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Circular 1177

Procedural Guide for the Development of Farm-Level Best Management Practice Plans for Phosphorus Control in the Everglades Agricultural Area[1]

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This guidebook was written specifically to address the concern of reducing phosphorus (P) loads in drainage water leaving the Everglades Agricultural Area (EAA). The information contained in this guidebook may be applied to any agricultural area composed primarily of organic soils or Histosols. However, ***please be aware that this information may not be applicable to any other soil types***. The reader is referred to Bottcher and Izuno (1994) for further water management, crop, soil, and environmental characteristics of the EAA.

Introduction

Heightened concerns in recent years about the impact of the quantity and quality of drainage waters from the Everglades Agricultural Area (EAA) on the Everglades have prompted the South Florida Water Management District (SFWMD) to develop both an EAA regulatory program and plans for a series of stormwater treatment areas (STAs). These efforts are the result of many years of study, debate, political wrangling, and complex litigation. The intent of these programs is to ensure that water quantity and quality in south Florida are preserved and conserved to serve all interests.

Initially, abatement program efforts were centered around the SWIM (Storm Water Improvement and Management Act) plan, a program being developed for the Everglades by the SFWMD. In 1988, however, the SWIM process was overshadowed by a lawsuit filed in Miami Federal District Court. The passage of the Marjory Stoneman Douglas Act in 1991 was critical to the resolution of the lawsuit by defining how some of the settlement requirements might be met and funded. This lawsuit resulted in a July 1991 settlement that directed the SFWMD to design and install STAs, and to develop and implement a regulatory program (EAA BMP Rule). The BMP Rule requires that all farmers in the EAA basin implement farming practices to reduce the P discharge from their properties to achieve a P load reduction at the SFWMD pump stations along the southern border of the EAA. These farm water quality practices are known as "best management practices" or BMPs.

The BMP Rule requires that the BMPs reduce the amount of total-P in drainage water leaving the EAA by 25% before it enters the STAs. The STAs will then have to reduce the total-P discharge further to obtain a reduction of 75% as stipulated in the lawsuit settlement. The P reduction will be measured against the historical total-P load for the baseline years 1979 through 1988.

This guidebook describes some of the BMPs that are appropriate for implementation in the EAA in terms of design, installation, management, and P reduction potential. Because only a limited number of BMPs have

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been studied to date (1995), and because BMP technologies from other areas cannot be directly transferred to the EAA, this guidebook will be limited to discussions of how to get started with BMPs. **It is important to note that field and farm-scale evaluations of BMPs are currently being done. Therefore, the quantitative effectiveness of the BMPs at these levels are not yet known.** As research and other monitoring data become available, the BMPs will be refined and presented in greater procedural detail in future revisions of this guidebook. Despite the aforementioned limitations, this guidebook should be a useful tool in the development of BMP plans to meet the requirements of the BMP Rule for reductions in P loads leaving the organic soils of the EAA.

Note that the BMPs in this guidebook currently pertain only to P load reductions. While other Class III water quality standards may be positively affected by the BMPs described herein, the effects of BMP implementation on those standards have not been evaluated to date (1995).

What are BMPs?

"Best management practices", used in context with the EAA, are those on-farm operational procedures designed to reduce P losses in drainage waters to an environmentally acceptable level, while simultaneously maintaining an economically viable farming operation for the grower. Practices that have a high potential for negatively impacting the financial profitability of a farm are not, therefore, considered to be BMPs. In cases where the economic price of implementing certain BMPs puts an excessive financial burden on the farmer, such practices could only be considered BMPs if external funds were available to return an acceptable profitability to the farm.

It is important to note that the above definition is not the same as the one given in the SFWMD's BMP Rule. The Rule definition is specific to practices that will reduce P levels by 25%. The Rule does not adequately take into account profitability. However, it is clear that if profitability is not maintained, the practice itself cannot be maintained. Therefore, the reader is cautioned that the practices presented in this guidebook, though labeled as BMPs, will only be BMPs for an operation if they can be implemented on the particular farm in an economically viable fashion.

Water Quality Design Criteria for BMPs in the EAA

The overall design criteria for implementing BMPs in the EAA should simply be to minimize the amount of P leaving a farm at resonable cost. Though the BMP Rule has targeted a specific level of P reduction, it is in the best interest of all parties to maximize P reduction to the greatest extent possible. Phosphorus reduction levels greater than the 25% BMP Rule criterion will serve to reduce costs of the STAs and enhance the environmental/political image of the EAA. Credits can also be "earned" by growers who achieve P load reductions of 40% or more.

As previously mentioned, the EAA BMP Rule, which is actually the Regulatory section of the Everglades SWIM Plan, requires that by 1996, BMPs reduce the total-P delivered to the Everglades system from the EAA by 25%. This reduction is required only for water generated within the EAA. Pass-through water from Lake Okeechobee to the Water Conservation Areas (WCAs) will be handled separately by the STAs.

Verification of a reduction in P load will be based on the comparison of adjusted annual P load measurements with historical load measurements for the years 1979-1988. Future annual loads will be adjusted for differences in land area (land taken out for the STAs) and in rainfall variations from the 1979-88 base period. In this way, valid comparisons can be made.

The P load reduction comparisons can be made only at *EAA basin outlets* (S2, S3, S5-A, S6, S7, S8, and S100) because no historical data are available for individual farm discharges. Compliance with the BMP Rule will, therefore, be judged at the EAA basin level, requiring that the net impact of all the BMPs within the basin reduce P loads by 25%. For this reason, the BMP Rule is primarily an implementation rule in that it requires BMP plans for each farm to be developed and implemented within a given time schedule. Failure to implement BMPs would result in enforcement penalties/fines. Furthermore, if basin compliance is not met, specific water quality load standards could be set for each individually permitted farm discharge point. Non-compliance at the basin level will necessitate the revision of each BMP plan, additional BMP implementation, and updated scheduling and enforcement requirements.

An early baseline option was made available to growers wishing to use a farm-level measured baseline P load to be judged against, instead of the 1979-88 basin-wide baseline. However, to take advantage of the early baseline option, growers had to start monitoring operations at an earlier date. Additionally, there was some question as to how the early baseline data would actually be used, as well as the validity of using a single year's data.

Background for Using the BMPs in This Guidebook

Before implementing or evaluating the applicability of the BMPs suggested herein, a person must consider the following points.

Uncertainty of BMP Effectiveness Ranges

Each BMP presented in this guidebook is provided with an estimated range of the P reduction percentage expected when implemented in the EAA. When applying these reduction ranges, it is necessary to understand both what they represent as well as their uncertainty. Only three of the listed BMPs have been field tested, and these were tested for only a limited set of conditions. Therefore, most of the stated P reduction ranges were based on corollary data and basic knowledge of the physical and chemical processes occurring in the EAA. The presented BMP effectiveness (%P reduction) ranges include this uncertainty. These ranges also reflect the variability in existing conditions between farms in the EAA. Farms implementing a BMP for the first time can expect to experience the full benefit of that BMP, whereas those farms already conscientiously and correctly practicing a specific BMP should, of course, expect no additional P reduction due to continued use of that BMP. As more data become available, these ranges will be narrowed appropriately.

Concentration Versus Flow Control for Phosphorus Load Reductions

Best management practices are designed to reduce total-P loads by either reducing the volume of water discharged, reducing the concentration of P in the water, or both. The fertility and fertilizer BMPs were designed to reduce P concentrations, whereas the water management BMPs were developed primarily to reduce the net water discharge from a farm, though some P concentration reductions should also be realized.

The relative acreage to which various BMPs can be applied is extremely important for determining the basin level impact of a BMP. For example, BMPs targeted to reduce total-P concentrations will be most effective for heavily fertilized crops and low oxidative soils. Although these conditions represent only about 15% of the entire EAA basin, these crops generally require higher levels of drainage that can greatly increase the P loads. Therefore, P concentration reduction BMPs could have major or minor basin level impacts. Because of this, it is estimated that about 5-15% out of the proposed 25% decrease could be achieved by P concentration reductions. The remaining 10-20% would be directly attributed to drainage volume reductions.

Note that the above percentages are only estimated limits for achieving the 25% Rule criterion and are not the limits of a fully implemented BMP program. Such a program could potentially produce P load reductions of up to 60%. The actual percentage attributed to concentration versus volume reductions will depend on the farm-level selection of BMPs.

Basin Response to Farm Level BMPs

The total-P load reduction ranges presented here are for the responses expected from individual farming systems with only a single crop, fertility, and water management system. Therefore, the combined impact of BMPs across a large farming operation, or the entire basin, must be corrected for the percentage of land that each unique farming system represents within that larger area. The farm-scale P reduction ranges are based on a combined analysis of several studies. None of these studies, however, included farm-scale experiments. The presented ranges, therefore, cannot currently be proven on the basis of scientific data.

Based on individual BMP effectiveness ranges, Izuno and Bottcher (1991) estimated that the overall range of P reduction that could be achieved in the EAA basin was between 20% and 60%. This range reflected their opinion of what could be achieved at a reasonable cost (20% reduction figure) and, in addition, what might be realized at a higher, unknown cost (60% reduction figure). Though a 40% or greater P load reduction might reasonably be expected through implementation of BMPs, assurances cannot be given that these levels could be accomplished within the previously stated definition of a BMP (i.e. a practice which reduces farm discharge P loads while maintaining the economic vitality of the farm).

Impacts of BMPs on Crop Yields

The BMPs presented in this guidebook are designed to have minimum negative impacts on crop yields. The reader, however, is cautioned that data currently available on yield impacts remains limited. Therefore, any implementation of BMPs must be done with a cautionary approach. ***Sudden, large changes in farm operations are not recommended***, especially in regard to water retention. Practices of this kind should be implemented in a step-wise fashion so that an understanding of both the nature of the BMP as well as its impact on yields can be properly assessed by the growers. It is important for farm operators to learn the full operational responses of any single BMP with a multitude of conditions before attempting to carry out any further large scale activities.

Accumulative Effects of Multiple BMPs

The presented reduction ranges are not necessarily cumulative for multiple applications of BMPs. The effectiveness of any one BMP may be significantly reduced, or eliminated, by the additional implementation of another BMP. Hence, the influences on farm operations, soil and crop nutrition, and hydraulic characteristics of an existing BMP must be taken into account when considering supplementary BMPs. This is particularly true for BMPs in the same category, such as those dealing with flow reduction.

Reduced Drainage Versus Water Supply

There is some concern that the regional water supply might be negatively impacted if proposed BMPs significantly reduce the amount of water being pumped from the EAA farmlands. It is important to note that BMPs can only impact regional water supplies if they increase evapotranspiration (ET) from the farm. Since ET is expected to increase only when the water retention BMPs are being used (and then only slightly), the question becomes: "What happens to the water that is no longer being pumped?". The answer is that it will still be in Lake Okeechobee because the majority of the reduced drainage will be directly reflected in reduced irrigation demand by the farms. The water in Lake Okeechobee will continue to be available for regional water supply. Off-setting existing EAA drainage water with pass-through Lake water represents about a 50% reduction in P loading to the STAs. It is worth noting that, given these conditions, the STAs will likely have significantly higher ET rates than existing land uses, resulting in a net regional water supply loss.

Best Management Practices for the EAA

A. Fertility and Fertilizer BMPs

A-1: Calibrated Soil Testing

Depending upon current practices, using a Calibrated Soil Test (CST) procedure could potentially reduce P discharge loads from 0-25% for an individual vegetable grower and 0-10% for a sugarcane farmer. This procedure simply reduces the potential of over-fertilization of the soil due to the absence of soil testing, inappropriate soil testing, or inappropriate fertilizer recommendations.

Calibrated soil testing provides fertilization recommendations based on yield response curves developed by correlating soil nutrient levels measured in laboratory soil extractants with field-measured yield responses to different fertilizer application amounts. The term "calibrated" refers to the fact that the actual laboratory P level measured in the soil is calibrated to an actual production field yield response for the crop of interest. Soil testing laboratory recommendations should be based upon the use of a CST for the soils and climatic conditions of the area. Use of extractants that may be calibrated for other sections of the country are not appropriate. Within the EAA, the University of Florida has expended considerable efforts in calibrating a water extractable phosphorus (Pw) procedure to crop response for these organic soils. At this time, no other CST exists. Laboratories offering this CST should also be using the most current interpretations and recommendations for this extraction procedure. The Institute of Food and Agricultural Sciences (IFAS) Soils Testing Laboratory at the Everglades Research and Education Center (EREC) uses a CST for crops where sufficient data are available.

To determine if you and your soil testing service are using an appropriate CST procedure, compare it to the following.

Calibrated Soil Testing Procedure

Step One: Development of a consistent and representative soil sampling procedure is critical to all CSTs. The soil samples being sent to the laboratory must be representative of the actual field condition. Soils naturally have high spatial variability for many of the soil parameters, including extractable phosphorus levels. Therefore, multiple soil samples from the root zone should be taken randomly throughout a field (single management unit) to account for this variability. If the field is known to be uniform in soil type, water management, and cropping history, then the subsamples can be thoroughly mixed together for a single sample to represent of the entire field. If uniform conditions cannot be established for a particular field, then testing of additional samples (still with subsampling) for various subsections of the field should be carried out. Areas with different cropping and management histories, and soil types, should always be sampled separately. Until sampling data are available to prove the uniformity of a management area, sampling should be done for areas no greater than a 0.25 section, and preferably at the 40-acre block level.

Banding of fertilizers typically does not interfere with the use of a CST. For the most part, practices include tillage after harvesting a crop that has received banded fertilizer placement. This practice usually mixes the soil sufficiently so that the bands are no longer a concern. The use of beds for lettuce production, a crop exhibiting definite P discharge reductions when fertilizer is band applied (about 50%), requires extra soil mixing when the beds are destroyed. Cross-directional cultivating of the fields should be sufficient.

Step Two: Development of yield response curves is the most costly and time consuming phase in the development of a CST. It is also the most important phase. The curve is developed by conducting multiple field fertility experiments on fields/plots that have had soil sampling done prior to fertilization. It is best to use several groups of fields/plots with different pre-fertilization soil P levels (ranging from very low to very high) and to have enough fields/plots within each soil P level to determine an accurate yield response curve. Examples of yield response curves for two pre-fertilization soil P levels are shown in Figure 1.

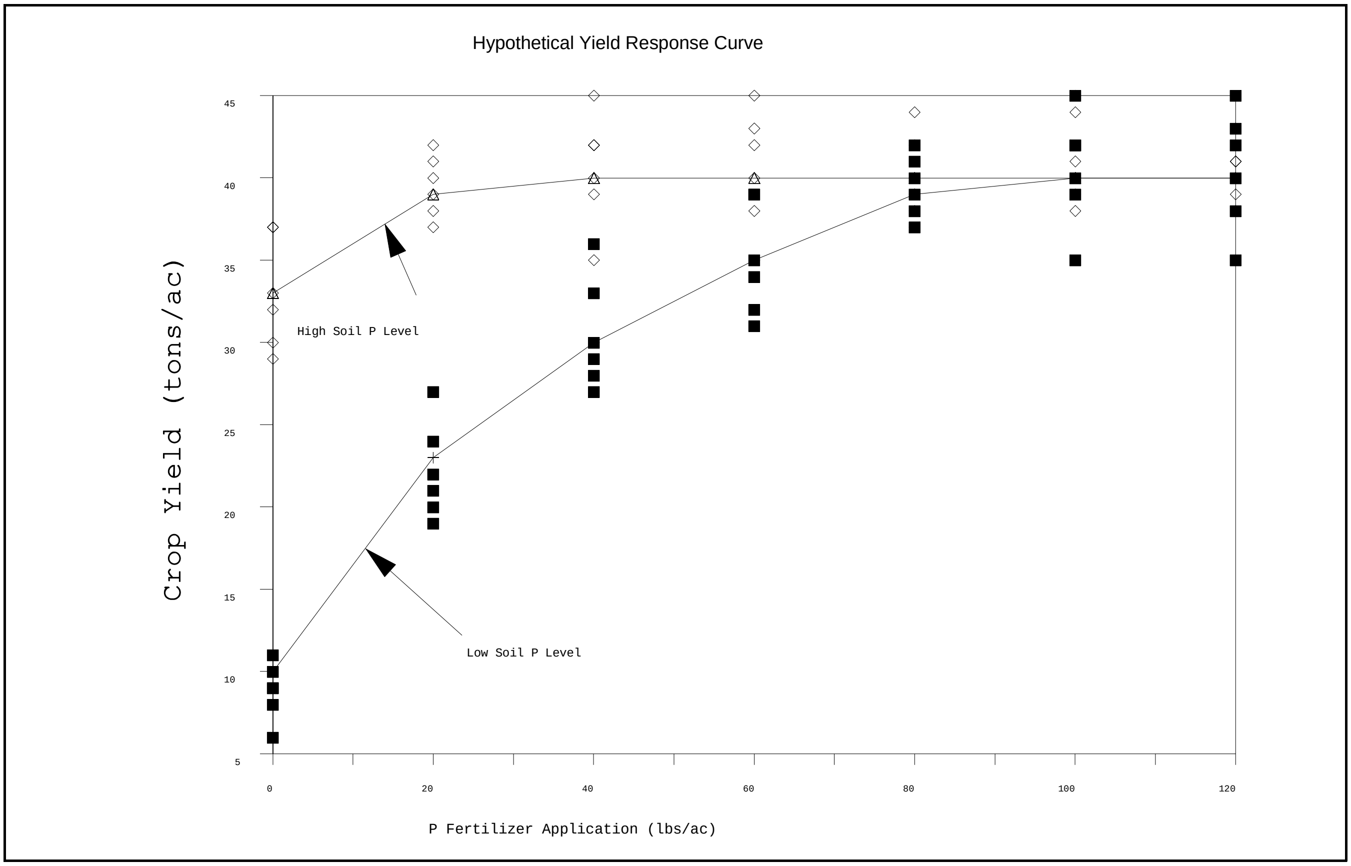

Figure 1. Hypothetical crop yield response for P fertilization for two given soil P levels.

The crop yield response shown in Figure 1 illustrates the problems that can be associated with interpreting the data. The line for each pre-fertilization soil P level in Figure 1 is a linear connection of the means. However, the current "best approach" is believed by many to be the use of both a linear plateau and a simple quadratic regression. The zone of P rates within the critical point of the linear plateau model and the maximum of the quadratic model contains the lower and upper bounds, respectively, for a P recommendation. Rhoads and Hanlon (1990) tried a probability-of-response approach with snap beans and determined that the current interpretation and recommendations (Hanlon et al., 1990) were appropriate.

The bottom line is that the data variability within response curves prevents accurate interpretation of an optimal fertility rate which ideally would be based on the point where the marginal cost of fertilization becomes equal to the marginal revenue from increased yield. An accepted procedure (used by the IFAS Extension Soil Testing Laboratory in Gainesville) is to plot soil test levels versus crop response starting at the 0 P rate (this curve would look very much like those in Figure 1 with soil test level/applied fertilizer amount on the x-axis). The soil P levels are grouped into ratings of "very low, low,....,high, very high" and specific recommendations are made for individual crops.

Another approach would be to plot the optimal or "best approach" fertilization rate from each of the individual yield response curves (Figure 1) against the pre-fertilization soil-test P level to produce the CST response curve (Figure 2).

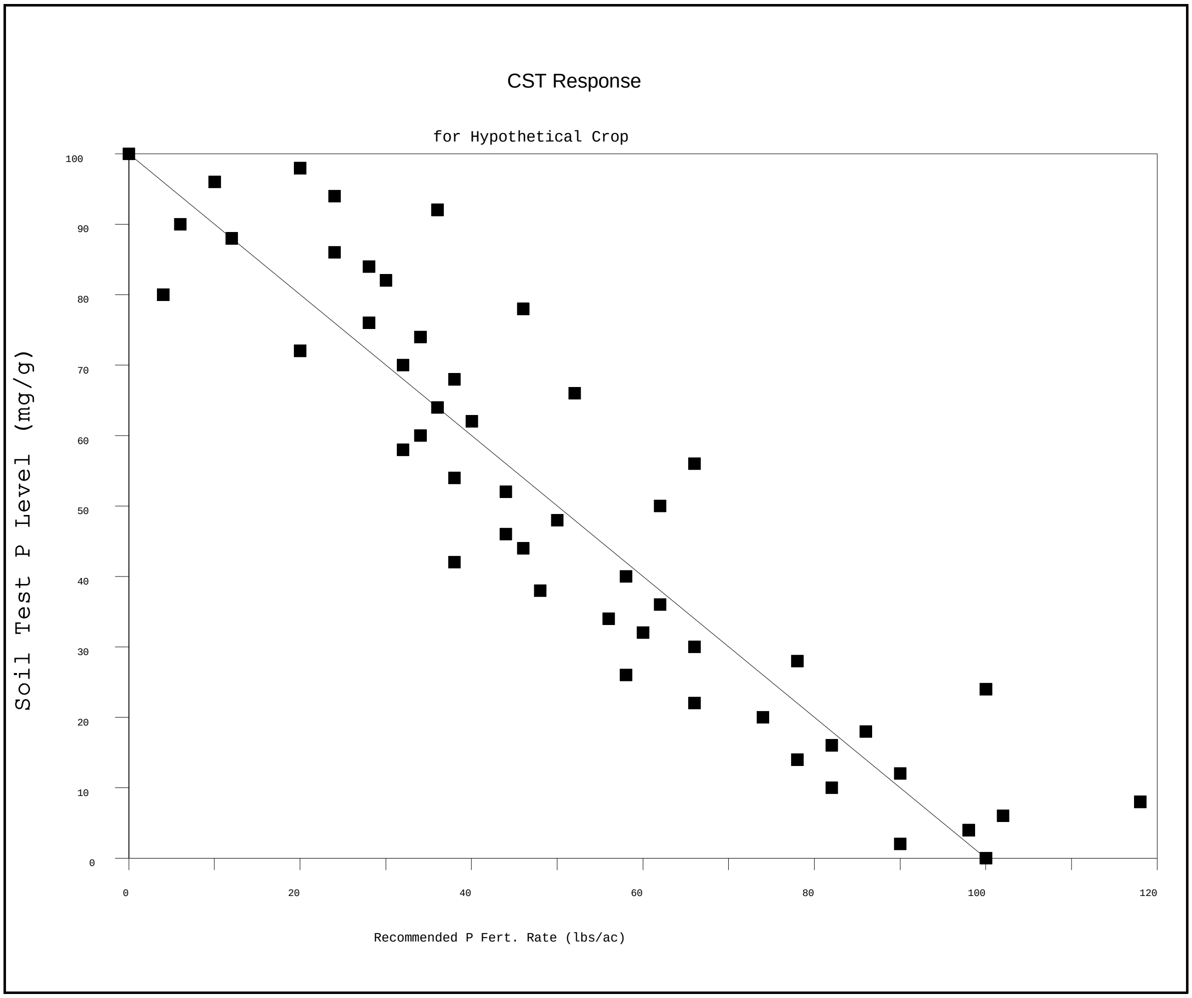

Figure 2. Hypothetical calibrated soil test (CST) response curve to provide optimal yield response for a given soil test level.

The line in this CST curve implies an accuracy greater than is known, so grouping into ratings as above is still necessary. This approach differs only in the presentation. Both approaches use the philosophy of fertilizing the crop and not the soil. The CST response curves determined by either approach can then be used to make future fertilizer recommendations based on soil-test values and crop type alone. It is important to re-emphasize that the optimal fertilization rate occurs not where the yield is maximized, but rather, where the marginal cost of adding more fertilizer equals the marginal revenue gained by the increased yield. This point will always be reached before the maximum yield is attained. However, due to the uncertainty in the CST curves, it is generally better to select the optimal fertility rate as the point where the yield response curve begins to flatten out which is more specifically defined in the "best approach" discussed above.

The appropriate laboratory soil-P extraction procedure for estimating the actual amount of P in a soil sample available to a crop varies according to soil properties. The CSTs have been developed for mineral soils using the Mehlich-1 (double acid) extractant, and for organic soils using a water extraction (Pw). Using Pw on mineral soils is not recommended by IFAS because it has not been calibrated. Using Mehlich-1 on organic soils is not recommended by IFAS because it has been only marginally calibrated. Espinoza (1992) found that the Mehlich-3 extractant might be better than either the Mehlich-1 or Pw, but additional work is needed.

For further information on soil testing, contact the Soil Testing Laboratory at the EREC in Belle Glade. Specific soil sampling, soil testing, and fertilizer recommendations can be found in Circular 817 (Hanlon et al., 1990) and the Sugarcane Growers Newsletter by Coale (1989).

A-2: Banding Fertilizer

Banding fertilizer applications instead of broadcasting could reduce P losses by 0-40%, and application rates on the order of 50%, dependent upon the crop and existing soil fertility levels. Banding refers to the placement of fertilizer in a strip or band adjacent to the crop roots. Protection from adverse chemical reaction with the soil, poor root uptake due to root morphology, and reduced leaching with smaller, lower-P-rate zones are the reasons for banding. Banding will be most effective for crops such as vegetables and sugarcane that do not have continuous root mats between rows.

The primary impediments to banding are the cost of obtaining or developing banding equipment which will properly deliver fertilizer without injuring the plants and the development of CST fertilizer recommendations for each crop. It is important to note that an appropriate CST must still be used to assure proper application levels. Residual fertilizer bands could also cause future soil testing problems if post-crop tillage does not sufficiently mix the soil.

Background to Banding of Fertilizer

Banding can be implemented at different levels of intensity and by different mechanical techniques. Available banding techniques range from single pre-plant applications to post-plant side-dress application(s) after a pre-plant broadcast application, and to banding for both pre-plant and post-plant conditions. Side-dress banding is the most common technique currently in practice. Extending banding to the pre-plant condition is more difficult. Typically, side-dressing places the fertilizer on the soil surface (mechanically easy to accomplish). Pre-plant banding, on the other hand, ideally places the fertilizer in a band below the soil surface. Getting the pre-plant band in an optimal position in relation to the plant roots to obtain uniform distribution within the band requires precise field equipment. Additionally, the optimal positioning and sizing of the pre-plant band is not fully understood for many crops due to the different abilities of plants to adapt their roots to utilize the band. However, the current general understanding is sufficient to reduce P fertilizer application rates dramatically. As additional information on pre/post-plant banding techniques becomes available, the P application rates will likely be able to be reduced even further.

Generally, standard soil sampling techniques utilizing a CST are appropriate for pre-plant conditions. The pre-fertilization soil test, the so called predictive soil test, is used to assist with the need for, and rate of, fertilization for a crop to be grown. Soil sampling techniques for post-plant conditions, the so called diagnostic test, require limiting randomized subsampling to the active root and banded zone. Post-plant soil testing has not been promoted primarily because tissue testing is a more reliable indicator of the nutrient status in the field. Further, diagnostic soil testing cannot be interpreted accurately because data for such sampling are limited, and in organic soils, the seasonality of mineralization rates is unknown.

The residual effects of previously banded fertilizer applications have not been documented to create significant non-uniform soil fertility conditions in a field for the next crop. Subsequent tillage normally mixes the soil sufficiently. Matching subsequent crop pattern to residual bands might be possible but has not been studied. Further, matching crop patterns to residual bands may not be desirable.

Getting Started With Banding

The following procedure is suggested to make the transition from broadcast to band fertilization. ***Sudden, large changes in farm operations are not recommended***. It is important to gain further experience with the BMPs to gain confidence and prevent undesirable problems.

Step One: Contact the University of Florida (UF)-Institute of Food and Agricultural Sciences (IFAS) crop specialist at the EREC-Belle Glade or at the Palm Beach County Extension Offices (West Palm Beach or Belle Glade) to obtain the latest information on banding for the crop of interest. Specific information for lettuce and sweet corn have been reported by Sanchez et al. (1990 and 1991) and Hocmuth et al. (1994). If information is not available, or is too limited for your use, continue with Steps 2 and 3.

Step Two: Selection of banding equipment is the first step in developing an effective fertilizer banding program. Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7 show the common types of banding equipment. This equipment can be used independently or in combination with other field equipment such as planters, cultivators, tillers, or sprayers. Whenever possible, fertilizer banding equipment should be incorporated with other equipment to minimize field operations.

Phosphorus fertilizer can be applied in either a liquid or granular form, though the liquid source is typically more costly. Liquid fertilizers require a positive displacement pump to assure uniform application which, typically, is better than the more prevalent granular spreading systems. Granular spreaders use a slotted rotating drum or disk system to dispense the granules. Once applied to the soil, fertilizer uniformity within the band will also vary according to the form. Liquids tend to form nutrient rich fingers along macropores in the soil after application as a function of moisture content, soil type, and structure. Granular forms, on the other hand, will not spread as quickly and will, therefore, tend to release the P to the surrounding soil more slowly.

There will obviously be a balance between uniformity of application and the cost of the application equipment. Therefore, the value of the crop and its sensitivity to banding must be considered when selecting equipment. The uniformly tilled banding system is the most expensive, while the surface strip applicator is the least expensive. If the appropriate field equipment for your condition cannot be determined from the available literature, then field tests are needed. Field testing basically requires that various application techniques be used in randomized replicated plot experiments. The specifics of setting up field trials will not be described here, but can be obtained from a UF-IFAS crop specialist.

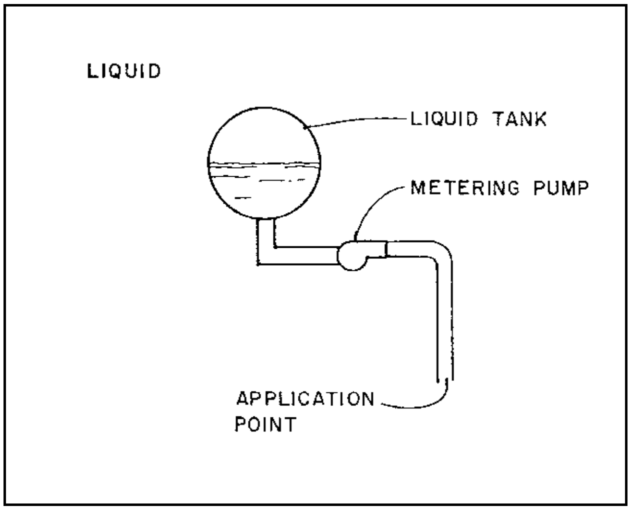

Figure 3. Liquid delivery system.

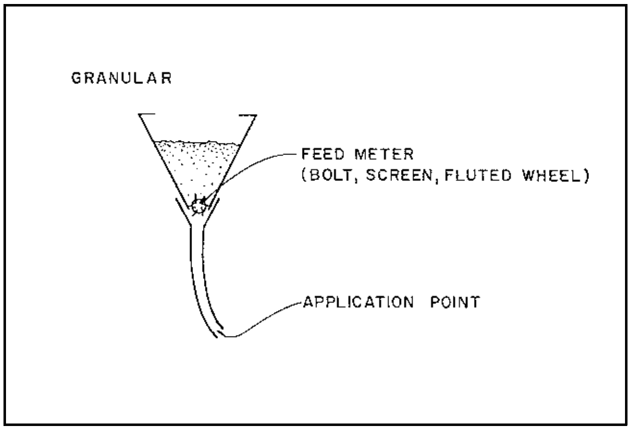

Figure 4. Granular delivery system.

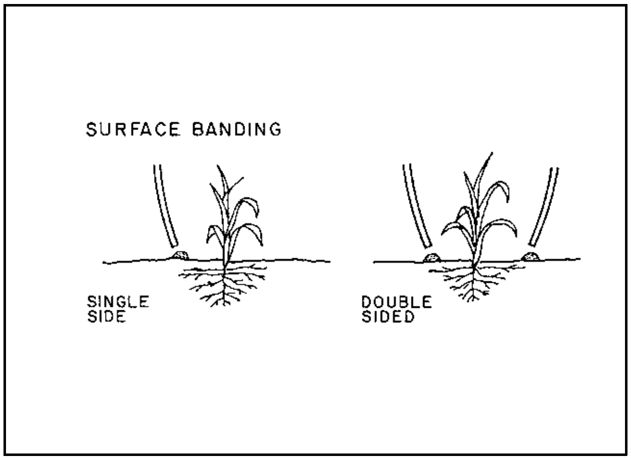

Figure 5. Common types of ground banding equipment: surface banding.

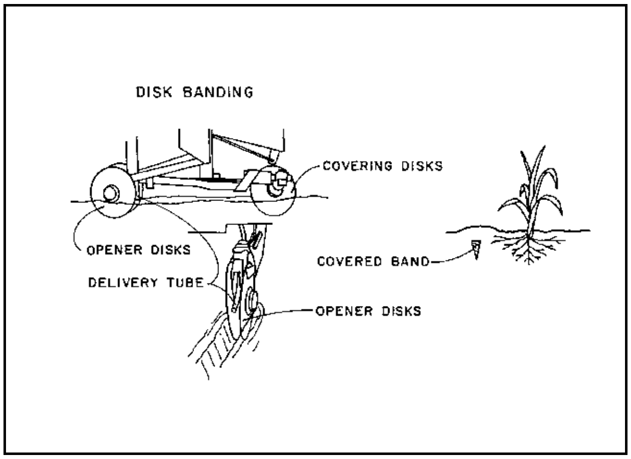

Figure 6. Common types of ground banding equipment: disk banding.

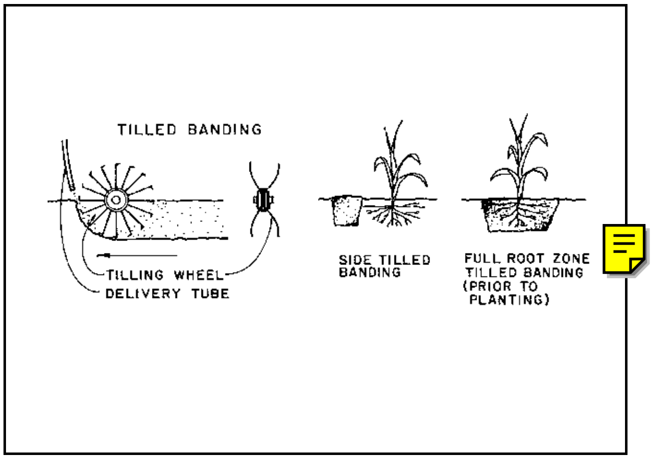

Figure 7. Common types of ground banding equipment: tilled banding.

Step Three: Once the equipment and application techniques have been selected, it becomes necessary to run standard fertility trials to determine the CST response curves for the particular crop and soil conditions. The problems described earlier concerning soil sampling and residual fertilizer must be considered during these fertility trials. Again, to get details on the appropriate procedures for conducting the field trials, contact a UF-IFAS crop specialist.

A-3: Prevention of Misplaced Fertilizer

Preventing fertilizer spills and avoiding the direct spreading of fertilizer into drainage ditches could reduce P losses by 0-15%. As little as 8 ounces of P per acre in drainage water can be viewed as a pollution problem given current levels being discussed. Because of this, it is critical to minimize, if not stop, any direct application of P fertilizer to farm water conveyance structures whether they are dry or filled with water. Once P is dissolved in surface waters, there are very few options available for removing it. This condition differs considerably from the alternative possibilities of removing P while it is still in the soil/plant system. Keeping the P in the field, therefore, can significantly reduce the quantities of P leaving the farm. Also, when a large amount of P fertilizer is spilled in one spot on the soil surface, excessive P losses will result because soil P concentrations will then exceed plant uptake and soil adsorption capabilities. Eliminating equipment leaks and inadvertent spills in loading/staging areas and on roads, and employing proper clean-up procedures, will also help greatly to reduce farm P discharge loads.

Proper training of the field operators responsible for handling, loading, and operating fertilizer spreading equipment, and the correct maintenance of field equipment can help to eliminate the spilling of P fertilizers in undesirable locations and the spreading of P into open waters. The spreading of fertilizer directly into field ditches can also be controlled by using side-throw fertilizer spreaders along drainage ditches or appropriately spacing the drive lanes to prevent fertilizer from reaching ditches (Figure 8 and Figure 9).

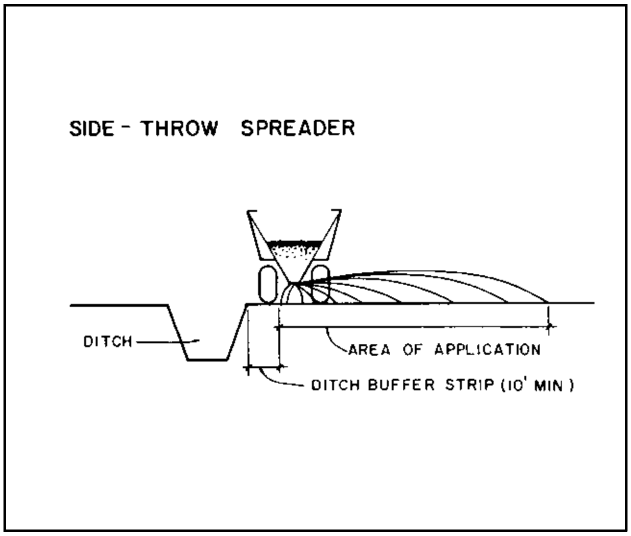

Figure 8. Proper fertilizer spreading techniques near open water ditches: side-throw spreader.

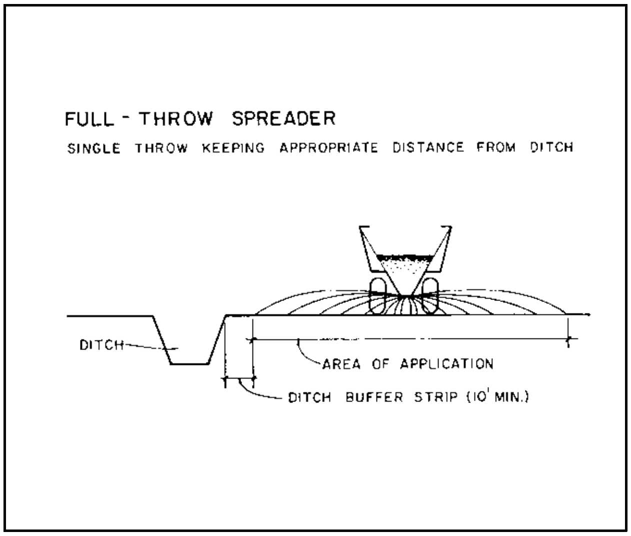

Figure 9. Proper fertilizer spreading techniques near open water ditches: full-throw spreader.

Particular care is needed when making end turns because of the opportunity they afford to double apply or repeatedly reach field head ditches. Special broadcast spreaders that use air pressure to expel granular fertilizer through orifices in a boom, with deflector plates at the boom ends, enable an applicator to fertilize a field uniformly and precisely.

Aerial applications of P make it more difficult to keep fertilizer out of ditches, but better control can be achieved by proper flagging and pilot awareness of the environmental issues.

A-4: Split Application of Fertilizer and Use of Slow Release Forms

Split applications of P fertilizers and the use of relatively slow release forms have limited application for field crops in the EAA. Only under special conditions, such as intensive vegetable or sod production, would split applications of P even be considered. These conditions would normally only require a single split application. Slow release forms of P, such as rock phosphate, are not readily available and are typically inefficient with respect to providing for plant needs. Additionally, the guidelines for the proper use of this P form have yet to be developed and benefits scientifically proven in the EAA. Therefore, split applications and slow release P forms would have limited applicability in the EAA, except for the special cases mentioned above. For these special cases, P losses could be reduced anywhere from 0-5%.

Split application and slow release techniques are much more applicable to nitrogen fertilization on mineral soils. For a general discussion of nitrogen and other fertility topics, please read IFAS Circulars 816 (Bottcher and Rhue, 1983) and 817 (Hanlon et al., 1990).

B. Water Management BMPs

B-1: Minimizing Water Table Fluctuations

Minimizing downward water table fluctuations in vegetable and sugarcane fields could reduce P losses for individual farms by 0-50%, depending on existing conditions. This BMP relates primarily to stopping the over-drainage of the organic soils. Preventing the water table from dropping below a minimum level will limit the amount of P being mineralized. Temporary upward fluctuations of the water table during certain periods of the growing season are acceptable, especially after rainfall events to limit or prevent pumping.

Water table control relates both to the temporal (over time) variations of the water table at a given location on the farm as well as to the spatial (across farm) variations throughout the entire farm and between different farm locations at any given time. Temporal variations can best be managed by improving the operational schedules for both drainage pumps and irrigation inputs since pump scheduling can also influence P concentration. For example, aside from a potential initial slug discharge of particulate-P at the beginning of a drainage event, water discharged early in a drainage event is often of better quality than the water discharged later in the event. Spatial variations can be managed most efficiently by having sufficient hydraulic capacity in the canal system and by using both flashboard culverts and laser leveling. Higher pump and conveyance system capacities may be needed to eliminate the practice of dropping water tables below minimum levels prior to storm events to assure adequate drainage capacity after the storm. Each of these water table management options and related crop management concerns will be discussed below.

Optimal Water Table

Drainage and irrigation schedules should focus on maintaining a water table that will provide optimal crop production while simultaneously minimizing water quality impacts. Suggested minimum rooting depths for various crops are provided in Table 1. For water quality control, the *minimum* rooting depths in Table 1 should also be considered the *maximum depth.* Ideally, the water would be maintained exactly at this depth at all times. Obviously, such water table control is impossible. Therefore, a reasonable management scheme would be to minimize fluctuations around the optimal water table depth.

Allowable Water Table Fluctuations

Crop roots will adapt and grow to fill the aerated soil profile above the water table. Short-term downward fluctuations of the water table can create the situation where a larger volume of aerated soil exists than can be used by the crop roots while at the same time it is increasing the risk of water stress. In addition to the lower water table adversely impacting crop production, the additional aerated soil volume will increase soil mineralization rates and related nutrient releases. Downward water table fluctuations, therefore, should be prevented if at all possible.

Upward fluctuations of the water table, on the other hand, can saturate a portion of the root zone which will limit mineralization, but can also adversely impact crop growth. The impact of temporary root saturation on crop growth is a function of the crop, temperature, soil, crop maturity, as well as of the degree, frequency, and duration of saturation. Table 2 provides the relative maximum time to allow for the full drainage of the active root zone of major EAA crops after a rainfall event. The table reflects the most crop sensitive condition. Adjustments to these values should be made based on individual farming conditions, if known. Table 2 also reflects the potential urgency of dropping the water table based on the percent of the root zone saturated after a drainage event. Since a higher water table does have the advantage of reducing mineralization of the soil, the draw-down of an upward fluctuation should be delayed to the maximum allowable time shown in Table 2. This practice will also reduce pumping volumes. Obviously, knowledge of the actual water table location in the field is mandatory for proper management. The use of water table observation wells is highly recommended.

Table 1. Minimum water table depths for maximum yields in the EAA (adapted from Snyder et al., 1978 and 1987, and Coale, 1988).

Crop	**Water Table Depth**	
	cm	**in.**
Snap Beans	45.7-61.0	18-24
Cabbage	45.7-61.0	18-24
Cauliflower	61.0	24
Celery	61.0-76.2	24-30
Sweet Corn	76.2-91.4	30-36
Lettuce	45.7-61.0	18-24
Onions	45.7-61.0	18-24
Peas	45.7-61.0	18-24
Potatoes	45.7-61.0	18-24
Tomatoes	45.7-61.0	18-24
Escarole	61.0-76.2 est.	24-30 est.
Endive	61.0-76.2 est.	24-30 est.
Radishes	35.6-40.6 est.	24-30 est.
Parsley	35.6-40.6 est.	24-30 est.
Sod	45.7-61.0 est.	18-24 est.
Sugarcane	61.0 est.	24 est.

Table 2. Maximum allowable time (days), as a function of the percent of root zone saturated, to fully drain the root zone after a rainfall event[1].

Crop	**100% Saturated**	**50% Saturated**	**25% Saturated**
Vegetables	0	.5	1
Sod	2	4	8
Sugarcane	5	9	14

[1] Current data do not exist for these crops. The values were generated by the the EAA Environmental Protection District and IFAS experts. The data should be considered advisory only and should be used with caution.

Individual growers should experiment on small areas of their farms to determine the saturation sensitivity for their individual crops because saturation sensitivity can vary significantly between farms.

Temporal Water Table Control

Temporal water table control means keeping the water table as close as possible to the optimal water table over time. Temporal variations can best be managed by improving the operational schedules for both drainage pumps and irrigation inputs. Operational schedules need to address the following parameters:

1) predicted rainfall;
2) actual rainfall (measured on farm);
3) pump/irrigation capacities;
4) crop susceptibility to water stress;
5) hydraulic capacity of ditch/channel system;
6) in-field as well as ditch water levels; and
7) seepage.

Pump operation schedules should be varied according to these parameters in a sophisticated fashion. For example, high discharge rates may be necessary at the beginning of high volume and intensity rainfall events, whereas during smaller storm events, pump start-up may need to be delayed to determine if it is even necessary to pump. In all cases, it is critical that the operational schedule terminate drainage discharge before the water table is dropped below the optimal level.

Temporal water table control can best be achieved by developing relationships between farm inflow and outflow rates versus the water table response interior to a specific field. These water table response relationships can be determined by plotting pump and irrigation flow rates against water table levels recorded within the fields. Examples of typical response curves are provided in Figure 10. The most useful water table response relationships would be for the two extremes where there is either the maximum (wet and draining) or minimum (dry and irrigating) available water condition in the soil profile. Field ditch water levels can be used as rough estimates of in-field water tables, but using data from water table wells in the fields is strongly recommended. Additionally, placing several field water table indicators or recorders throughout the farm will allow for the determination of the spatial variation of water table responses across a farm. Spatial water table control is discussed in the next section.

It is important to note here that the water table response curve for both drainage and irrigation will be significantly affected by seepage into a farm. In areas with severe seepage problems, irrigation input may never be needed because irrigation demand can be met or exceeded by seepage (sometimes requiring inordinate amounts of drainage pumping). During storm drainage, higher discharge rates must also be used to compensate for the additional water. Water table response curves similar to those depicted in Figure 10 can be achieved for high seepage areas, but at a high water management cost.

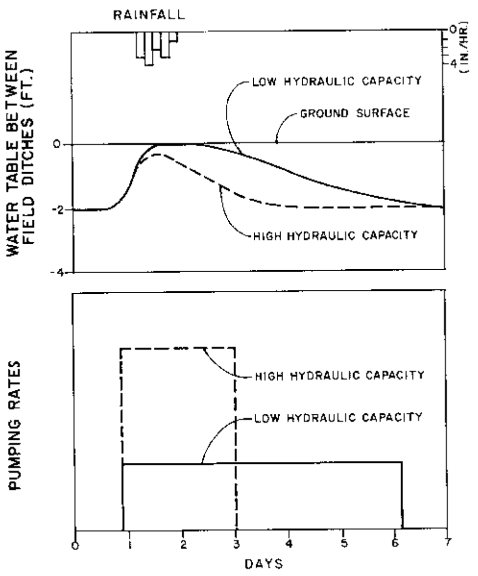

Figure 10. Typical response relationship between the farm level outflow (pumping) to the in-field water table.

Once the water table response relationships are known, a water budget accounting program for the in-field root zone should be developed. This budget must take into account the evapotranspiration (ET) and rainfall (actual and/or predicted), as well as the water table response to inflows or outflows. The water table movement (WT_m) in response to rainfall and ET can be roughly estimated by the following relationship (units are in inches):

$$WT_m = 7 * (\textit{excess rainfall} - \textit{excess ET})$$ **Equation 1**

Note that the 7-inch response coefficient can vary from 5 to 12 inches, depending on soil properties. Due to the relatively low sensitivity of WT_m to water management control criteria, however, 7 inches should work well for most conditions.

This relationship would mean that one inch of rain could raise the water table approximately 7 inches. The key words here are "could raise" because a portion of the rainfall or ET could possibly be utilized to replace or remove available water in the aerated soil profile without displacing the water table. In other words, if the soil is very dry, then about 0.5 to 1.0 inch of rainfall may be needed to re-wet it before the water table will rise. Conversely, about 0.5 to 1.0 inch of ET may have to occur before the water table will drop. The amount of rainfall or ET "left over" after filling the available water storage reservoir in the soil profile is called "excess" rainfall or ET. The standard irrigation "accounting method" can be used to keep track of the available water in the soil profile.

The accounting method uses the following relationship (units are in inches):

Change in Available Water = Rainfall **-** *ET* **Equation 2**

The total available water is approximately equal to the difference between the field capacity and the wilting point of the soil, multiplied by the depth of the aerated soil.

Using the above water budget information, irrigation and pump scheduling decisions can then be optimized for water table control. Irrigation scheduling, drainage/pump operations or predicted versus observed rainfall should be used in decision-making.

Irrigation scheduling should be based on setting inflow rates to match farm-wide ET rates once available water has been exhausted. This could be done operationally by observing the in-field water table levels and "accounting" for the currently available water. Then, using Equation 2, an estimate can be made of the time when the excess available water will become depleted. Taking the estimated time to depletion in conjunction with the water table response curve (Figure 10), the correct time to initiate irrigation can be calculated.

The rate of farm level irrigation inflow can be roughly estimated by predicted ET rates. Continuous fine-tuning based upon observed in-field water table levels, however, will be the best procedure for maintaining optimal water tables after irrigation has been initiated.

During irrigation, the available water in the soil profile is normally at its lowest level. The soil, therefore, will have the capacity to store about 0.5 to 1.0 inch of rainfall before excess water will cause the water table to rise (Melaika and Bottcher, 1988). Irrigation should be immediately terminated after any significant rainfalls (about 0.2 inch) to prevent upward water table fluctuations that could result in additional future pumping demands. The time until re-initiating irrigation can be calculated by the same procedure described above.

Drainage or pump operations to remove excess rainfall can be scheduled in a similar fashion to irrigation. Now, however, the potential rise in the water table due to measured or predicted rainfall must be considered in the scheduling of the pump(s). Due to the time delays between pump start-up and water table response in the field (Figure 10), it is normally not practical to use only the observed in-field water table levels as control guides. The actual or predicted rainfall should be employed to estimate the water table rise by using Equation 1. Once again, the amount of available soil water storage, as determined by the "accounting method" described above, must be subtracted from the rainfall amount before use in Equation 1. The predicted water table rise can then be compared to the water response curve (Figure 10), the crop saturation tolerance (Table 2), and the predicted ET for the allowable saturation period. This comparison should be made in the following fashion:

Step 1: Obtain the predicted water table level from Equation 1 using the excess rainfall (predicted or observed) and consult Table 2 to estimate the allowable time needed to return the water table to optimal levels.

Step 2: Determine the volume of ET that will occur before the crop experiences saturated water stress by multiplying the estimated ET rate -- based on crop and season (Jones et al., 1984) -- by the allowable recovery time obtained in Step 1. If the ET volume exceeds the excess rain, pumps should not be turned on and estimates for future irrigation scheduling should be made. If the ET volume is less than the excess rainfall, pumping should be initiated immediately and run only as long as necessary to remove the water volume difference between the excess rainfall and the ET calculated. Removing this water as quickly as possible by using full pump capacity will typically provide for lower P concentrations in the discharged water.

Step 3: Repeated calculations will be needed because of the variability of rainfall. Each adjustment will require the repetition of Steps 1 and 2 with a continuous tracking of allowable root zone saturation. It should be apparent that these continuous and frequent adjustments will become very complicated over short time periods. It is recommended, therefore, that a portable computer be programmed with the appropriate algorithms. Such a program is not currently available, but is presently being developed by UF-IFAS and should be available by the end of 1996.

The above procedure will require significant training of staff and on-farm experience before it will become fully functional. In the interim period, it is suggested that at least automatic "cut-off" controls be placed on all farm pumps to assure that over-drainage is reduced to a minimum. A "cut-off" float can be installed at a water level in the main farm canal no more than 0-6 inches (depending on farm size, pump capacity, ditch capacity, soils, and crops) below optimal in-field water table levels. Automatic "on" switches can also be used to initiate or re-initiate pumpage. Such automated systems will primarily serve to protect against pump operators failing to turn off pumps before significant over-drainage has occurred. Note that float control systems are prone to failure without regular maintenance and should not be considered a replacement for assigning an operator the job of periodically checking the pump.

An optimally designed drainage system would not require multiple pump cycles to remove excess rainfall. Multiple pump cycling is an indication of insufficient hydraulic capacity, i.e. water level gradients needed to move water to the pump station are excessive. Data have shown that water pumped early in a storm is typically of better quality than water pumped later in the storm. Therefore, removing excess rainfall as quickly as possible without over-draining the fields is important. Obtaining sufficient hydraulic capacity is further discussed in a later section.

Selection of predicted versus observed rainfall should be based on the following considerations. Observed rainfall should be used whenever possible because it represents the real situation. However, it may become necessary to initiate pumping based on *predicted* rainfall if the crop's water saturation stress sensitivity is such that a delay in gaining water table control through use of observed data could cause crop damage. Typically, predicted storms of less than 1 inch of rainfall require *no prepumping* for any crops. Storms between 1-3 inches will only impact vegetables, while storms greater than 3 inches could potentially impact all crops. The procedure described earlier, however, should be used to determine the potential for the occurrence of a detrimental impact. It is important to note that the sensitivity of the farm and field water tables vary seasonally due to crop rotations, different growth periods, and storm frequency. Fallow periods have no saturation limitations, except for land preparation needs.

Spatial Water Table Control

Spatial water table control implies keeping the water table depth throughout the farm as uniform as possible with time. Variable water tables across a farm are typically the result of an uneven ground surface, inadequate hydraulic capacity of the primary farm canal system and field ditches, and/or poor culvert maintenance and/or management. All of these conditions can cause excessive soil mineralization and related P release.

Uneven ground surfaces can be responsible for variable soil moisture conditions and related high P losses across a farm or within a field, even if a uniform water table is maintained throughout the canal/ditch system. Laser leveling is the best way to eliminate these soil surface undulations. However, if a farm has a significant elevation change from one side of the property to the other, then control culverts will be needed to separate the land into an appropriate number of large blocks within which the soil can be economically laser-leveled. Booster pumps will be needed to move water in the upslope direction between each of the blocks. Since irrigation flowrate requirements are less than for drainage, it is usually most economical to have the land sloping toward the main drainage pump station so that only irrigation would have to be handled by internal farm pumps. It is possible in some situations to release the irrigation water directly into the farm's highest elevation block, eliminating the need for any internal booster pumps. To do this, however the canal, pump, and culvert system must be designed with sufficient flow capacity.

Inadequate hydraulic capacity can cause non-uniform drainage and irrigation across a farm. Typically, under-drainage occurs in areas located further away from the pump station, while areas nearer the pump become over-drained as depicted in Figure 11 and Figure 12.

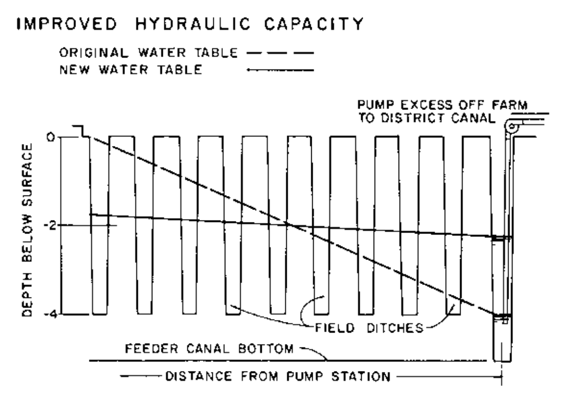

Figure 11. Corrective technique for poor water table uniformity across a farm due to inadequate hydraulic capacity of farm canals.

This over-drainage of areas can result in excessive soil mineralization and associated P losses. Inadequate hydraulic capacity can also result in a slower, "pulsing" type of water table drawdown which can produce higher P concentrations in the drainage water. Variability of the water tables across a farm can be managed by designing sufficient flow capacity in the farm canal/ditch system and maintaining and managing flashboard culverts in feeder/field ditches.

Inadequate field ditch spacing as depicted in Figures 13, Figure 14, Figure 15 and Figure 16 can be another hydraulic limitation. If the soil is "tight" (i.e. has a low hydraulic conductivity), significant water table variations between adjacent field ditches can occur for long periods of time after a storm. The only ways to increase the mid-field water table drawdown is to drop the field ditches very low or shorten the distance between ditches. The dropping of the field ditch water levels is not advised because of the severe over-drainage that will occur near the ditches before the mid-field levels drop. It is recommended, therefore, that the ditch spacing be set appropriately to assure sufficient drainage. The rate of water table drop at mid-field as a function of ditch spacing can be calculated by using one of several drainage equations or computer models. An agricultural or drainage engineering expert should be consulted to complete a drainage spacing analysis.

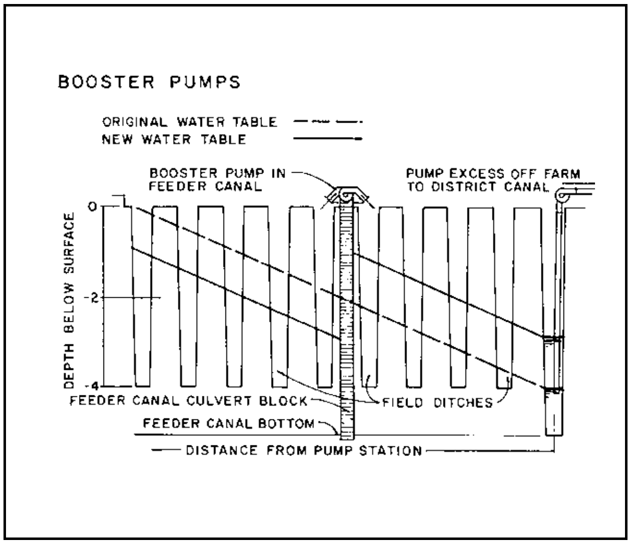

Figure 12. Corrective technique for poor water table uniformity across a farm due to inadequate hydraulic capacity of farm canals, using booster pumps in feeding canals.

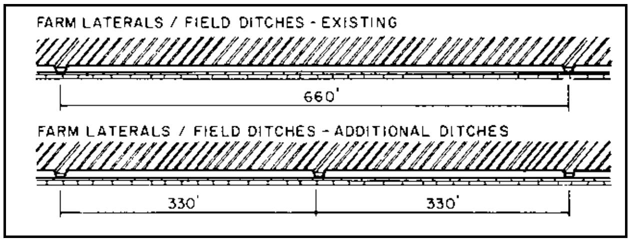

Figure 13. Influence of additional ditches for drainage control during subirrigation.

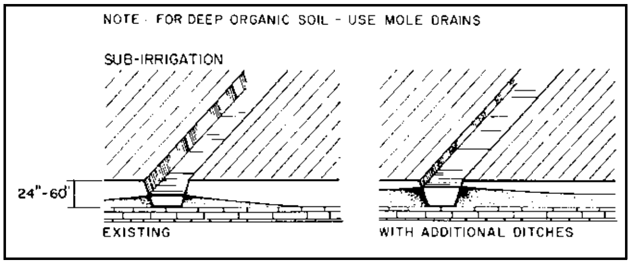

Figure 14. Influence of additional ditches for drainage control during subirrigation.

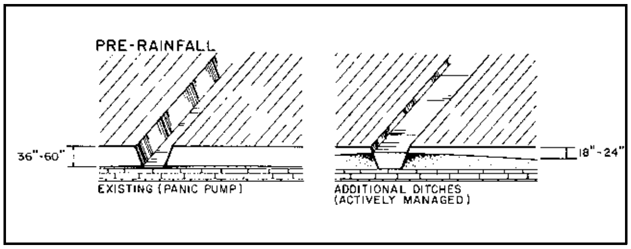

Figure 15. Influence of additional ditches for drainage control before rainfall.

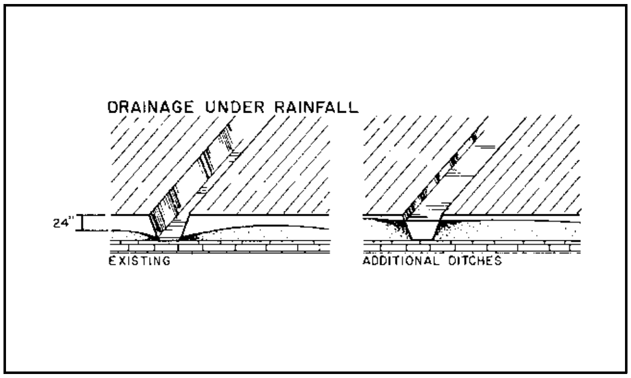

Figure 16. Influence of additional ditches for drainage control during rainfall.

Adequate hydraulic capacity of the primary canal/ditch system can be determined by either a computer hydraulic analysis of the system or by field measurements of water levels across the farm during a pump event. Because irrigation flow rates are about one third of drainage flow rates, only drainage need be considered for sizing the canal/ditch system.

The canal system should be designed to provide minimally sufficient drainage for the field at the furthest flow distance from the farm pump without dropping the water tables in the fields nearest the pump by more than a few inches. The drainage response relationship procedure described previously will provide the necessary assessment information for drainage capacity.

Inadequate flow capacity in a canal system can be corrected by increasing the size of the canals/ditches and/or by blocking the farm into hydraulic units and using booster pumps at specific locations throughout the system. This essentially creates hydraulically defined "mini-farms" within the main farm, with each being managed independently with respect to water table levels. Figure 11 and Figure 12 show how the increased canal capacity and booster pump arrangement would enhance water table uniformity across the farm. The location and number of booster pumps and the sizing of canals/ditches will require an engineering analysis of the canal system that is beyond the scope of this guide.

In-field water table non-uniformity can be partially compensated for without increasing canal system capacity by restricting the flow from field ditches using culverts with flashboard risers. The boards in the culverts closest to the pump station should not be pulled below a few inches of the optimal water table during a drainage event. This allows the main feeder canals to drop significantly without rapidly draining the fields nearest the pump. Experience will have to be obtained for each individual farm system to determine the appropriate board settings throughout the farm that will provide the most consistent uniformity. This procedure is more labor intensive and provides less water table control than other procedures which increase the hydraulic capacity of the drainage system. Therefore, this is not the ideal way to gain uniformity, but it can be useful when the flashboard culverts are already in place. Using flashboard culverts and booster pumps within a hydraulically blocked farm will provide the best water table control for addressing both water quality and quantity concerns.

Irrigation uniformity can be best controlled by the appropriate use of flashboard culverts and/or laser leveling. It is essential that the ground surface be as uniform as possible to maintain optimal water tables throughout a farm. There are no efficient water management practices that can correct for variable ground surfaces within a water management unit or control block.

Irrigation inflows must exactly match the farm ET losses or else the water tables will either rise or fall. The dynamic changes of ET demands during relatively short time periods create the need for continuous control of inflows. Optimal water levels are typically managed either by regulating the inflow rates by automatic inflow control or by using flashboard culverts and a recycling canal system as depicted in Figure 17 and Figure 18. Regulated inflow control offers the lowest labor cost and the lowest potential water discharges from the farm. It does, however, require a very level farm with sufficient hydraulic ditch capacity to assure no more than a few inches of water table variation across a farm or a farm block.

Regulated inflows for water table maintenance can be achieved by using automatically controlled gate structures or pumps. Both gates and pumps would utilize a float control system to activate them. For optimal management, a "smart" controller -- programmable for variably regulating flow rate based on main canal water levels -- can be employed.

When farm slope uniformity and/or automated inflow control are not available, flashboard culverts can be used. These flashboard culverts can be operated at the field ditch level or at a larger block level. A recycling irrigation system is depicted in Figure 17 and Figure 18. Water is fed (typically by gravity, but sometimes pumped) into the feed end of the field canal/ditch and spills over the flashboards at the other end of the ditch. This allows the flow rate into the feeder canal/ditch to remain relatively constant while the flow over the boards varies according to the ET demand in the field.

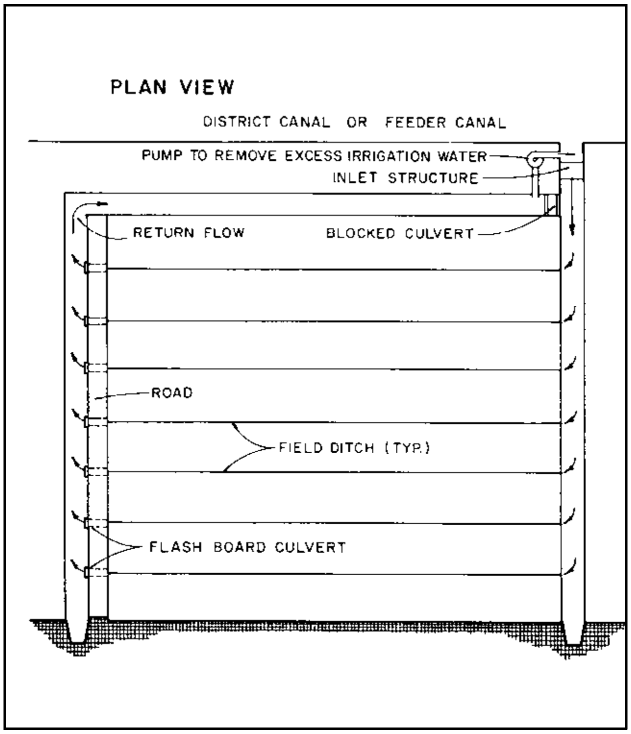

Figure 17. Plan view of irrigation water table control system using flashboard culverts and a return system.

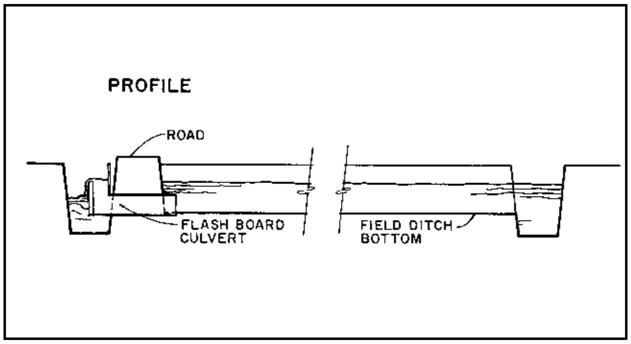

Figure 18. Profile of irrigation water table control system using flashboard culverts and a return system.

To deal with the return flow into the collector ditch, a fairly small pump that maintains the collector ditch's water level below the flashboard elevation can be installed. The pass-through water is most readily managed by being pumped off the farm. It can later be used again by anyone along the canal system. However, to prevent this irrigation through-flow water from being credited against your drainage discharge, you should pump it into the inlet basin of the main irrigation inlet structure. This procedure will assure that the through-flow water returns to your farm. Monitoring of its discharge, thus, may not be necessary. ***Do not assume this to be true. Check with the proper authorities first.***

B-2: On-Farm Retention of Drainage Water

Retention of drainage on-farm could reduce phosphorus losses by 15-60%. This BMP requires a farm to have the capacity to store additional storm drainage water on-site both during and after rainfall events without adverse impacts on crop production.

On-farm storage of water can be accomplished in three ways. The first technique is simply to let water tables throughout the farm rise by reducing pumping times. The second technique involves a strategy requiring a higher level of management than the first technique where water is only allowed to rise in isolated blocks within the farm. The third storage technique is to build a separate storage reservoir on the farm. Each technique will be discussed in greater detail in this document with pros, cons, and specific design considerations being presented.

Temporarily Raising Water Tables in the Fields

Temporarily raising water tables in the fields after storms has the advantage of being easily implemented by changing pump schedules. Its main disadvantage is increased soil wetness and a higher risk of crop damage. If crops such as vegetables that are intolerant to wet soil conditions are involved, very limited additional wetness is acceptable. This BMP, therefore, is of limited benefit for vegetable operations. However, more water-tolerant crops such as sugarcane should be able to use this BMP effectively. If vegetables are being grown within the confines of the sugarcane farm, hydraulic isolation of the vegetable blocks is necessary to properly implement this BMP. To determine the amount of in-field storage and related drainage required for a given storm, the soil water content expected from that storm must be estimated. The water table and soil moisture accounting procedure must then be followed. It is important to remember that water table fluctuation control is concerned mainly with downward fluctuations. Upward movement, therefore, is permissible to a greater degree. This water management analysis procedure will also allow one to estimate the actual retention capabilities of the farm.

Until sufficient experience is gained, the use of the moisture accounting and pump control algorithms will seem fairly complicated and confusing. However, once confidence is gained, these calculations will become a routine part of farm operation, providing growers with a valuable understanding and control of the water management system. Such an understanding could likely lead to other benefits for the farm. To get started, however, it is suggested that a farm-specific program be developed with the support of private or governmental water management experts.

Storing Water in Isolated Farm Blocks

Storing water in isolated farm blocks can be useful in cases where different crops are being grown upstream of an internal pump station, or when the movement of water between blocks is desired. The use of sugarcane lands to store drainage water from vegetable areas within or outside the farm is a good example of crop block storage. However, because of the potential importance of this BMP, vegetable drainage water storage in sugarcane will be discussed separately. This section will focus instead on block storage techniques for sugarcane farming operations.

Fallow sugarcane lands and rice fields are ideal storage locations for excess rainfall. However, storage in fallow/rice lands is limited by the available acreage (seasonal and usually only about 20% of the farm area) and the need to hydraulically isolate (dike) this area. Hydraulically isolating blocks will necessitate the use of additional pumps, culverts, and dikes. These typically have been of a temporary nature. Permanent diking, culverts, and ditching systems, however, once installed, can simplify future operations and improve overall farm water management. The diking referred to in this instance can simply be the normal road access dikes and ditch spoil separations. No large scale diking would be required.

Research and farmers' experiences during flood periods have demonstrated that there is a relatively high potential tolerance of sugarcane for prolonged root inundation, both partial and complete. This ability to withstand root submergence for extended periods of time depends upon plant cultivar and maturity, as well as on soil type and degree of soil/water aeration (Deren et al., 1991). Storing water in fields cropped to sugarcane has solid potential as a BMP, but additional research concerning the interactions of soil type and water level with cultivar and length of time of inundation are required before full-scale implementation.

The water conveyance system on a sugarcane farm must be modified so that drainage water can be moved from one block of land to another within the farm drainage system. This system will require setting up gated culverts and pumps on isolated feeder channels so that water can be raised in a given block of land by draining it from another block within the farm. Low level diking will be needed if land flooding is anticipated. It may be advantageous to have the feeder ditches arranged to allow water to be pumped from one side of a block to the other to maintain a flow across the block. Water kept in motion is better aerated and thereby, as hypothesized by some, reduces the negative impact of root zone inundation. However, no scientific data are available to verify this claim. Therefore, it is not yet known whether flow from one block to another on a rotational basis would be better than recycling water within blocks. In any event, it is advisable to start out on a small scale to gain experience before expanding to a farm-wide system.

Procedure for Beginning a Block Storage System

When a heavy rainfall occurs, excess water could be pumped into the first farm block until its allowable water saturation time is reached (Table 2). This block could then be appropriately drained into a second block until its water saturation time limit has been reached. This process continues until the excess water is evapotranspired from the system or until there are no more available blocks. At that time, the excess drainage water will need to be pumped from the farm. However, it may be likely that by then one of the earlier blocks will have regained storage capacity so that additional excess drainage water could be routed to it. Figure 19 and Figure 20 show an example of a farm layout that utilizes a block storage technique.

On-Farm Storage Reservoirs

On-farm reservoirs for storing excess rainfall on-site for later use for irrigation could reduce P losses by 10-60%. Such reservoirs would require that a minimum of 5-10% of the farmer's land be removed from production. The reservoirs would be constructed of either muck or marl dikes (preferred for reduced seepage losses). These would require a pump station and release gates for water control. Their sizing would be based on the desired water retention, height of dike, and water level control requirements of the farm. For example, a sugarcane farm would require smaller reservoirs on a per acre basis than a vegetable farm.

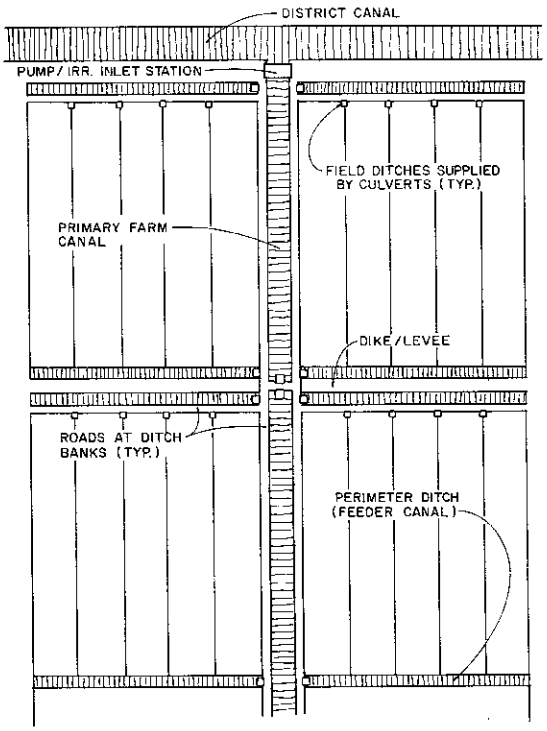

Figure 19. Plan view of one possible block storage system.

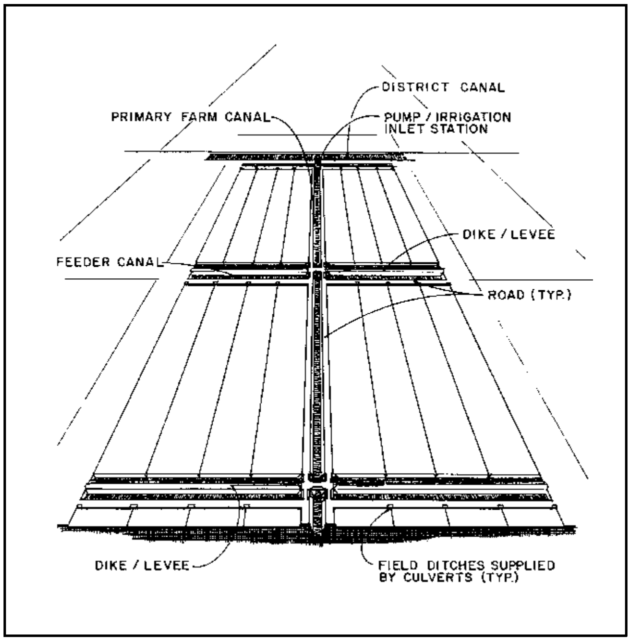

Figure 20. Aerial view of a possible block storage system.

On-farm storage reservoirs offer the simplest managerial scheme of any of the previous retention systems because their operational procedure is simply to pump all excess water into the reservoir until its capacity is reached, at which time water is released off the farm. Conversely, irrigation is drawn from the reservoir until its storage capacity is depleted, at which time water is brought into the farm. The reservoir has the additional advantage of removing some of the P from the water during storage.

There are, however, several disadvantages to retention ponds:

1) The acreage required for the reservoir is permanently removed from crop production. Depending on the degree of retention desired and dike heights, this acreage could amount to 10 percent, or more, of existing cropland;

2) Seepage from the storage reservoir may create additional operational costs due to increased pumping;

3) The reservoir's additional water surface area will increase the consumptive use of water on the farm; and

4) Cost of construction and loss of farm productivity make this system very expensive.

For some farms the operational advantages could outweigh these disadvantages.

B-3: Retention of Vegetable Field Drainage Water in Sugarcane or Fallow Fields

This BMP could reduce P losses by 20-90% on any given farm. The 90% reduction would reflect a situation where a significant amount of sugarcane land was available to receive the vegetable drainage water. The use of vegetable drainage in sugarcane fields can also offset some of the fertilizer requirements in the receiving fields. However, the P loading rates being introduced to the sugarcane field should not exceed recommended rates. The P loss from the sugarcane lands would likely increase slightly due to receiving this water, but the net P loss from the vegetable and sugarcane lands together would be significantly reduced.

This BMP will require the availability of *hydraulically isolated* sugarcane land adjacent to the *hydraulically isolated* vegetable field/block to minimize cost and the difficulty of moving water to sugarcane land. Drainage water from the vegetable area would be pumped into neighboring sugarcane blocks to maintain optimal vegetable production. Excess water within the sugarcane blocks would then be managed in the same manner as previously outlined.

The primary design concern for delivering vegetable drainage into sugarcane fields is the rotational nature of vegetable production from year to year and from farm to farm. Vegetables are often grown on sugarcane lands during the rotational fallow period that occurs once every 3 to 5 years. This means that the hydraulic isolation for the vegetable field would be used only once every four years, creating a greater per acre expense compared to continuous vegetable production. However, since the hydraulic blocking of a sugarcane farm may already be advantageous for water retention, the adaptation of one of the sugarcane blocks for temporary vegetable production could be easily handled with little additional expense. The potential P reduction by both block retention and vegetable drainage into sugarcane lands is so high that a permanently blocked farm system should be strongly considered.

C. Use of Aquatic Cover Crops

This BMP, when used during the vegetable production off-season and during the flooded fallow rotation of sugarcane, could reduce off-farm P discharges by 5-20%. An aquatic cover crop such as rice will uptake a significant portion of the excess P that becomes readily available during any flooding fallow operation.

Additional diking and pump facilities will be needed to maintain the required flood conditions if not already available. The permanently hydraulically blocked farming system could be readily used for growing aquatic crops. Rice is probably the only major aquatic crop available at this time with sufficient economic value to be considered.

The major management consideration for growing an aquatic crop in rotation with non-aquatic crops is the "drain-down" period. The water, which must be removed from the field at the end of the aquatic cover crop season, should not be directly discharged from the farm because it will likely contain elevated P levels due to P releases from the soil and from bird droppings. Scheduling of the drain-down operations so that they match available on-farm retention capacities of surrounding blocks is very important. The retention capacity of the surrounding farm blocks can be determined by defining the amount of water to be drawn down as excess rainfall. As cited earlier in reference to vegetable drainage retention in sugarcane land, the P in water drained from the flooded soil can be utilized as a potential fertilizer source in surrounding lands.

D. Coordinated Farm Cropping Patterns

Coordinated farm cropping patterns is a necessary part of the water management BMPs, although it is not really a BMP in itself. This practice refers to changing the farm cropping patterns of vegetables, sugarcane, flooding fallow, etc. to accomplish the optimal use of the above BMPs. For example, retention of vegetable drainage in surrounding lands cannot be successfully implemented if available sugarcane fields are not conveniently located near the vegetable fields and if the vegetable fields are not hydraulically isolated. Because of the above-described relationship, any specific reductions in P due to coordinated cropping patterns would be reflected in the above individual BMPs.

Coordinating a farm's cropping pattern is critical to the success of a BMP program. The blocking and rotation of crops offer significant operational and water quality advantages. Additional planning will be needed to assure that future crop rotations do not create one or more of the following situations:

1) Vegetable production status lacking sufficient sugarcane land for water retention;

2) Inability to hydraulically isolate water-sensitive crops within a large farm operation;

3) Insufficient isolation of the flooded fallow lands needed to successfully achieve hydraulic control or aquatic crop (rice) production; and/or

4) Large changes in farm phosphorus losses that create potential regulatory problems.

One cropping pattern change that could be considered a BMP is the definitive change from one crop to another in order to reduce P losses from the farm. Moving from highly fertilized and water management intensive crops to those requiring less fertilizer and less intensive water management can reduce P losses. In situations where additional P reductions are required and the existing BMPs for the crop being grown do not meet this requirement, a crop change may be the only option. However, this should only be considered to be a BMP if the economic vitality of the farm is not adversely impacted.

Sediment and Particulate-P Control BMPs

During high volume and intense rainfall events, it is not unusual to find that close to 25-75% of the total-P discharged from a farm is associated with particulate matter (Izuno and Bottcher, 1991). This particulate matter consists of inorganic and organic soil particles, crop debris, and pieces of (or whole) aquatic plants and animals in varying stages of decay. Controlling the efflux of these P-bearing particulates could greatly reduce TP loads in the EAA (5-50%). Methods for reducing particulate-P discharges in the EAA have yet to be researched adequately. It is important to note that particles do not become sediment until they have settled to the channel bottoms. Until that point, they are suspended particulate matter. Hence, one must consider particulate origin, bedload movement, resuspension of sediment, and the transport of suspended particles when attempting to reduce particulate-P discharges.

Suspended particles carrying P originate from three primary sources: 1) soil particles eroded into ditches; 2) plant material washed into the ditches; and 3) plant material growing within the ditches and canals. Soil particles can enter a drainage stream in three primary ways: 1) entrainment in sheetflow off innundated fields; 2) sloughing of ditchbanks; and 3) wind-borne particles deposited in open channels. These particles can then either continue in the flow-stream to be discharged off-farm or they can settle out of the flowing or non-flowing water and be deposited on channel bottoms as sediment. The channel bottom sediment can then make its way to the discharge point through *bedload movement or resuspension* during future pumping events.

There are several potential methods for reducing the transportability and discharge of soil-origin P-bearing particulate matter. Ideally, soil should be kept in the fields. Hence, overland sheetflow during drainage should be stopped, or greatly reduced, by using stable low berms around the edges of each field block. Inlet structures with sedimentation basins, or soil stabilizing cropping practices such as vegetative buffer strips could also serve to reduce the erosion of soil particles. Berms force field drainage water to pass through the soil profile before entering the farm conveyance structures. Ditchbank stabilization practices should be employed. People and machinery should not approach the edges of the ditchbanks since their weight can cause displacement and collapsing of the ditchbanks. Rodent and rabbit control could also be an important practice since their burrows greatly destabilize the ditchbanks. The maintenance of uniform vegetative bank cover, such as grass, will also reduce bank erosion. However, mowing operations could also result in highly mobile P-bearing grass clippings to be deposited in the ditches and canals.

Once soil particles enter the farm water conveyance structures, they will either be transported off-farm or settle to the channel bottom. If flow velocities are low enough, movement of the deposited sediments will not occur to any great extent. Pump capacities and ditch and canal capacities will govern the flow velocities, with low pump capacities and large ditches and canals yielding the lowest velocities. Methods of trapping sediment, or filtering particles out of the drainage stream, are being tested for their applicability in the EAA. Ditch maintenance programs (cleaning and stabilization) are also being considered as potential practices to reduce P-bearing sediment transport.

Much of the particulate-P appears in the form of aquatic plant (both floating and rooted) detritus. These particles are extremely light and have relatively large surface areas, making them hard to settle out of the flow stream, easily resuspended, and difficult to control in farm water conveyance structures. Reductions in discharge of these types of particulates rests with the control of aquatic plant growth in the channels and along the banks.

Summary of BMPs

Table 3 provides a summary of the best management practices presented in this document. As demonstrated by the currently available information, a 25% reduction in P loading using BMPs is a reasonable and obtainable goal. Greater reductions, however, are potentially obtainable. Table 3 shows how water management BMPs have a greater potential for reducing P loads than fertility practices. It is important to remember, though, that water management BMPs primarily achieve their reductions by decreases in water volume, whereas fertility BMPs have a greater likelihood of lowering P concentrations. Sediment control BMPs appear to hold promise for P load reduction, but the lack of research makes it difficult estimate their effectiveness.

Seepage Control

One variable that the farmer cannot always control is the amount of seepage water entering the farm from nearby areas with higher water levels. This problem is most acute for farms bordering the WCAs and Lake Okeechobee because of water table elevation differences of as much as seven feet.

Seepage to and from the primary canals in the EAA is also a problem. Even though head differences (1-3 feet) are less than those directly attributed to the Lake or the WCAs, the seepage paths are normally shorter. The nature of the soils and underlying strata permits a significant amount of water to flow (seep) under and through the dikes retaining this water. In some regions of the EAA, the underlying marl rock is extremely permeable so that, if the higher water bodies have canals cut into this formation, very large seepage rates can occur. Some farms are forced to pump this seepage water off-farm continuously to avoid inundation and to maintain optimal water tables.

The BMP Rule allows for seepage to be removed from the P reduction requirements through a variance option when the existing condition can be appropriately documented. Documentation must include continuous discharge and rainfall records for the farm. If seepage is a major problem, contact the South Florida Water Management District immediately to discuss ways of accounting for it.

Fertility BMPs, as well as some of the water management BMPs, can still work for farms suffering from excessive seepage. The relative beneficial impact of these BMPs, however, will be reduced because the expressed BMP reductions would only be for the rainfall excess portion of the farm's discharge. In extreme cases, a majority of the P being pumped from the farm may have originated in seepage water that will not be impacted by BMPs.

Seepage rates can only be decreased by the following techniques:

1) Reducing the hydraulic gradient by reducing head differences (not normally practical) or by increasing flow path. This would require increasing dike thickness or distance to first farm canal; and/or

2) Reducing hydraulic conductivity of media in flow path by limiting the extent of cuts into the marl rock for farm canals/ditches near farm borders or by installing low conductivity barriers (not normally practical).

Table 3. Reference List of Proposed Best Management Practices for the Everglades Agricultural Area.

BMP Code/Name	Phosphorus Reduction Range (%)[1]	Crop
Fertility BMPs	5-20[2]	All
Calibrated Soil Testing	0-10 0-25	Sugarcane Vegetables
Banding of Fertilizer	0-40 0- 5	Vegetables Plant Care
Prevention of Misplaced Fertilizer	0-15	All
Split Application of Fertilizer and Use of Slow Release Forms	0-10	All
Water Management BMPs	20-60[2]	
Minimizing Water Table Fluctuations	0-50	All
Retention of Drainage On-Farm	15-60	Sugarcane
Retention of Vegetable Field Drainage Water in Sugarcane or Fallow Lands	20-90	Vegetables
Use of Aquatic Cover Crops	5-20	All
Coordinated Farm	n/a	All
Sedimentation	5-50	All
NET BASIN EFFECT if all BMPs implemented	20-60[2]	All

[1] Ranges are for individual farms after considering uncertainty and the variability of farm management unless otherwise noted.

[2] Phosphorus reduction range is for entire EAA Basin. Note that the upper limits are very theoretical and are not expected to be achieved without significant cost.

Often seepage rates cannot be reduced and simply require additional pumping. In these cases, it will be necessary, from a monitoring standpoint, to separate farm drainage discharges from the discharges to control seepage for a true measure of BMP effectiveness to be obtained. In some situations, it may be possible to install and maintain a seepage interceptor canal to control and measure seepage rates. The interceptor ditch effectiveness in collecting this seepage water, however, will vary according to the characteristics of the underlying marl rock layer. The best method of separating seepage flow is to conduct a hydrological analysis of the discharge records in combination with a time series of the surrounding water levels. A professional engineer should be consulted for detailed analysis, but a rough estimate of the seepage rate can be calculated by adding pump discharge rate to the estimated farm evapotranspiration rate and subtracting the estimated irrigation rate. This calculation is best performed during a prolonged dry period. We suggest that the separated flows (seepage and excess rainfall) be reported in the BMP Rule permit reports.

Water Monitoring

Monitoring of the quantity and quality of water entering or leaving a farm, as well as specific internal water conditions, is useful in developing and refining a BMP program. The BMP Rule required that outflow volumes of water and P be monitored starting in October 1993. Because the BMP Rule only pertains to outflows to SFWMD canals, its monitoring requirements will not provide a complete picture of the water and P dynamics on a farm.

As emphasized throughout this guidebook, the success of any BMP program will depend heavily on the farmer's knowledge and understanding of the hydraulic and P dynamics of the farm. The only way to really know if a particular practice is working is to monitor its effects. An appropriate monitoring program should include water flow measurements, rainfall, P concentrations of drainage and irrigation water, and in-field water table levels. Details of the equipment and procedures for monitoring are provided in the Institute of Food and Agricultural Sciences Extension Circulars 1036 (Izuno et al., 1992) and 1040 (Taylor et al., 1992), entitled "Agricultural Water Quality Sampling Strategies" and "Water Quality Sampling, Analysis, Instrumentation, and Procedures," respectively.

Conclusions

Ongoing environmental concerns for the Everglades continue to require that the Everglades Agricultural Area release the cleanest (low P) water possible to the south. It is in the best interest of all parties to reduce phosphorus levels as much as possible *as long as the economic vitality of the agricultural industry is not undermined*. The best management practices presented in this guidebook can be used by growers to attain the required P reductions, without imposing significant economic hardship, if the BMPs are implemented in the step-wise fashion as suggested. Sudden, large changes in farming operations are not recommended until the grower is fully secure in his/her experience in the implementation and on-going use of these practices.

As seen in Table 3, the currently available information indicates that the projected 25% P load reductions achieved through the implementation of BMPs is a reasonable and obtainable goal, and that even higher reductions are potentially obtainable. The presented BMPs are designed both to reduce P concentrations in the drainage water, as well as to optimize the use of freshwater resources. It is expected that the greatest reductions in P loads from the EAA will occur due to reduced drainage volumes.

A successful BMP program will require farm operators within the EAA to significantly increase their knowledge and management skills. They will need to be aware of crop responses to water table variations as well as understand detailed hydraulic responses of the water control systems to climatic conditions. Though an increased level of knowledge and managerial skills will be needed, they will more than likely improve overall farm efficiency and thereby offset some of the costs of the BMPs. With the implementation of the BMP programs outlined in this guide, the future farming vitality of the EAA can be maintained while protecting downstream natural resources.

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