CR10X, Campbell Scientific, Logan, UT) based on flow volume calculations and hydrograph geometry (Tremwel et al., 1996). The low relief of the pastures relative to the changing water levels in the adjacent Harney Pond Canal required that the discharge measurement and sampling system accommodated flow in both directions, including inflow (backflow) from the canal as well as runoff to the canal (Fig. 2.6).

The water samples collected by the automated water samplers were shipped to the Harbor Branch Environmental Laboratory (Ft. Pierce, FL) in 1998 and the Tennessee Valley Authority Environmental Chemistry Laboratory (Chattanooga, TN) in 1999-2002, and to PPB analytical laboratories (Gainesville, FL) in 2003. The samples were preserved with H_2SO_4 and analyzed for total phosphorus (TP), nitrate/nitrite (NO_x), ammonium (NH_4^+), and total Kjeldahl nitrogen (TKN), using standard analytical protocols (EPA, 1993). The flow volume measurements were combined with the chemistry results in a database to calculate net nutrient loads from each pasture plot.

In addition to autosampler samples, more than 250 manual grab samples of pasture runoff were taken on 33 occasions from 1998 - 2003. Both unpreserved filtered grab samples and preserved (H_2SO_4) unfiltered grab samples were taken on each sampling date just upstream from the flume. Preserved grabs were analyzed for the same parameters as samples taken by the automatic water samplers (see above), and unpreserved filtered grabs were analyzed for soluble reactive P (SRP) and nitrite (NO_2). Each time manual grab samples were collected, the dissolved oxygen (DO) content, pH, and conductivity of surface water were measured at approximately 6” below the water surface immediately upstream of the flume.

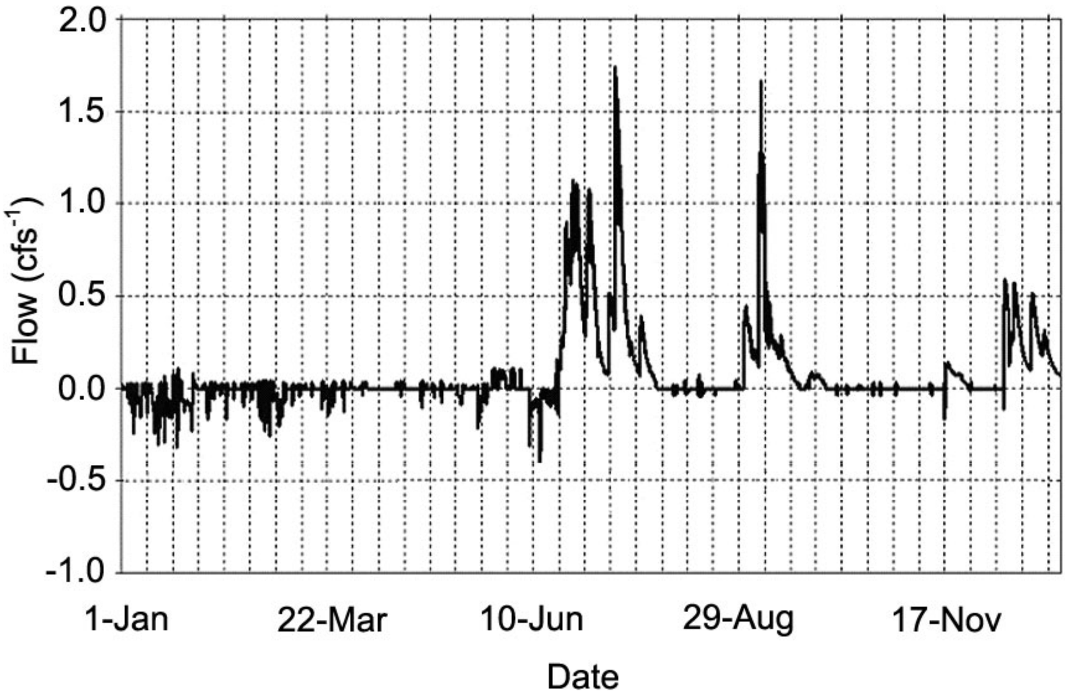

Figure 2.6. Example of a hydrograph from a summer pasture (SP2) in 2002 showing period of intermittent back flow into the pasture and outflow from the pastures, which occurred mainly during the wet season (June – October).

2.5 Pasture soils

Five soil series were mapped on the experimental sites by USDA-NRCS and the proportion of different soil series differed between summer and winter pastures; 89% of the area in the summer pastures is Felda fine sand, and 70% of the winter pastures is Pineda fine sand overlain with a muck layer (Table 2.3). Felda fine sand and Pineda fine sand both are sandy or loamy, siliceous, and hyperthermic Alfisols that differ only in terms of the color of the E and Bw horizons. A substantial portion (87%) of the Pineda soils in the winter pastures is overlain by a thin layer (2.5–15 cm) of muck; this muck layer is not as prevalent on the Felda soils in the summer pastures (Table 2.3). Other soil series present in smaller amounts were Tequesta and Gator muck, which occurred in nearly all depressions, with the majority being Tequesta muck (Table 2.3). The Tequesta depressions had about 20 – 25 cm of muck with an argillic layer (Bt/clay enriched layer) 50 – 130 cm below the surface. Bradenton soil only occurred in very small amounts under cabbage palm hammocks. There was no significant difference among the summer (SP1-SP8) pastures in terms of major soil series (muck or muck layer versus non-muck soils) (χ^2= 13.81, P>0.05), however the proportion of muck or muck layer versus non-muck soils did vary among the winter pastures, WP1–WP8 (χ^2= 40.77, P<0.001).

Table 2.3. Percent of area occupied by different soil types and wetlands in summer pastures SP1-SP8, and winter pastures WP1-WP8.

Pasture	Area ha	Area mapped soils (ha)	Felda Fine Sand	Felda Fine Sand +muck	Bradenton Fine Sand	Gator Muck	Pineda Fine Sand	Pineda Fine Sand +Muck	Tequesta Muck	% wetlands based on area of muck soils
SP1	22.0	21.6	67.0%	11.3%	0.7%	3.1%			17.9%	20.9%
SP2	19.0	18.9	88.6%	1.3%					10.0%	10.0%
SP3	20.4	20.3	89.5%						10.5%	10.5%
SP4	20.5	20.2	92.9%						7.1%	7.1%
SP5	20.9	20.9	97.6%						2.4%	2.4%
SP6	19.4	19.5	96.7%						3.3%	3.3%
SP7	19.2	19.22	94.3%						5.7%	5.7%
SP8	20.3	18.6	85.7%		0.6%				13.7%	13.7%
	161.9	159.3	89.1%	1.6%	0.2%	0.4%			8.8%	9.2%
WP1	33.2	32.6	20.0%	56.3%	1.5%			16.5%	5.8%	5.8%
WP2	31.3	30.8	0.3%	24.4%	0.7%			69.5%	5.1%	5.1%
WP3	33.6	33.4			1.0%			93.7%	5.3%	5.3%
WP4	34.1	32.5			0.2%		6.7%	91.5%	1.6%	1.6%
WP5	32.3	27.8					30.0%	68.8%	1.2%	1.2%
WP6	32.1	32.1					38.6%	59.7%	1.7%	1.7%
WP7	30.2	30.2					1.2%	94.5%	4.3%	4.3%
WP8	30.3	29.5		27.2%		1.4%	7.2%	58.0%	6.2%	7.6%
	257.2	248.9	2.5%	13.5%	0.4%	0.2%	10.5%	69.0%	3.9%	4.1%

2.6 Pasture vegetation

Prior to the start of experimental treatments, Werner et al. (1998) conducted vegetation and other biological monitoring in the 16 pastures. Analysis of the vegetation data (Table 2.4), which excluded wetlands in the pastures, shows that the percent cover of six taxa (bahia grass, carpetgrass, broomsedge, sedges, smut grass and redtop panicum) was largely responsible for a significant difference between the vegetative community structure in the summer and winter pastures prior to the start of the stocking density treatment (Discriminant Analysis, Wilkes' Lambda = 0.550, d.f. = 1, $P < 0.001$). The summer pastures, largely dominated by bahia grass (mean = 82% cover) only differed among pastures in the percent of carpetgrass and smutgrass (two invasive forage grasses) (Nested ANOVA, with split for summer versus winter, F values and P values are given in Table 2.4, d.f. = 7). In contrast the winter pastures, which had less bahia grass (mean = 42%), were more species-rich, and differed among pastures in the percent of bahia, carpetgrass, broomsedge, sedge spp., bluestem, field paspalum, and redtop panicum (Nested ANOVA, F and P values in Table 2.4, d.f. = 7). Prior to the experimental treatment, plant biomass, forage production and forage utilization showed seasonal trends and also varied between summer and winter pastures.

Table 2.4. Percent cover of vegetation on summer pastures SP1-SP8, and winter pastures WP1-WP8, in 1995 (based on data presented in Werner et al., 1998). F and P values are from a Nested ANOVA of the percent cover for each species among pastures, split for summer versus winter pastures. Bold numbers indicate significant differences among pastures.

Scientific Name	**Common name**	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**	**SP8**	**F**	**P**
Paspalum notatum	bahia grass	87%	76%	88%	93%	84%	87%	63%	78%	0.94	0.482
Axonopus affinis	carpet grass	11%	3%	10%	1%		7%	29%	17%	**2.50**	**0.024**
Setaria geniculata	Foxtail		9%					3%		1.68	0.130
Cynodon dactylon	bermuda grass	2%	7%							0.88	0.525
Paspalum dilitatum	dallis grass					9%				0.92	0.495
Centella asiatica	Centella		1%		1%	2%		1%	2%	1.38	0.231
Sporobolus indicus	smut grass		4%					2%	1%	**2.12**	**0.054**
Andropogon glomeratus	Bluestem			2%	1%	2%	1%			0.86	0.544
Paspalum urvillei	vasey grass				1%	2%	2%			1.04	0.415
Juncus effusus	Softrush				2%		1%	1%		0.73	0.649
Cyperaceae spp.	Sedges				1%	1%			1%	0.76	0.625
Eupatorium capillifolium	dog fennel						2%			1.00	0.440
Phyla nodiflora	Lippia							1%		1.00	0.440
Hydrocotyle umbellata	Pennywort								1%	1.00	0.440
Polygonum sp.	Smartweed				<1%					1.00	0.440

		WP1	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP7**	**WP8**	**F**	**P**
Paspalum notatum	bahia grass	78%	32%	79%	24%	16%	18%	52%	38%	**4.50**	**<0.001**
Axonopus affinis	carpet grass		3%		33%	36%	26%	20%	6%	**3.51**	**0.003**
Andropogon virginicus	Broomsedge	9%	24%	9%		20%	48%			**3.13**	**0.007**
Cyperaceae spp.	Sedges	3%	10%	4%	6%	3%	2%	12%	40%	**4.86**	**<0.001**
Andropogon glomeratus	Bluestem		3%	3%	8%	14%	2%	17%	13%	**3.79**	**0.002**
Paspalum laeve	field paspalum		23%	1%	20%	9%	4%			**2.60**	**0.020**
Hedyotis uniflora	hedyotis	4%		1%	7%					1.62	0.146
Axonopus furcatus	big carpetgrass			3%		2%				1.44	0.207
Setaria geniculata	Foxtail	3%								0.93	0.491
Eleocharis spp.	Spikerush	2%	1%							0.85	0.552
Centella asiatica	Centella	1%	1%		1%					0.71	0.662
Panicum rigidulum	redtop panicum								3%	**3.08**	**0.008**
Bidens alba	Beggarticks		1%							1.08	0.387
Eupatorium capillifolium	dog fennel					1%				0.93	0.491

3.0 Meteorological conditions during the study period

There was significant variation in monthly and annual rainfall from 1998 to 2003, which contributed to variation in the timing and amount of surface runoff from the experimental pastures. The project began in November 1998, following an El Niño event that contributed to higher than normal rainfall in January through March of 1998. This El Niño event was followed by a prolonged La Niña event that was associated with a severe drought in 2000 (Fig. 3.1).

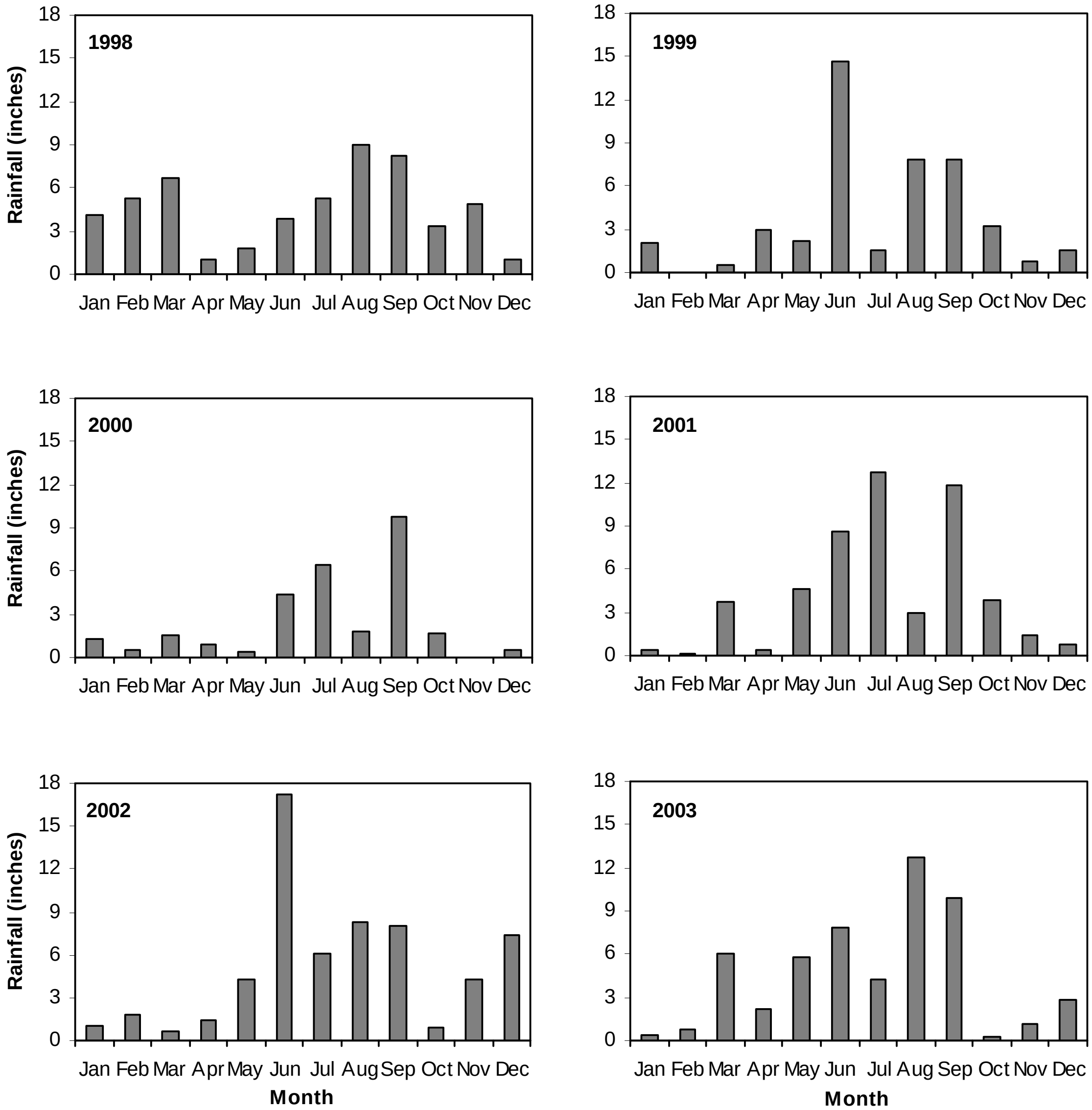

Figure 3.1. Monthly rainfall totals for 1998-2003. Data are from the main weather station manual rain gauge at MAERC.

Drought conditions broke in 2001 and annual rainfall from 2001 through 2003 was average or above average for the region. At the end of 2002 and early 2003 there was a minor El Niño event that was associated with above average rainfall in November and December of 2002 and March of 2003, which resulted in the only time during the project that winter runoff events occurred. Summary files of the meteorological conditions during the study period have been submitted to the SFWMD and are being prepared for uploading into their publicly available online database, DBHydro.

4.0 Surface runoff amounts and nutrients in surface runoff

4.1 Surface runoff during the study period

Total annual runoff varied with annual rainfall but overall patterns were different for the summer and winter pastures (Table 4.1). Runoff represents net outflow from the pastures after subtracting any back flow that occurred during the year. Back flow in the winter pastures occurred mainly when water was pumped onto the ranch from the Harney Pond Canal during the dry season to provide water to cattle in that section of the ranch. Inflow into the summer pastures occurred mainly when the Harney Pond Canal was raised to an elevation higher than the elevation of surface water in the summer pastures. Extreme drought conditions resulted in exceedingly low runoff amounts in 2000. In 1998 and 2003 the total runoff was significantly greater from the winter pastures than from the summer pastures but this was not the case in 2001 and 2002 when runoff amount from the two pasture types was very similar. The reason for the differences between summer and winter runoff in the different years is not known but might have been due to regional control of canal levels, variable rainfall patterns or other factors. More detailed analysis of temporal patterns of runoff, back flow, and pasture hydrographs is provided in reports submitted to FDEP (Capece et al., 1999; 2003).

Table 4.1. Total rainfall (cm) and surface runoff (cm) during the study period. Different superscripts following values within a column indicate significant differences in runoff amounts between summer and winter pastures (ANOVA; P<0.05). Rainfall amounts are taken from the manual rain gauge at the main weather station at MAERC.

Pasture Type	1998[1]	1999	2000	2001	2002	2003	Average
Rainfall	138.3	114.6	74.3	130.1	155.9	137.7	125.1
Summer pasture runoff	11.4[b]	8.9	0.5	31.2	33.5	18.8[b]	17.4
Winter pasture runoff	22.9[a]	12.9	1.7	27.6	32.1	44.2[a]	23.6
Pooled SEM[2]	3.6	2.6	1.3	4.7	4.2	5.2	3.8

[1]The runoff for 1998 does not represent a complete year because the monitoring stations were not functioning until July and there were winter flow events in 1998 due to El Niño.
[2]Pooled ANOVA model standard error for the pasture type effect.

4.2 Runoff physical parameters

Surface runoff from summer pastures had higher pH, higher conductivity, and lower dissolved oxygen (DO) than did runoff from the winter pastures (Table 4.2). The higher pH of the surface runoff in summer pastures was consistent with the higher pH in summer pasture soils (average, 4.79 ± 0.73; range 3.67 - 8.70) relative to winter pasture soils (average, 4.26 ± 0.39; range, 3.25 - 5.53) (ANOVA; $P < 0.05$). The higher soil pH in the summer pasture soils was likely due to intermittent applications of lime to those pastures over the past 30 years at a rate of 0.5 to 1.5 tons per acre. Higher conductivity in runoff from the summer pastures than in runoff from the winter pastures indicates a higher concentration of dissolved solids, which could be related to the higher nutrient concentrations in the summer pasture runoff (see below), or differences in vegetation, soil type or elevation between the two pasture arrays. The lower DO levels in the runoff from the summer pastures suggest greater heterotrophic activity, possibly stimulated by the higher nutrient content of summer pasture runoff (see below) or due to the slightly lower elevation of the summer pastures, creating more anaerobic conditions in those pastures.

The DO in back flow was greater than the DO in forward flow in the summer pastures and the pH was significantly greater in back flow than in forward flow in the winter pastures ($P < 0.05$, Kruskal-Wallis test). Back flow in the summer pastures was due mainly to increased elevation of the nearby Harney Pond Canal and reflects the greater DO of incoming canal water than in surface runoff from the summer pastures. Back flow into the winter pastures was due mainly to pumping of water from the Harney Pond Canal into the winter pasture area during dry periods to ensure adequate water for cattle and reflects the higher pH of canal water relative to runoff from the acidic winter pastures.

Table 4.2. Summary of surface runoff physical parameter data for grab samples taken during 1999-2003 from the summer and winter pastures for both forward flow and back flow conditions. Values are means of the average values for each pasture type on each sampling date. Values in parentheses are one standard deviation. Means within a row followed by a different superscript are significantly different ($P < 0.05$, Kruskal-Wallis test).

Physical parameter	N_s/N_w[1]	Pasture type	
		Summer Pastures	Winter Pastures
		Forward flow	
Temp (ºC)	32/38	25.1 (3.2)	25.2 (3.2)
pH	32/38	6.04^a (0.63)	5.35^b (1.09)
Cond. (µS cm^3)	33/37	325^a (99)	137^b (61)
DO (ppm)	31/37	1.16^b (1.19)	1.87^a (1.03)
		Back flow	
Temp (ºC)	9/5	25.0 (2.5)	24.3 (3.9)
pH	9/5	5.96^b (0.50)	6.41^a (0.75)
Cond. (µS cm^3)	8/3	258 (53)	190 (110)
DO (ppm)	9/5	1.53 (0.44)	1.76 (0.92)

[1]N_s is the number of sampling occasions in the summer pastures and N_w is the number of sampling occasions in the winter pastures.

4.3 Influence of stocking rate on nutrients in surface runoff

Cattle stocking rate had no significant effect on the concentration of any measured nutrients in surface runoff during the study period (Tables 4.3 - 4.6). Cattle stocking rate had no effect on concentration of total P (TP) or total N (TKN) in any year in either pasture type (Tables 4.3 and

4.4). In 1998 in the summer pastures, NH_4^+ concentrations were significantly higher in the pastures that were assigned the high stocking rate than in pastures that were assigned the low stocking rate, but this is considered a random effect because the stocking rates were not applied until November 1998, and the effect was not observed in any subsequent years (Table 4.5). In general, cattle stocking rate had no effect on NO_x concentrations except in 2003 when NO_x concentrations were significantly higher in the control and low stocking rate treatments than in the medium and high stocking densities in the winter pastures only (Table 4.6). This difference is unlikely to be related to cattle stocking rate because it occurred in only one year in a single pasture type. Furthermore, these differences in NO_x concentration are not biologically meaningful because overall NO_x concentrations were very low.

Cattle stocking rate had no effect on nutrient loads, which are the product of nutrient concentration and total runoff volume (Tables 4.7 - 4.10). Loads of TP and TKN were elevated in pasture SP7 in 2002 and 2003 leading to a higher average nutrient load in the medium stocking density treatment in those years (differences not statistically significant), but this was likely not related to the stocking treatment (Tables 4.7 and 4.8). Inspection of the SP7 site in 2003 revealed that sediment had built up around the intake to the autosampler, which may have caused excess sediment to be taken up by the autosampler, leading to the anomalously high TP and TKN concentrations and loads at that site in 2002 and 2003. (Corrective action was taken in 2003 to raise the intake and clear out sediment that had accumulated at the upstream side of the flume). Loads of NH_4^+ did not differ among stocking treatments although NH_4^+ loads were elevated in SP7 in 2002 and 2003 as discussed above for TP and TKN. Loads of NO_x were low overall and did not differ among nutrient treatments.

4.4 Discussion of the lack of a stocking rate effect

Results from this study do not support the initial hypothesis that cattle stocking rate would have a significant effect on nutrient loads in surface runoff from beef cattle pastures in the Lake Okeechobee Basin. To the contrary, the results show that under typical stocking rates in seasonally wet south Florida cattle pastures cattle stocking rate had no consistent effect on any nutrient parameter measured. The high stocking rate was considered to be representative of regional averages, but the medium and low stocking rates were considerably below regional averages. The results from this study cannot be extrapolated to situations where there are very heavily stocked or overgrazed pastures. It is possible that potential effects of cattle stocking rate on surface runoff from summer pastures was overridden by the effects of accumulated P from previous fertilizer use, as discussed below in Section 4.5, which addresses the influence of pasture type on nutrient loads.

The initial assumption was that cattle would increase nutrient loads in runoff and that adjustments to stocking rate would be an effective Best Management Practice (BMP) for reducing non-point source pollution from cattle ranches. Cattle transform nutrients from less available forms in vegetation to more labile forms and deposit nutrients in highly concentrated patches in dung and urine. Release of nutrients from these waste products during heavy rains or direct deposition of waste into drainage ditches are plausible routes by which cattle might increase nutrient runoff. Cattle can also stimulate nutrient release into surface water by re-suspending nutrient-laden sediments as they walk or loaf in ditches and wetlands (Line et al.,

Table 4.3. Concentrations of total phosphorus (TP) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average concentrations in mg L^{-1} for all samples collected during the indicated calendar year.

Block	Treatment	1998	1999	2000	2001	2002	2003	Average
Summer	Control	0.56	0.58	0.45	0.94	0.82	0.78	0.69
	Low	0.40	0.58	0.41	0.98	0.66	0.74	0.63
	Medium	0.21	0.58	0.22	0.79	0.92	0.99	0.62
	High	0.69	0.57	0.28	0.79	0.60	0.56	0.58
	Average	0.47[a]	0.58[a]	0.34	0.88[a]	0.75[a]	0.77[a]	0.63[a]
Winter	Control	0.10	0.14	0.18	0.13	0.12	0.05	0.12
	Low	0.07	0.11	0.47	0.15	0.17	0.11	0.18
	Medium	0.07	0.15	0.13	0.11	0.12	0.09	0.11
	High	0.08	0.09	0.34	0.20	0.18	0.25	0.19
	Average	0.08[b]	0.12[b]	0.28	0.15[b]	0.15[b]	0.13[b]	0.15[b]
Pooled SEM[1]		0.06	0.04	0.12	0.05	0.11	0.1	0.06

[1]Pooled ANOVA model standard error for pasture type effect.
[ab]Pasture type averages followed by different superscripts are significantly different (*P*<0.05).

Table 4.4. Concentrations of total Kjeldahl nitrogen (TKN) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average concentrations in mg L^{-1} for all samples collected during the indicated calendar year.

Block	Treatment	1998	1999	2000	2001	2002	2003	Average
Summer	Control	3.43	4.98	2.76	3.92	3.16	3.22	3.58
	Low	3.63	4.39	2.82	3.62	3.00	3.12	3.43
	Medium	3.11	4.77	2.13	3.92	4.26	5.23	3.90
	High	3.84	4.37	2.27	3.52	3.15	2.94	3.35
	Average	3.50	4.63	2.50	3.75[a]	3.39	3.63	3.57
Winter	Control	3.67	3.79	3.69	3.09	3.05	3.11	3.40
	Low	3.5	6.6	4.46	2.82	2.85	3.05	3.88
	Medium	3.51	3.04	4.27	2.93	2.58	2.64	3.16
	High	3.60	3.68	4.23	2.80	2.61	2.81	3.29
	Average	3.57	4.28	4.16	2.91[b]	2.77	2.90	3.43
Pooled SEM[1]		0.15	0.86	0.66	0.17	0.27	0.44	0.32

[1]Pooled ANOVA model standard error for pasture type effect.
[ab]Pasture type averages followed by different superscripts are significantly different (*P*<0.05).

Table 4.5. Concentrations of ammonium (NH_4^+) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average concentrations in mg L^{-1} for all samples collected during the indicated calendar year.

Pasture type	Treatment	1998	1999	2000	2001	2002	2003	Average
	Control	0.28[cd]	0.29	0.31	0.47	0.25	0.17	0.28
	Low	0.21[d]	0.26	0.13	0.36	0.29	0.15	0.23
Summer	Medium	0.28[cd]	0.31	0.12	0.38	1.14	0.27	0.42
	High	0.36[c]	0.56	0.11	0.42	0.27	0.14	0.31
	Average	0.27[a]	0.36	0.17	0.41	0.49	0.18	0.31
	Control	0.19	0.21	0.54	0.31	0.20	0.13	0.26
	Low	0.17	0.18	0.78	0.24	0.19	0.13	0.28
Winter	Medium	0.19	0.21	0.89	0.32	0.18	0.17	0.33
	High	0.19	0.22	1.19	0.23	0.20	0.18	0.37
	Average	0.19[b]	0.21	0.85	0.28	0.19	0.15	0.31
Pasture SEM[1]		0.02	0.12	0.28	0.09	0.23	0.04	0.09

[1]Pooled ANOVA model standard error for pasture type effect.
[ab]Pasture type averages followed by different superscripts are significantly different (*P*<0.05).
[cd] Stocking rate averages followed by different superscripts are significantly different (*P*<0.05).

Table 4.6. Concentrations of nitrate/nitrite (NO_x) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average concentrations in mg L^{-1} for all samples collected during the indicated calendar year.

Pasture Type	Treatment	1998	1999	2000	2001	2002	2003	Average
	Control	0.01	0.02	0.01	0.07	0.04	0.01	0.03
	Low	0.01	0.01	0.01	0.04	0.06	0.01	0.02
Summer	Medium	0.01	0.02	0.03	0.07	0.06	0.01	0.03
	High	0.02	0.01	0.01	0.06	0.03	0.01	0.02
	Average	0.01	0.02	0.02	0.06	0.05	0.01[b]	0.03
	Control	0.02	0.01	0.11	0.09	0.07	0.04[c]	0.06
	Low	0.02	0.05	0.03	0.18	0.11	0.04[c]	0.07
Winter	Medium	0.02	0.03	0.37	0.21	0.06	0.02[d]	0.12
	High	0.04	0.02	0.10	0.08	0.05	0.01[d]	0.05
	Average	0.03	0.03	0.15	0.14	0.07	0.05[a]	0.07
Pooled SEM[1]		0.00	0.01	0.05	0.05	0.02	0.00	0.02

[1]Pooled ANOVA model standard error for pasture type effect.
[ab]Pasture type averages followed by different superscripts are significantly different (*P*<0.05).
[cd] Stocking rate averages followed by different superscripts are significantly different (*P*<0.05).

Table 4.7. Loads of total phosphorus (TP) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average annual loads in kg ha^{-1}.

Block	Treatment	1998	1999	2000	2001	2002	2003	Average
Summer	Control	0.92	0.57	0.16	3.84	3.50	1.20	1.69
	Low	0.56	0.77	0.06	4.30	3.09	1.15	1.65
	Medium	0.58	1.13	0.09	3.27	3.72	2.83	1.93
	High	0.88	0.80	0.04	3.45	2.82	1.38	1.56
Winter	Control	0.12	0.13	0.05	0.61	0.42	0.19	0.25
	Low	0.11	0.14	0.06	0.45	0.28	0.26	0.22
	Medium	0.09	0.17	0.04	0.33	0.34	0.25	0.20
	High	0.12	0.15	0.09	0.64	0.50	0.52	0.34

Table 4.8. Loads of total Kjeldahl nitrogen (TKN) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average annual loads in kg ha^{-1}.

Block	Treatment	1998	1999	2000	2001	2002	2003	Average
Summer	Control	4.68	4.31	0.71	14.87	11.29	6.02	6.98
	Low	4.78	6.50	0.59	11.56	11.24	7.21	6.98
	Medium	7.57	8.67	1.21	13.38	16.84	20.04	11.28
	High	6.77	5.59	0.20	12.24	11.48	5.79	7.01
Winter	Control	7.65	4.29	1.02	10.19	10.43	13.29	7.81
	Low	5.28	4.38	0.62	7.70	5.75	10.95	5.78
	Medium	6.27	3.06	1.00	9.08	6.67	9.41	5.91
	High	6.50	4.65	0.83	8.36	6.77	7.92	5.84

Table 4.9. Loads of ammonium in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average annual loads in kg ha^{-1}.

Pasture type	Treatment	1998	1999	2000	2001	2002	2003	Average
Summer	Control	0.19	0.30	0.05	2.10	0.66	0.25	0.59
	Low	0.19	0.36	0.01	1.34	0.79	0.29	0.50
	Medium	0.23	0.55	0.03	1.34	3.32	0.79	1.04
	High	0.22	0.43	0.01	1.60	0.80	0.25	0.55
Winter	Control	0.35	0.28	0.17	0.75	0.54	0.58	0.45
	Low	0.21	0.22	0.15	0.61	0.35	0.40	0.32
	Medium	0.34	0.21	0.29	0.91	0.48	0.61	0.48
	High	0.21	0.32	0.34	0.49	0.46	0.50	0.39

Table 4.10. Loads of nitrate/nitrite (NO_x) in summer and winter pasture runoff by stocking rate for 1998-2003. Values are average annual loads in kg ha^{-1}.

Pasture Type	Treatment	1998	1999	2000	2001	2002	2003	Average
Summer	Control	0.02	0.01	0.00	0.11	0.11	0.03	0.04
	Low	0.01	0.01	0.00	0.12	0.04	0.01	0.03
	Medium	0.02	0.02	0.00	0.06	0.09	0.03	0.04
	High	0.03	0.00	0.00	0.04	0.08	0.01	0.03
Winter	Control	0.06	0.02	0.02	-0.16	0.11	0.10	0.02
	Low	0.03	0.03	0.00	-0.27	-0.05	0.06	-0.03
	Medium	0.04	0.02	0.13	0.11	0.09	0.04	0.07
	High	0.03	0.03	0.00	-0.12	0.08	0.03	0.01

2000). Despite these potential routes for increased nutrient runoff due to cattle activity our results suggest that these processes do not have a significant cumulative effect at the whole pasture scale during a 5-year treatment period.

Several reasons might account for the lack of influence of cattle stocking rate on nutrients in surface runoff in an extensive grazing situation. Forage productivity in these pastures is high (3,500-4,500 kg ha^{-1}, peak standing biomass) and overall forage utilization at the high stocking density averaged only 30% even in the more densely stocked summer pastures. This relatively low utilization is not unusual for south Florida cow-calf operations where overall ranch stocking densities are constrained by forage availability during the dry season, leading to underutilization of forage at peak biomass production during the wet season. Cattle do not bring any nutrient inputs into the pasture system but only recycle the nutrients within the system. Although their waste products can increase nutrient availability, the area of impact is small and diffuse and most of these nutrients are taken up by the vegetation or soil microbial community, although they can be leached off during wet periods when the soil is saturated (Nash et al., 2000). Furthermore, the effect of cattle on erosion was low in these systems because overall slopes at the sites were less than 1% and peak flow rates in the drainage ditches averaged less than 1 m sec^{-1}.

It is possible that nutrient deposition can become skewed toward particular areas relative to shade, watering or feed structures where cattle spend a disproportionate amount of time and nutrients can build up in the soil near these structures (West et al., 1989; Franzleubbers et al., 2000). If these areas are close to waterways or routes of surface runoff they could have the potential to contribute to increased nutrient loads. This effect was not observed during the course of this experiment but more recent data from samples collected in winter 2004 indicates that available soil P was elevated around shade structures, feed barrels, and watering structures. Over a longer term these sites might contribute to P loss in runoff, depending on their proximity to flow paths for surface runoff.

Under current management practices, there was actually a net export of P in calves from the experimental pastures (Table 4.11). When the summer and winter pastures were considered together as a whole ranch unit more P was exported in calves than was imported in mineral and winter supplemental feed, and the net P export was greatest for the high stocking density (range for high stocking density, 0.13 to 1.3 kg P ha^{-1}). The net export of P in cattle was lower in years

Table 4.11. Phosphorus budgets for the experimental pastures for 1999-2001 including imports in feed and rainfall and exports in calves and surface runoff in terms of total elemental P. Values are means for two replicates of each stocking treatment.

	Phosphorus Imports			Phosphorus Exports					
Stocking rate	Mineral	Molasses	Rainfall	Calves	Winter pasture runoff	Summer pasture runoff	Total surface runoff	Cattle net P export[1]	Total net P export[2]
					kg ha^{-1}				
					1999				
Control	--	--	0.32	--	0.12	0.51	0.27	--	-0.05
Low	0.21	0.36	0.32	1.11	0.12	0.68	0.38	0.53	0.59
Medium	0.17	0.47	0.32	1.52	0.15	1.01	0.54	0.88	1.10
High	0.26	0.92	0.32	2.43	0.13	0.71	0.39	1.26	1.34
					2000				
Control	--	--		--	0.05	0.16	0.09	--	-0.12
Low	0.21	0.36	0.21	1.15	0.06	0.06	0.06	0.58	0.43
Medium	0.17	0.48	0.21	1.47	0.03	0.09	0.06	0.82	0.67
High	0.26	0.84	0.21	2.38	0.09	0.04	0.07	1.30	1.14
					2001				
Control	--	--	0.36	--	0.61	3.84	1.87	--	1.51
Low	0.16	0.79	0.36	1.15	0.45	4.30	1.92	0.20	1.76
Medium	0.25	1.02	0.36	1.38	0.32	3.27	1.44	0.11	1.19
High	0.31	1.52	0.36	2.14	0.64	3.45	1.72	0.32	1.68
					2002				
Control	--	--	0.44	--	0.42	3.50	1.60	--	1.16
Low	0.29	0.59	0.44	1.21	0.28	3.08	1.36	0.33	1.25

Medium	0.40	0.79	0.44	1.50	0.34	3.72	1.64	0.31	1.51
High	0.66	1.38	0.44	2.71	0.50	2.82	1.39	0.67	1.62
					2003				
Control	--	--	0.39	--	0.15	1.41	0.64	--	0.25
Low	0.30	0.91	0.39	0.99	0.11	1.27	0.56	-0.22	-0.05
Medium	0.30	1.08	0.39	1.33	0.14	1.50	0.66	-0.05	0.23
High	0.37	1.65	0.39	2.16	0.20	1.14	0.56	0.13	0.31

[1] Cattle net P export is calculated as: (calves) – (mineral + molasses); negative values indicate a net import of P.
[2] Total net P export is calculated as (calves + surface runoff) - (mineral + molasses + rainfall); negative values indicate a net import of P.

when greater amounts of winter feed (molasses) were offered, and there was actually a net import of P to the cattle operation in the low and mid stocking density treatment in 2003 (Table 4.11).

4.5 Influence of pasture type on nutrients in surface runoff

Pasture type had a large influence on nutrients in surface runoff, particularly on concentrations and loads of P (Table 4.3, Fig. 4.1). Averaged over all years, TP concentration was 4.2-fold greater in summer pasture runoff than in winter pasture runoff (range, 1.2 - 5.9) (Table 4.3). The only year when there was no significant difference in TP concentration between the two pasture types was 2000, which was an extreme drought year with extremely low runoff amounts (Table 4.3). When this year was excluded from the analysis the average TP concentration in summer pasture runoff was 5.5-fold greater than in winter pasture runoff.

Not only were runoff P concentrations greater in summer than in winter pastures, but a significantly greater proportion of total P in summer pasture runoff was soluble reactive P (SRP), the most biologically available form (Table 4.11). The ratio of SRP to TP in manual grab samples was 0.73 for summer pasture runoff but only 0.41 for winter pasture runoff. Average total P in manual grab samples was 4.6-fold greater in summer pasture runoff than in winter pasture runoff. By comparison, the average SRP concentration in grab samples was 8.8-fold greater in summer pasture runoff than in winter pasture runoff.

Table 4.11. Average nutrient concentrations (±SD) of grab samples taken from the experimental pastures during 1999-2003. Values the averages for each pasture type on each sampling date (N=33). Means within a row followed by different superscript letters are significantly different (Kruskal-Wallis test, *P* < 0.05).

Nutrient parameter	Pasture type	
	Summer pastures	Winter pastures
	mg L^{-1}	
NH_4	0.14 (0.12)	0.13 (0.12)
NO_2	0.03 (0.01)	0.02 (0.01)
NO_X	0.03 (0.07)	0.08 (0.14)
TKN	3.56[a] (1.35)	2.91[b] (0.84)
Total P	0.69[a] (0.45)	0.15[b] (0.15)
SRP[1]	0.53[a] (0.48)	0.06[b] (0.06)
SRP/TP[2]	0.73[a] (0.29)	0.41[b] (0.28)

[1]Soluble reactive phosphorus
[2]Ratio of SRP to total P

Total annual P loads were consistently much greater in summer pasture runoff than in winter pasture runoff (Fig. 4.1). Phosphorus loads in winter pastures ranged from 0.06 - 0.51 kg ha^{-1} and in summer pastures ranged from 0.08 - 3.71 kg ha^{-1}. Excluding data from the drought year,

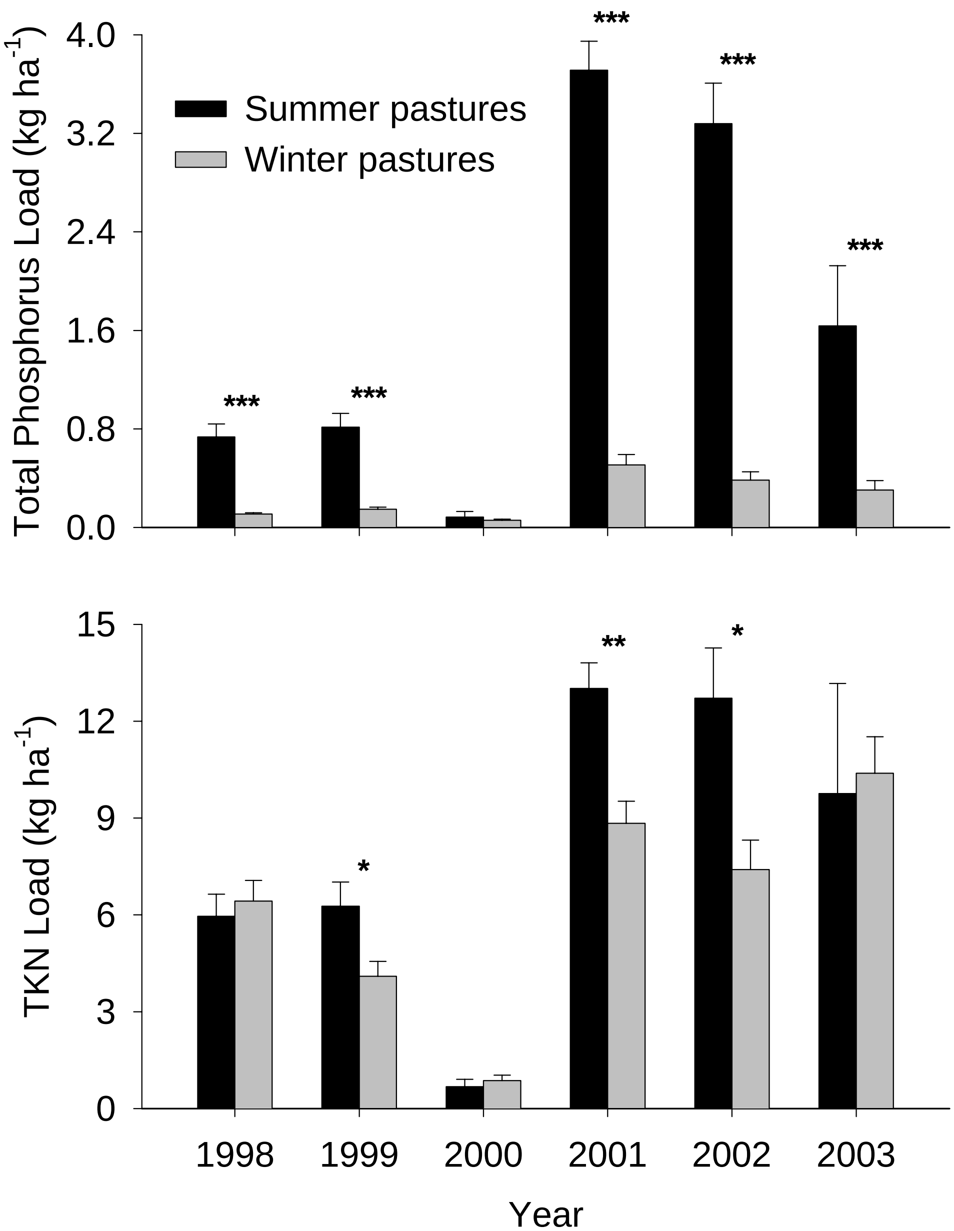

Figure 4.1. Annual loads (mean ± SE) of total phosphorus (TP), and total Kjehldal nitrogen (TKN) in surface runoff from summer and winter pastures from 1998-2003. Asterisks above pairs of bars indicate significant differences between summer and winter pastures at the 0.05 (*), 0.01 (**), and 0.001 (***) levels (N=8).

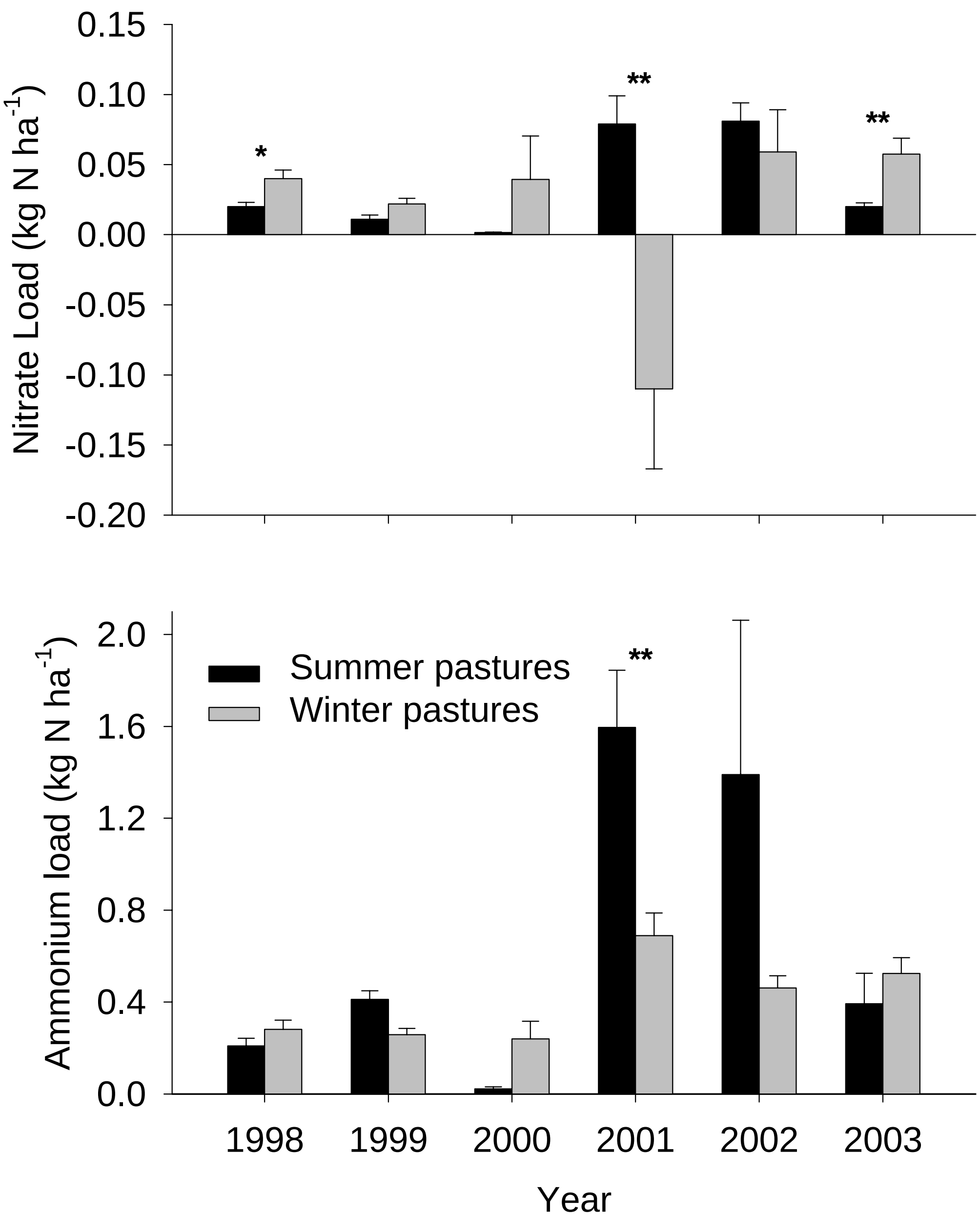

Figure 4.2. Annual loads (means ± SE) of nitrate/nitrite (NO_x) and ammonium (NH_4^+) in surface runoff from summer and winter pastures from 1998-2003. Asterisks above pairs of bars indicate significant differences between summer and winter pastures at the 0.05 (*), 0.01 (**), and 0.001 (***) levels (N=8).

2000, the average annual P loads from summer pastures were 7.0 times greater than the average loads from winter pastures (range = 5.4 - 8.5).

Pasture type also had a significant influence on loads of total nitrogen (TKN). Concentrations of TKN were significantly greater in summer pasture runoff than in winter pasture runoff in 2001 (Table 4.4). When concentration and flow data were combined the total load of TKN was significantly greater from summer pastures than from winter pastures in 1999, 2001, and 2002. Average TKN concentrations in manual grab samples were also significantly greater in summer pasture runoff than winter pasture runoff (Table 4.11).

Pasture type had significant but inconsistent effects on concentrations and loads of inorganic N in surface runoff. Average concentrations of NH_4^+ were greater in summer than in winter pastures in 1998 and total NH_4^+ loads were significantly greater in summer than winter pastures in 2001 (Table 4.5, Fig. 4.2). Nitrate/nitrite (NO_x) concentrations were greater in winter than in summer pastures in 2003, and NO_x loads were greater in winter than summer pastures in 1998 and 2003. Nitrate/nitrite loads were greater in summer than in winter pastures in 2001, mainly due to inflow of higher nitrate water into the winter pastures during the winter drought of 2001, when there was a net inflow of NO_x into the winter pastures in 2001. Overall NO_x loads were negligible relative to other N forms in runoff and in terms of potential biological effects.

The higher TKN loads from summer pastures in 3 of 5 years and greater NH_4^+ loads from summer pastures than winter pastures in one year may have been due to the use of N fertilizer in the summer pastures. The summer pastures were fertilized annually with approximately 50 kg N per ha per year, whereas the winter pastures have never been fertilized. The soil samples from the pastures have not yet been analyzed for total N content but the data on inorganic N in the pasture soil did not indicate that inorganic N concentrations are consistently greater in the summer than in the winter pastures as was the case with available P. Nitrogen is susceptible to microbial transformations, such as denitrification, that can lead to gaseous loss of N. Also, nitrogen is a more limiting nutrient than P, and pasture vegetation is a strong sink for inorganic N. Nitrate is the form of inorganic N most susceptible to leaching but nitrate concentrations were very low in pasture soils especially during flooded periods when most surface runoff occurred.

4.6 Relationship between surface runoff and soil chemistry

Nutrients in surface runoff are derived mainly from soils and sediments and soil P concentrations were substantially greater in the summer than in the winter pastures. Soils in the experimental pastures were sampled and analyzed on several occasions during the course of the stocking rate experiment. On several occasions during 1998 - 2000, soils were sampled by different depth increments to 30 cm in both summer and winter pastures at 10 random locations within each pasture and were analyzed for double-acid-extractable P (Mehlich-1, DAP) and water-soluble P (WSP). The concentration of these labile or readily available forms of P was greatest in the surface 5 cm and decreased with depth. Concentrations of both DAP and WSP were greater in summer than winter pastures at all depths (Table 4.12). The average DAP concentration in the top 5 cm was 2.7-fold greater in the summer pastures than in the winter pastures and the average WSP concentration was 3.5-fold greater in the summer pastures than in the winter pastures

(Table 4.12). Thus, as was the case for the surface runoff, a greater portion of the soil P was in a soluble or readily available form in the summer pastures than in the winter pastures.

Table 4.12. Concentration in Mehlich-1 and water-soluble phosphorus in soil at 4 different depths in summer and winter pastures. Values are means (± SE) for two different sampling periods for each pasture type. Values within a column followed by a different superscript letter are significantly different ($P < 0.05$). All values for summer and winter pastures are significantly different at all soil depths ($P < 0.01$).

	Mehlich 1 P (DAP)		Water-soluble P (WSP)	
Soil Depth	Summer pastures	Winter pastures	Summer pastures	Winter pastures
	------------------mg kg^{-1}------------------			
0-5	40.1^{a} (6.6)	14.5^{a} (1.4)	35.1^{a} (2.5)	10.0^{a} (2.5)
5-10	13.7^{b} (1.5)	7.1^{b} (0.7)	5.8^{b} (0.5)	3.3^{b} (0.7)
10-20	8.5^{b} (1.0)	2.7^{c} (0.4)	1.5^{bc} (0.1)	0.9^{b} (0.1)
20-30	6.8^{b} (1.1)	0.8^{c} (0.1)	0.8^{c} (0.1)	0.4^{b} (0.0)

In 2003, soils in the experimental pastures were intensively sampled on a 55-m grid pattern to assess the spatial distribution of soil P in the pastures. The total soil P and DAP concentrations were, respectively, 1.4- and 2.2-fold greater in summer pastures than in winter pastures, but the WSP concentrations were actually greater in the winter pastures (Table 4.13). When these numbers were expressed in terms of the total content of P in the upper 15 cm of soil, taking into consideration differences between pastures in the amount of organic matter and soil bulk density, the total P and DAP contents were 1.6- and 2.4-fold greater, respectively, in the summer than in the winter pastures. Preliminary examination of the data indicates that there is significant spatial patterning in the distribution of P in the surface soil and these spatial patterns are currently being analyzed (Table 4.13).

The degree of phosphorus saturation (DPS) in the upper 5 cm of soil was 20% in summer pastures and 10% in winter pastures. A DPS of 25% has been defined as a critical value above which P is likely to be lost to soil solution (Breeuwsma et al., 1995) although this critical threshold value may vary among different soils (Beauchemin et al., 1996) and may already have been breached in the summer pastures in our experiment. In soils of more intensive dairy operations in the Lake Okeechobee Basin the sorption capacity of the A horizon in fine sandy Spodosols was reduced to almost zero causing an increase in P concentration equilibrated with lower soil horizons (Nair et al., 1998). A similar process may be operating in our improved beef cattle pastures used in the stocking rate study, although there may have been relatively more loss to surface runoff than to deeper soil horizons in these cattle pastures than on the dairies examined in the previous study because of the more poorly drained status of our soils in the current study.

Table 4.13. Soil P characteristics of the pastures determined from sampling the entire pasture area on a 55-m grid pattern. Values are means of pasture averages (N=8). Data are given in concentration as well as the total amount of P per area to a 15 cm depth. Values within a column followed by different superscript letters indicate significant differences between pasture types.

Pasture type	OM (%)	Total P	DAP[1]	WSP[2]
			mg kg^{-1}	
Summer	9.80	167.06^{a}	10.48^{a}	2.96^{b}
Winter	12.85	119.23^{b}	4.76^{b}	4.73^{a}
SEM[3]	0.59	11.88	1.20	0.51
			g m^{-2}	
Summer	--	25.97^{a}	1.91^{a}	0.56
Winter	--	15.12^{b}	0.78^{b}	0.79
SEM	--	1.52	0.20	0.10

[1]Mehlich-1 or double-acid-extractable P
[2]Water-soluble-P
[3]Standard error of the mean for a one-way ANOVA.

4.7 The legacy of past fertilizer use

The most likely reason for the greater P loads in surface runoff from summer pastures compared to winter pastures is the difference in historical fertilizer use between these two pasture types. The summer pastures have a long history of regular fertilizer application; whereas the winter pastures have never to our knowledge been fertilized[1]. Although we do not have specific records on the amounts of fertilizer added to the summer pastures in the past, several lines of evidence indicate that they were regularly fertilized with P fertilizer for at least 20-30 years up until 1987. We consulted the previous ranch manager (Dan Childs, manager from 1968-1996) and the son of the previous owner (Dan Durrance, owner pre-1968), both of whom indicated that the area used for the summer pasture array was regularly fertilized with P prior to 1987. In 1987 P fertilizer use was discontinued due to new recommendations from the University of Florida that P fertilizer use on bahia grass pastures was not necessary. Annotated pasture maps available at MAERC indicate that the pre-1987 recommended P fertilizer rate for improved pastures at Buck Island Ranch was 40 lbs of P_2O_5 or about 20 kg P ha^{-1}.

The elevated soil P levels in the summer pastures relative to the winter pastures are consistent with the long-term difference in P fertilizer history discussed above. In addition to the evidence provided on fertilizer history there are other ancillary data from these sites to support our conclusion that past fertilizer use is responsible for the differences in soil P levels in the pasture. Drs. Bill Orem and Bob Zielinski of the US Geological Survey analyzed the uranium content and uranium isotope ratios in several soil water samples from the experimental pastures to trace potential P fertilizer sources. This approach takes advantage of the fact that background levels of

[1] The previous ranch manager, Dan Childs, indicated that he applied rock phosphate fertilizer one time to areas in the South Marsh of Buck Island Ranch, which is where the winter pasture array is located, but we do not know whether this one time application occurred in the specific area used for the winter pasture array.

uranium (U) in soils of south Florida are low and that the $^{234}U/^{238}U$ isotopic ratio of naturally occurring uranium in soil is very different from the ratio in P fertilizer and imported feed (Zielinski et al., 2000). Results of the U analysis showed that U concentrations were significantly higher in summer pasture soils than in winter pasture soils throughout the upper 30 cm of the soil profile and that the $^{234}U/^{238}U$ activity ratio of U in summer pasture soils indicated that it came from a P fertilizer source. The $^{234}U/^{238}U$ activity ratio of surface runoff indicated that nearly 80% of the U in surface runoff from the summer pastures was derived from a P fertilizer source. These data are summarized in a paper that is currently being prepared for submission to *Applied Geochemisty* and a draft will be available once it has gone through internal review at the USGS.

In addition to the higher P concentrations in summer pasture soils relative to winter pasture soils, there are other factors that could have contributed to differential release of soil P from the different pasture types. Biogeochemical transformations of P are complex and are influenced by soil redox potential and fluctuations in redox, concentrations of iron and aluminum and microbial P transformations. The release of P from soils and sediments is also be affected by biochemical reactions of other compounds, such as sulfur. Details on these biochemical reactions are not available for pasture soils but there is evidence that sulfate concentrations are higher in summer pasture soils (Orem, unpublished data). Reduction of sulfate to iron sulfides can facilitate release of iron bound P, which is an important constituent of P in the pasture soils (Wetzel, 1999; Sperry, 2004). Future studies on detailed biochemical reactions soils would be needed to resolve mechanisms of P release from pasture soils.

Taken together, the verbally documented history of past fertilizer use, the differences in soil chemistry between pasture types, and evidence from U isotope analysis point strongly to past fertilizer use and the source of increased soil P and P loads in surface runoff in the summer pastures relative to the winter pastures.

5.0 Implications of cattle stocking rate for ranching operations

The water quality data do not indicate that adjusting stocking density would be an effective tool for reducing nutrient loads but it is also essential to evaluate the effects of cattle stocking density on cattle productivity, forage utilization, and ranch economics. Even if stocking rate adjustment were an effective tool for reducing nutrient loads, it would not be a realistic option if it were not an economically viable option for ranchers. The effect of cattle stocking rate on these other aspects of the ranch system were evaluated with research partners from UF-IFAS and MAERC with funding from the USDA National Research Initiative Agricultural Systems Program. The key components of this project from a ranching operations perspective included forage availability and utilization, cattle productivity and health, and economics.

5.1 Forage availability and utilization

The stocking rate treatments had a significant influence on available forage in the summer pastures but not in the winter pastures (Tables 5.1 and 5.2). In the summer pastures, forage availability was lower at the high stocking density than the control in all years and greater than in the mid and low stocking densities in some years (Table 5.2). The decreases in forage availability at the high stocking density indicate that there was higher forage utilization at the high stocking density, which was true during some production cycles (Table 5.3). Overall forage utilization was relatively low, with a maximum utilization of 32% of available forage at the high stocking density in the fourth production cycle. Thus, the stocking rate treatments were well within the carrying capacity of the pastures. This result has important implications for interpretation of the water quality results because it shows that the highest stocking rate used in

Table 5.1. Effect of stocking rate treatment on average available forage at the start and end of winter grazing over four complete production cycles[a].

	Stocking rate treatment[c]			
Collection Time[b]	Control	Low	Medium	High
	kg/ha			
Start	3920	4520	4360	4550
End	2530	2040	2580	1810

[a]Stocking rate treatments; Control = no cows, Low = 2.16 ha/cow, Medium = 1.62 ha/cow, and High = 1.41 ha/cow.
[b]Collection times correspond to; Start = October, Middle = February, and End = April.
[c]Available forage was lesser at end of winter grazing (April) compared to the start (October); $P < 0.05$.

Table 5.2. Effect of stocking rate treatment on available forage during the summer grazing months over four complete production cycles[a].

	Stocking rate treatment[b]			
Annual Cycle	Control	Low	Medium	High
	kg/ha			
1	3560 [c]	2990 [c]	2620 [cd]	2240 [d]
2	3840 [c]	3680 [c]	3650 [c]	2720 [d]
3	2800 [c]	2660 [cd]	2350 [cd]	2050 [d]
4	3910 [c]	2390 [d]	2340 [d]	1840 [d]

[a]Treatment x Cycle; $P < 0.01$. Summer grazing months extend from April to September of each production cycle.
[b]Stocking rate treatments; Control = no cows, Low = 1.35 ha/cow, Medium = 1.01 ha/cow, and High = 0.58 ha/cow.
[c,d] Means within annual cycle and across stocking rate treatments differ, $P < 0.05$. Pooled SEM = 261.

Table 5.3. Effect of stocking rate treatment on average (middle and end) percent forage utilization during summer grazing.

	Stocking rate treatment[a]		
Annual cycle	Low	Medium	High
	%		
1	30.5 [b]	30.5 [b]	30.7 [b]
2	14.9 [b]	5.1 [c]	26.3 [d]
3	14.2 [c]	22.2 [bc]	30.9 [b]
4	24.7 [bc]	15.7 [c]	32.1 [b]

[a]Stocking rate treatments; Control = no cows, Low = 1.35 ha/cow, Medium = 1.01 ha/cow, and High = 0.58 ha/cow.
[b,c,d] Means within collection time and across stocking rate treatments differ, $P < 0.05$; Pooled SEM = 3.0; Treatment x Cycle, $P = 0.01$.

this experiment was lower than a stocking rate that could have been sustained on the summer pastures given the amount of available forage. Under the high stocking rate, which represents a realistic regional average for cattle ranches, heavy forage cover is maintained during the summer rainy season when most surface runoff occurs. The water quality results cannot be extrapolated to situations with much higher stocking densities, where problems of overgrazing or denudation might occur.

5.2 Cattle production and ranch profitability

The cattle stocking treatment did not have a large impact on cow body condition, which is a subjective scale to assess the overall condition of the cows. Cows entering winter pastures in 1999 had similar body condition across stocking densities (Table 5.4). However, cows assigned to medium and high stocking rates had lower body condition at the end of the winter grazing period. This difference in body condition declined following 98 days of summer grazing, as cattle assigned to medium and high stocking rates regained their lost body condition (Table 5.4), such that at weaning, cows from all stocking densities had similar body condition.

Table 5.4. Effect of stocking rate on cow body condition score (BCS).

	Stocking Rate[1]		
Item	Low	Medium	High
	---------------- BCS[2] --------------		
Enter winter pastures (November 1999)	5.0	5.0	5.0
Enter summer pastures (April 2000)	5.0 [a]	4.2 [b]	4.0 [b]
Weaning (Sept 2000)	5.6	6.0	5.9
BCS change in winter	0.0 [a]	-0.85[b]	-1.0 [b]
BCS change in summer	0.60	1.80	1.85

[1]Stocking rates of 1.42, 2.52, and 3.31 acres/cow on summer pastures and 2.28, 3.98, and 5.29 acres/cow on winter pastures correspond to high, medium, and low rates, respectively.
[2]BCS = cow body condition score based on a 1 to 9 scale (1 = emaciated and 9 = obese)
[ab]Means within stocking rate with unlike superscripts differ, P < 0.05.
[ab]Means with unlike superscripts differ, P < 0.05.

Table 5.5. Effect of stocking rate on calf performance during the summer months (average 1999 and 2000).

	Stocking Rate[1]		
Item	Low	Medium	High
	------------------ lb ------------------		
Enter Summer Pastures[2]	376	374	351
Weaning[2]	544	522	527
ADG	1.95	1.74	2.03
Production, lb/acre[3]	60.4 [a]	77.4 [b]	136.5 [c]

[1]Stocking rates of 1.42, 2.52, and 3.31 acres/cow on summer pastures and 2.28, 3.98, and 5.29 acres/cow on winter pastures correspond to high, medium, and low rates, respectively.
[2]All measures of calf data are adjusted for sex.
[3]Production / Acre = [weaning rate for all treatments x sex-adjusted calf gain * stocking rate / 130 acres.
[ab]Means with unlike superscripts differ, P < 0.05.

Calf performance during the summer grazing period was similar, irrespective of stocking rate (Table 5.5). Production, as measured by pounds of calf weaned per acre of dedicated land, was greater for high compared to medium and low stocking rates (Table 5.5). Stocking density had no impact on cow pregnancy rate.

The high stocking density used in this study is similar to typical beef cow/calf production practices in south Florida. At the stocking rates examined in this study, the high stocking rate supported similar cow and calf performance as the lower stocking rates. When pasture productivity was considered, the high stocking rate provided the most weight of weaned calf per unit of dedicated land. A change in stocking rate has a one-to-one relationship with ranch revenues. If stocking rates decrease by 10 percent, ranch revenues decrease by 10 percent as well. At the same time, unit cow costs increase at an increasing rate as fewer brood cows are left to support the ranch's fixed costs. Consequently, ranch profitability decreases as stocking rates decline.

6.0 Recommendations

The results of this BMP optimization project do not indicate that reductions in cattle stocking rate would provide any benefit to decreasing nutrient loads from cattle pastures in the Lake Okeechobee Basin. There was no difference in nutrient runoff in any year between pastures stocked at low, medium or high cow-calf densities, or control pastures with no cows. This project did not address the potential effect of high-density stocking or overstocked conditions and our results cannot be extrapolated to such conditions. However, stocking rates on most ranches are limited by forage availability in the dry season and ranches are stocked at rates lower than those that could be sustained on forage available in the summer, when most surface runoff occurs.

Lower cattle stocking rates reduced ranch profitability relative to higher stocking rates, indicating that it would not be economically feasible for ranchers to reduce cattle stocking rates unless they received some other economic incentive to do so. Producing the maximum number of calves under environmentally sustainable stocking rates is critical to maintaining profitable cow-calf operations. Our results provide no evidence that modifying this critical aspect of ranch profitability would decrease nutrient loads from cattle pastures.

The greater nutrient loads from improved summer pastures than semi-improved winter pastures, and the link between past phosphorus fertilizer use, accumulation of phosphorus in pastures soils, and increased phosphorus loads in surface runoff indicate that nutrient management has a larger impact than cattle management on phosphorus loading. The sandy soils in the Okeechobee basin generally have a low phosphorus binding capacity with much of the phosphorus occurring in an organic form, which readily releases soluble phosphorus into soil solution during flooding-drying cycles (Nair et al., 1998; Wetzel, 1998). Thus, accumulated phosphorus can be released into soil solution and become susceptible to loss in surface runoff even when pastures soils have the capacity to store more phosphorus. These results have relevance for the entire Lake Okeechobee Basin because there is still a net import of phosphorus into improved pastures in the Basin (Hiscock et al., 2003). Most of this phosphorus ends up on soils and sediments, where it has the potential to contribute to elevated nutrient loads in surface runoff for many years after net phosphorus imports are discontinued.

The results of the stocking rate experiment indicate that water quality BMPs focused on decreasing phosphorus inputs and decreasing movement of accumulated soil phosphorus into surface runoff would be more effective than BMPs focused on cattle management. Phosphorus budgets from the experimental pastures indicate that cattle can be produced profitably with a net export of phosphorus in calves. Thus, it may be possible to balance phosphorus budgets on cattle operations without affecting ranch profitability, although it is not certain whether these relationships would hold for all ranching operations in the region. Reducing phosphorus runoff, either by adding amendments to bind soil phosphorus, managing water to reduce total runoff or capturing runoff phosphorus in wetlands or other edge of farm treatments are among the possible approaches for reducing the movement of accumulated phosphorus into surface runoff.

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