C-11653 Work Plan

Land Application of Residuals and Chicken Manure in the Lake Okeechobee Watershed: Phosphorus Considerations

December 11, 2000

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Objectives and Scope

The objective of this project is to evaluate the plant, soil, and water phosphorus (P) implications of applying domestic wastewater residuals (biosolids), animal manure, and water treatment residuals to south-central Florida cattle pastures. This objective will be met by undertaking a three-year field study in which a biosolids and a chicken manure are applied at different treatment levels, with and without water treatment residuals, on half-acre pastureland plots in the Lake Okeechobee Basin. The project includes sampling and measurement of waste products, soils, surface and ground waters, and vegetation for phosphorus accumulation and transport indicators. Results will be assembled and recommendations formulated on appropriate application rates of the tested waste materials. Planning, results and recommendations will be discussed with the public in two educational workshops.

Background

Disposal of both human and animal waste products is an unavoidable byproduct of population and economic growth. Land application of wastewater residuals and domestic animal wastes is a natural way of recycling nutrients and organic matter and achieving increases in soil productivity. However, the beneficial aspects of land application of waste materials must not be exploited at the expense of the potential environmental implications of such disposal/recycling practices.

More than 12 million acres of grassland in Florida require fertilizer to achieve an acceptable forage production level. Of these, 5 million acres are planted with bahiagrass. Pasturelands are some of the most productive plant systems regarding downward movement of nutrients through the soil. Permanent grass pastures are capable of high adsorption of nutrients due to prolific root mass they produce (Muchovej, 1997). Given the particular sensitivity of some Florida soils to significant leaching, studies of the fate of biosolids-bound P are prudent (O'Connor and Sarkar, 1999) if land application of biosolids is to become more widespread in the state.

Literature Review

Phosphorus and Eutrophication

Phosphorus is an essential element for plant growth, and its input has long been recognized as necessary to maintain profitable crop production. Phosphorus inputs can also increase the biological productivity of surface waters. Although N and C are also essential to the growth of aquatic biota, most attention has focused on P inputs, because of the difficulty in controlling the exchange of N and C between the atmosphere and water. Thus, P is often the limiting element, and its control is of prime importance in reducing the accelerated eutrophication of fresh waters. Large inputs of P from urban wastewater systems, surface runoff, or subsurface groundwater flow can remove this limitation and increase the aquatic biomass to ecologically undesirable levels.

The principal impacts of eutrophication relate to four phenomena: increased aquatic plant growth, oxygen depletion, pH variability, and plant species quality and food chain effects. The eutrophication threshold concentration of P for many P-limited aquatic systems is low, i.e., 0.03 mg/L (Pierzynski, Sims, and Vance, 1994). Daniel et al., (1998) reports that surface water concentrations of inorganic P and total P between 0.01 and 0.02 mg/L are considered critical values above which eutrophication is accelerated. Water bodies with naturally low P concentration (like several important water bodies in Florida) are highly sensitive to external inputs of P associated with fertilizer, manure, and residuals land application. Management of P to avoid eutrophication frequently focuses on reducing P loading to water bodies by reducing P inputs to agricultural settings and/or controlling the movement of P. Once a water body has been identified as being sensitive to P inputs, source fields and soils vulnerable to P loss in runoff must be carefully managed. For soils with a high or very high soil test P (STP) level, options may involve applying no more P than removed annually by the crop. Clearly, unlimited P inputs and numbers of animals within an agricultural system will lead to impaired water resources (Sharpley et al., 1994).

The loss of P from agricultural land is dependent on several factors, including the relative importance of surface and subsurface runoff in a watershed area, land management, and the amount, form, and availability of P in soil. The export of P in runoff occurs in particulate and dissolved forms. Particulate P includes P associated with soil particles and organic matter eroded during flow events and constitutes the major proportion of P transported from most cultivated land. Runoff from grass or forestland or non-erosive soils carries little sediment and is, therefore, generally dominated by the dissolved form. While dissolved P is, for the most part, immediately available for biological uptake, sediment P can be a long-term source of P for aquatic biota (Daniel et al., 1998). Generally the P concentration in water percolating through the soil profile is small due to sorption of P by P-deficient subsoil. Exceptions occur in acid organic or peaty soils where the adsorption affinity and capacity for P are low due to the predominantly negatively charged surfaces and the complexing of Al and Fe by organic matter. Similarly, P is more susceptible to movement through sandy soils with low P sorption capacities (Daniel et al., 1998).

Many Florida (and other US sandy coastal) soils present unique challenges for P management. On the positive side, such soils usually have low surface slopes and high water infiltration rates that promote water entry into the soil profile rather than runoff (and soil erosion). Extremely sandy Florida soils, however, often have poor P retention characteristics and allow P leaching; P behavior that is unique to most areas of the US. Leached (soluble, not particulate) P can contaminate shallow groundwater and, eventually, surface waters. This occurs via lateral (subsurface) flow of perched water tables to intercepting drains that then connect to surface water bodies. Harris et al. (1995) developed an indexing procedure that identifies Florida soils particularly susceptible to P leaching. Their scheme identifies many Spodosols (a dominant soil order in Florida), with their seasonally high water tables and poor P-retention capacities, as highly problematic.

Soil P Testing

A simple system is needed to assess the effect of agricultural management on the vulnerability for P movement from landscapes. The P indexing system (Lemunyon and Gilbert, 1993) has been developed as a field tool to fill this need. In developing the P indexing system, the transport (erosion and runoff) and source factors (STP and P applications), have been incorporated as they relate to P movement. The P indexing system effectively identifies sources of P movement within a watershed or basin area (Sharpley et al., 1993).

Rodriquez et al. (1995) tested two new methods to predict crop response to soil phosphorus. They found that the precision, range, and detection limit values from their new methods were similar to those from the original Mehlich P1soil test. The Mehlich P1 test is used to estimate available soil P in sandy acid soils low in organic matter. In the new methods, an H_2SO_4 extracting solution of either the same ionic strength (Method A) or same acidity (Method B) as the original Mehlich P1 extractant, extracted similar amounts of soil P.

Anion Exchange Membrane (AEM) values are a good tool for predicting potential P movement by soil erosion or runoff. Gale et al. (2000) found that membrane bound P was strongly correlated with manure application rate and available P ($NaHCO_3$). Best management practices for manure disposal need to consider the potential for P movement and the AEM technique provides a means for evaluating potential movement from the soil surface.

Accumulation of P in soil can be estimated by soil testing and the P sorption capacity of soils can be determined from sorption isotherms. However, sorption isotherms are time-consuming (Sample et al., 1980). Bache and Williams (1971) proposed the use of a P sorption index, obtained from equilibration of a soil for 17 h with a single P solution at a ratio of 1.5 g P/kg soil, as a fast and simple means to estimate P sorption maxima for soils. This was confirmed by Mozaffari and Sims (1994) for surface and subsurface horizons of soils from a watershed dominated by animal-based agriculture.

Efficient management of P amendments on soils susceptible to P loss often involves the subsurface placement of fertilizer and manure and the periodic inversion of P stratified soils to redistribute surface P accumulations throughout the root zone. Both practices may indirectly reduce the loss of P by decreasing its exposure to surface runoff and by increasing crop uptake of P and yield. A linear relationship exists between P levels in surface soil (0 – 2 cm deep) and Dissolved Reactive P (DRP) concentrations in runoff from the soil surface. Pote et al. (1999) showed that several STP extractants might be useful for predicting DRP concentrations in runoff. Increased concentrations of dissolved reactive P (DRP) in surface runoff are highly correlated to increased STP levels. Also, soil that contains high levels of P from excessive fertilization can become the primary source of DRP in runoff. Effects of STP levels on DRP concentrations in runoff are not always consistent across soil series, and much of the difference can be attributed to soil hydrology. This implies that knowledge of site hydrology can improve the usefulness of STP data for predicting DRP concentration in runoff. Besides, Pote et al. (1999) showed that some of these relationships can change with seasonal changes in field conditions, especially as warm, wet conditions prevalent in the early part of the growing season change to hot, dry conditions in late growing season in most parts of the US.

Land Application of Waste Materials

Long-term sustainability of an ecosystem in part depends on the ability of soils in the ecosystem landscape to recycle nutrients and reduce potential off-site water quality problems. The P sorption capacity of a soil plays a pivotal role in nutrient recycling in agro-ecosystems and in reducing the potential for transport of P to surface waters. This is reflected in increases in soil test P and total P in the surface and subsurface horizons of soils receiving animal manure or municipal biosolids.

From an environmental standpoint, continuous addition of P from animal manure at excessive rates particularly in soils low in Fe, Al and clay may lead to the saturation of a soil's P sorption capacity. Once this occurs, any additional input of P may result in its loss into shallow water tables or drainage water. In the Netherlands, long-term application of P in manures and fertilizers in quantities exceeding crop removal during the past two decades has resulted in saturation of more than 42% of the soils in grasslands with respect to P. As a result, soluble P concentrations as high as 1 mg/L, relative to a critical level of 0.1 mg/L for eutrophication of P limiting surface waters, have been reported in these areas (Breeuwsma and Silva, 1994). Sims (1991) pointed out that excess P accumulated in soils treated with organic waste (such as animal manure) has the potential to leach into the soil and enter the surface water through lateral transport.

Vivenkandan and Fixen (1990) measured soil test P in an Egan silt loam (Udic Haplostolls) 8 years after one single application of beef cattle manure. Despite P removal by eight crops of corn, available P in the surface horizon as estimated by Bray P1 (0.03M NH_4F + 0.025M HCl) was 169 and 320 mg/kg in plots that received 90 and 280 Mg/ha of manure relative to 45 mg/kg P in the check plot. Application of beef feedlot manure for 8 years at the rate of 67 Mg/ha/yr to a Pullman clay loam (Torretic Paleustolls) used for continuous grain sorghum production increased total P in the surface horizon (0 to 30 cm) from 353 mg/kg in an untreated check plot to 996 mg/kg in manured plots. Available P, as measured by Bray P1 (0.03M NH_4F + 0.025M HCl), increased from 15 to 230 mg/kg (Sharpley et al., 1984).

In addition to increasing soil test P and total P, addition of animal manure has been shown by some researchers to reduce the capacity of soil to sorb additional P. Application of beef cattle manure to an Egan silty clay loam (Udic Haplustoll) in southeast South Dakota increased soil soluble P to 27.5, 50, and 71.6 mg/L for treatments that received manure at the rates of 90, 199 and 280 Mg/ha (dry weight basis) respectively, relative to 3.2 mg/L in the check plot (Vivenkandan and Fixen, 1990). However, addition of animal manure has not decreased P sorption capacity in all soils (Field et al., 1985). The reduction in P sorption capacity of some manure amended soils has been attributed to the complexation of organic acids and anions (produced as manure decomposition end products) with Fe and Al and subsequent blocking of P retention sites by these complexes (Reddy et al., 1980; Sharpley and Halverson, 1993; Sims and Wolf, 1994; Singh and Jones, 1976).

Reddy et al. (2000) investigated the combined use of manure and fertilizer P, finding applying both the manure and fertilizer forms resulted in a greater crop yield and P uptake than applying the same total P rate using only one of these two P forms. When fertilizer P was supplied together with manure, the accretion of organic P was promoted. Generally the increases in organic P fractions due to manure additions are strongly associated with a concomitant increase in the soil organic carbon. Cropping without manure and fertilizer P depletes soil organic P, while regular additions of manure and fertilizer P favors its accumulation. The magnitude of depletion/build-up is strikingly larger for moderately-labile organic P (MLOP) and moderately-resistant organic P (MROP) fractions compared to others, indicating that these two fractions are major sources and sinks for plant-available P in soil.

These findings have significant implications for soils under cattle production in Florida. Much of Florida's cattle industry is located in south and central Florida. Soils in this area are primarily Spodosols, Entisols and Histosols (Flaig and Reddy, 1995). Surface horizons have low P sorption capacity due to low clay, iron, and aluminum. Additionally, many of these soils are artificially drained. These conditions may enhance the lateral movement of water and nutrients toward the drainage ditch and ultimately into the nearby streams and lakes (Campbell et al., 1995; Graetz and Nair, 1995).

Biosolids

One of the primary concerns associated with the land application of biosolids (sewage sludge) to pastures and rangelands is its effects on the quality of runoff water. The greatest challenge in land application of biosolids for beneficial use is predicting P bioavailability and N mineralization rates so that managers can amend the soil with the proper agronomic rate and avoid soil nutrient losses to ground and surface waters. Application rates of biosolids (and other non-hazardous wastes) are customarily based on the N needs of the crop being grown. This practice results in P inputs (~200 kg P/Ha) that usually exceed the amounts of P removed in normal crop production (~20-40 kg P/Ha), and promotes P accumulation in soils. In many states, such over-application of waste-borne P (and fertilizer-P) has led to 30% or more of soils being rated as high or excessively high in soil test P (Gartley and Sims, 1994). If a mechanism exists to transport particulate or soluble P to nearby surface waters, such P-rich soils may promote eutrophication.

Unfortunately, biosolids-bound P reactions have not received nearly the study that biosolids-bound N has. Evaluation of P availability in land-applied biosolids should consider the chemical nature and amount of P in the residuals and the physicochemical properties of the soil being amended. The forms and solubilities of P in residuals vary greatly with waste treatment processes, the composition of the wastewater, and the mode of digester operation (Sommers and Sutton, 1980). It follows that different types of residuals added to the same soil might exhibit varying degrees of P bioavailability.

O'Connor and Sarkar (1999) experimented laboratory, greenhouse and field data to determine the fate of residuals-borne P in Florida soils and to develop environmentally sound residuals application guidelines for P. Objectives include determining the bioavailability of residuals-P, the forms of P in residuals and how the forms change in residuals-amended soils, and the extent to which residuals-P leaches. Laboratory studies focused on P forms; greenhouse studies addressed bioavailability and leaching objective.

Bioavailability of residuals-P was evaluated by plant uptake of P relative to fertilizer-P applied at equivalent total P rates. As expected, bioavailability depended on both the residuals and amended soil properties. Residuals with abundant KCl-extractable P (readily available) had P bioavailabilities nearly as great as fertilizer-P, whereas residuals with low KCl-P values had much lower P bioavailabilities. Differences in P bioavailabilities were masked in high soil test-P soils that adsorbed abundant P, but were obvious in poorly P-sorbing soils in both greenhouse and field studies. They recommend characterization of both residuals (KCl-extractable P) and soils (oxalate-extractable Fe and Al, soil test-P) to estimate effective residuals-P bioavailability. Using total residuals-P, or some fixed percentage of total P does not accurately assess residuals-P availability.

Residuals-P is dominantly inorganic and, for the residuals studied by O'Connor and Sarkar (1999), primarily in Fe and Al forms. In soils, or residuals, with abundant oxalate-extractable Fe and Al, P solubility, bioavailability, and leachability are limited. Residuals with abundant Fe and Al can increase P retention temporarily (2-3 years in the field) in poorly P-sorbing soils, making P less subject to leaching. Results suggest that adding Fe and Al to a waste treatment stream, or mixing domestic residuals with water treatment residuals, can significantly reduce residuals-P solubility and P leaching in poorly P-sorbing soils (O'Connor and Sarkar, 1999).

Mehlich-I and Fe-strip soil tests were equally effective in predicting plant uptake of P. Mehlich-I is routinely run by soil testing labs and, thus, likely preferable. Preliminary data suggest that measuring Fe and Al in the Mehlich-I extract may also successfully characterize a soil's P-sorbing tendency. The soil test may, thus, serve both agronomic and environmental testing purposes.

Based on data collected from laboratory, greenhouse and field studies, O'Connor and Sarkar (1999) developed a qualitative scheme useful for guiding residuals applications. The scheme identifies poorly P-sorbing soils amended with high KCl-P class AA residuals as being undesirable (extensive leaching of P expected). Strongly P-sorbing soils (with or without abundant native soil test-P) may be safely amended with class AA residuals. Soils with intermediate oxalate-extractable Fe and Al contents can be problematic, depending upon residuals-P characteristics. Residuals application rates may have to be reduced to supply P equivalent to plant P needs to protect against P leaching when residuals are high in KCl-P.

Pierce et al. (1998) found that surface application of biosolids did not significantly change total or plant species-level aboveground biomass. Surface application of treated municipal sewage sludge was actually observed to reduce runoff in semiarid grasslands. The mechanism for this reduction in runoff yield is increased ground surface roughness. Increased P and NH_4-N concentrations in runoff from sludge-amended plots are simply due to the higher P and NH_4-N loading to the soil. Because contact between the sludge and soil is minimal, the primary mechanism for P transport into runoff is from the soluble and suspended organic fraction. In a study conducted by Harris et al. (1995), all measured N and metals concentrations in runoff from biosolids-amended lands, were less than current water quality standards for agricultural use.

In Florida, required setback distances from surface waters for residuals applications promote soil and residuals retention. This minimizes the threat of surface water contamination with eroded soil-associated (particulate) P. Environmentally sound guidelines for residuals application to such soils can be especially complex. Guidelines should consider the crop needs for nutrients (N, P), initial P status of the soils, P-retention capabilities of the soils, and P characteristics of the residuals. Given the particular sensitivity of some Florida soils to significant leaching, studies of the fate of biosolids-bound P are prudent. Such studies should seek to characterize both the nature of P in biosolids (e.g., forms, extractability or "availability", etc.) and the nature of P reactions in various soils (e.g., reaction products, extractability, retention/release tendencies, etc.). It is possible that environmentally sound residuals application guidelines for P would be biosolids/soil-specific.

Sludge is a valuable source of plant macro and micro nutrients (N, P, Cu, Fe, Mn, Zn) and organic matter, but it also contains heavy metals (Cd, Cr, Ni, Pb) that are potentially hazardous. Leaching of heavy metals is a concern because some metals accumulate in the soil, thus becoming toxic to plants and humans. Land application of biosolids (sewage sludge) can significantly increase heavy metal concentrations in agricultural soils (Sloan et al., 1998). For soil management and water quality purposes, it is important to determine the long-term fate of biosolid-applied heavy metals. Most metals in water treatment sludges occur predominantly in weakly mobile, non-bioavailable forms (Elliott et al., 1990). With increased soil acidification, mobility and bioavailability of metals increases. The initial leaching of heavy metals is attributed to their soluble or exchangeable forms and to the subsequent slow leaching to the solid compounds.

Poultry Litter

Land application of poultry wastes serves a dual role: first, it alleviates the practical problems associated with build-up of litter and manure; second, it fertilizes receiving crops. The application rate depends on whether the primary objective is to maximize the fertility related aspects of the waste or to simply dispose of the waste (Edwards and Daniels, 1992). The excellent fertilizer value has been reported by a number of investigators. Jacobs et al. (1996) list three benefits of using poultry manure and litter as a fertilizer in Florida. The primary benefits are that poultry wastes provide the essential nutrients N/P/K; the secondary plant nutrients calcium, sulfur and magnesium; and the minor nutrients zinc, copper, boron and manganese. A second benefit of poultry manure is that it provides Florida acid soils a source of lime by virtue of the calcium carbonate content of the poultry wastes. A third benefit is the organic matter poultry manure adds to the soil. This enhances the soil moisture holding characteristics of sandy soils thus improving soil retention and uptake of plant nutrients.

Sloan et al. (1996) identifies poultry manure as perhaps the most desirable of the natural fertilizers by virtue of its high nitrogen content delivered in combination with other nutrients and organic matter. Poultry manure is often produced in areas where it is needed for crop, hay, and pasture fertilization. The increased size and frequent clean out of many poultry operations make this material available in sufficient quantities and on a timely basis to supply significant fertilizer needs. Land application of litter has been shown to increase yields of pasture grasses such as tall fescue, orchardgrass, bermudagrass, and tall fescue-clover (Adams et al., 1994). Broiler litter slowly releases nutrients, particularly N, so growth rates of grasses following litter applications are not as pronounced as observed with commercial fertilizers (Honeycutt et al., 1988).

Application of animal manures in excessive amounts can result in increased surface runoff of nutrients and degradation of ground water. In general, plots receiving poultry litter have significantly greater losses of most nutrient parameters (Sauer et al. 1999). However, the potential for nutrient losses can be reduced by using soil amendments such as by-products of the drinking water pretreatment process, commonly referred to as Water Treatment Residuals (Al-WTR), alum sludge, or alum hydrosolids. This material contains aluminum oxides capable of adsorbing soluble P (Peters and Basta, 1996). WTR aluminum exists as an insoluble form of aluminum oxide and does not dissolve in soil environments of pH greater than 5. Gallimore et al. (1999) documented that reductions in P runoff were attributed to amorphous Al while reductions in NH_4-N were related to the cation-exchange capacity of the Al-WTR.

Shreve et al. (1995) conducted a study to determine the effect of chemical amendment (Alum) on P concentrations and load in runoff and to evaluate the effects of amended litter on forage production. Litter was broadcast applied to fescue plots at 11.2 Mg/ha (dry weight basis) alone and in combination with alum sulfate at a 1:5 amendment/litter ratio. Rainfall simulators were used to produce 3 runoff events at 2, 9, and 16 days after litter application. The addition of alum reduced P concentrations in runoff by 87 and 63% of that from litter alone for the first and second runoff events, respectively. The application rate of poultry litter has been observed to also affect NO_3-N concentration in vadose water under fescue plots, such that fertilizing pastures with poultry litter may enhance NO_3-N movement to groundwater (Adams et al., 1994). The risk of increased sediment runoff into nearby water bodies is a concern often raised regarding Al-WTR application to pasture lands. However, Gallimore et al. (1999) has shown that Al-WTRs can be applied without a resulting increase in sediments or Al concentrations in runoff.

Addition of poultry litter to soil greatly increases soluble reactive P concentrations but additions of chemically-amended litters, especially with high rates of alum and ferrous sulfate, significantly decreases these concentrations compared to additions of unamended litter. The addition of Al and Fe amendments to litter results in low P solubility in soils over a wide pH range for long time periods. Shreve et al. (1996) found that with addition of litter containing 200 mg alum/kg litter, soil SRP decreased from initial concentrations of 4.5 to 11.5 mg P/kg down to approximately 1 mg P/kg after 294 days. Direct application of aluminum sulfate [$Al_2(SO_4)_3 \cdot 14H_2O$] to poultry litter greatly reduces P concentrations in runoff and decreases NH_3 volatilization. Shreve et al., (1996) cites precipitation and/or adsorption reactions as the probable mechanism for this observed decrease in P solubility in the litter. The mechanism for inhibition of NH3 volatilization is aluminum sulfate lowering the litter pH, which controls the NH3:NH4 ratio.

Soluble P can also be reduced by mixing poultry litter with direct chemical amendments such as CaO, $CaCO_3$, $AlSO_4$ or $FeSO_4$. Calcium reacts with soluble P to form insoluble Ca phosphates in soils at moderate to high pH (pH>6). Gallimore et al. (1999) showed that $Ca(OH)_2$ (slaked lime) decreased P solubility in poultry litter in the same manner as CaO (quick lime). Reagent-grade CaO and $Ca(OH)_2$ were found to be the best amendments in reducing soluble P in chicken litter. Since slaked lime is less caustic, this treatment would be preferable to quick lime, which can cause severe burns upon skin contact (Moore et al., 1994).

Liming of poultry litter can increase its pH but this change dissipates with time, due to equilibration with atmospheric CO_2. This gradual reduction in pH after liming may result in increased P solubility, since calcium phosphates solubility is extremely pH dependent (Moore et al., 1994). The mechanism by which alum removes phosphate from solution is pH-dependent. Under acidic conditions (pH<6) $AlPO_4$ forms, whereas at pH 6 to 8, an $Al(OH)_3$ floc forms, which removes P from solution by sorption of inorganic phosphate and entrapment of organic particles containing P. The optimum pH range for P removal by Al is 5.5 to 8.0 (Moore et al., 1994).

Removal of P using iron, ($Fe_2(SO_4)_3 \bullet 2H_2O$ or $FeCl_3$) is enhanced by maintaining the litter pH at a higher level. An adjustment of pH is also necessary for ferric iron systems that contain SO_4, such as the $Fe_2(SO_4)_3 \bullet 2H_2O$ treatment, because when extremely acid conditions occur, water soluble P levels increase dramatically. Ferrous sulfate ($FeSO_4 \bullet 7H_2O$) additions greatly decrease the solubility of P in poultry litter. Water soluble P concentrations were not significantly different in $FeSO_4$ treatments amended with $CaCO_3$, indicating that P removal with this compound is less pH dependent than for some of the other Fe compounds (Robinson et al., 1995).

Robinson and Sharpley (1996) found that the reaction of P added as poultry litter leachate was different from that added as KH_2PO_4 to six soils. In leachate-treated soils, the short-term bioavailability of P (strip P) was consistently lower than in KH_2PO_4-treated soils. From an agronomic standpoint, the data indicate that poultry litter has a higher residual P fertilizer value than the KH_2PO_4 source. They concluded that manure application rates for agronomically and environmentally sound P management guidelines should not be based solely on data from mineral fertilizer trials.

The influence of drying temperature on the release of N and P should be considered when determining the optimum timing of poultry litter application. It is suggested that the timing of poultry litter application coincide with active periods of crop growth to combine maximum agronomic productivity with minimum edge-of-field losses of N and P to surface and groundwater (Robinson et al., 1995).

Water Treatment Plant Residuals

Alum [$Al_2(SO_4)_3 \bullet 14H_2O$] is used in the drinking water treatment process to destabilize colloids for subsequent flocculation and water clarification. Alum sludge is the water treatment residual (Al-WTR) from this process and is considered to be a waste material. Biosolids (sewage sludge) are a by-product of the wastewater treatment process. The disposal of Al-WTR alone would be beneficial to soils high in P, since the Al-WTR can adsorb soluble P. Likewise, the co-application of Al-WTR and biosolids may be advantageous to municipalities as a means of disposing of high P bearing biosolids in an environmentally sound manner. Because of Al-WTR's ability to adsorb P, Al-WTR could play a role in the removal of P in sewage treatment plant effluent (Ippolito et al., 1999). It is possible that too much Al-WTR applied to a soil, in conjunction with biosolids, can induce natural P deficiencies. If co-applying Al-WTR and biosolids to soil at ratios greater than 8:1, all biosolids available P, as well as some plant-available soil P, could be adsorbed by the Al-WTR. The P adsorptive capacity of Al-WTR is a function of Al-WTR age, pH, particle-size fraction and surface area, and the availability of P. Increasing the ratio of Al-WTR to biosolids in a mixed material will decrease shoot P concentration in some type of grass such as in blue grama. Increased Al-WTR rates increases dry matter yields, decreases P and Al shoot concentrations. This increase in dry matter combined with the decrease in concentrations results in no net effect on total mass of P and Al uptake into grass shoots (Ippolito et al., 1999).

Alum amendments reduce trace metals in runoff. This reduction appeared to be related to the concentration of soluble organic C (SOC). Metals concentrations were higher using untreated litter compared to alum-treated litter (Moore et al., 1998). Alum-treated litter or alum hydrosolids have neutral or alkaline pH and Al exists as insoluble Al oxides, which should not release toxic Al or produce acidity in soil or aqueous systems (Peters and Basta, 1996). Copper concentrations are significantly lower when alum-treated litter is used rather than normal litter.

Soil pH is an indicator of the relative availability of nutrients. Low soil pH stress is a major growth limitation to crop production in many regions. At low pH, it is not often the H^+ ion activity that limits growth, but the toxicity and/or deficiency of other elements. On the basis of existing literature, Al toxicity is one of the yield-limiting factors that have been identified in acid soils. It is very difficult to determine the direct effects of H^+ ion toxicity on plant growth in acid soils because of the changing interrelationships that occur between pH and Al concentrations in the soil solution, and the changing availability of essential nutrients (Fageria et al., 1990).

Aluminum concentration can be sufficiently high in acid soils with pH values of 5.5 or below to be toxic to plants. The aluminum species which are responsible for the phytotoxic effect appear to be a small fraction of the total aluminum in the soil solution. It is not possible at present to run routine chemical tests to accurately determine the level of toxic aluminum species in individual soils. The bioassay for identifying Al-toxic soils can be simplified based on the observation that aluminum toxicity first affects the roots. It is possible to use root length to quantify aluminum toxicity in soil. At this early growth stage, in many species the root system is limited to one primary root, which simplifies the measurement. Many soil horizons with pH values of 5 or below are not toxic to plant roots. The poor relationship between pH and root length indicates that we cannot assume that poor plant growth on an acid soil is the result of aluminum toxicity. Even soils with high levels of soil solution aluminum may not produce toxic effects in plants. Much of the solution aluminum in non-toxic, acid soils must be in complexes or other forms which keep the activity of toxic forms very low. The consistency of results when test parameters are varied indicate that a two-day petri dish technique should be a useful routine test or diagnostic tool for work with acid soils (Sawhney et al., 1996).

Demonstration Project Design

The demonstration project design of the study (Tables 1 and 2) will consist of 51 plots, 3 plots evaluating a traditional commercial fertilizer product plus a 48-plot randomized block study consisting of three blocks with each block evaluating two phosphorus sources (one biosolids and one chicken manure) applied at 4 treatment levels, with and without an alum-base water treatment plant residual. The anticipated treatments for the biosolids are 0, 0.5, 1, and 5 tons per acre dry weight basis. These treatments were formulated using IFAS recommendations for both N and P nutrient requirements of south Florida pasturelands. In addition, a supplemental commercial fertilizer treatment (#17) is included in each block. This commercial fertilizer treatment will be applied at the P agronomic rate. The treatments may vary in number of P sources or rates being investigated within contractual constraints if new information becomes available to the TRT that deems design change beneficial to the objectives of the study.

Table 1. Description of treatments, 2x4x2 factorial.

Treatment No.	P Source	P Rate, kg/ha	Alum Rate, kg/ha
1	Residual	P1 (Control)	0
2	Residual	P1	X
3	Residual	P2	0
4	Residual	P2	X
5	Residual	P3	0
6	Residual	P3	X
7	Residual	P4	0
8	Residual	P4	X
9	Manure	P1 (Control)	0
10	Manure	P1	X
11	Manure	P2	0
12	Manure	P2	X
13	Manure	P3	0
14	Manure	P3	X
15	Manure	P4	0
16	Manure	P4	X
17*	Commercial Fertilizer	P3	0

* Represents a supplemental treatment in addition to the balanced randomized block design

Table 2. Sample layout, with treatments randomized within each block.

Block 1

9	8	13	3	10	7	1	14	11	2	15	12	5	6	16	4	17

Block 2

17	3	14	8	12	1	6	2	16	7	13	4	9	5	10	15	11

Block 3

6	1	9	2	5	10	7	13	4	11	14	8	15	12	16	3	17

Site Selection

Site selection is a critical step in the project development process. Considerations in the selection of a host site for the experiment include:

1. Cooperation of land owner
2. Availability of waste materials for land application
3. DEP permit for land application of biosolids
4. Suitability and uniformity of soil type
5. Reasonable background levels of phosphorus in soils
6. Uniform topography and drainage characteristics over 20 acres
7. Proximity to research support infrastructure
8. Accessibility by residuals application and hay harvesting equipment
9. Suitable grass type (stargrass or bahiagrass)

Officials of the SFWMD have selected a pasture on Kirton Ranch as the project site. The project will be located at this site if the background soil P levels are deemed acceptable. Kirton Ranch is located approximately six miles northeast of Okeechobee. If the Kirton Ranch site is determined to be unsuitable for the project then the project will be conducted at MacArthur Agro-ecology Research Center (MAERC) at Buck Island Ranch. Buck Island Ranch is within the Lake Okeechobee Basin. This site is 10,000 acres and is a ranch typical of the Lake Okeechobee region. The MAERC ranch manager and research director have expressed a willingness to host the project, thus satisfying condition 1.

Condition 2 (availability of waste materials) is an unanswered question requiring further investigation.

Condition 3 (DEP permit), if needed, will be pursuited with DEP officials at the South District office in Ft. Myers. They have expressed willingness to facilitate the permitting process for this project. Requirements include: completion of the permit application (AUP.pdf) and producing a copy of the SFWMD Staff Report for the Surface Water Management Permit issued for the ranch. A representative from the DEP Ft. Myers office has offered to conduct a site inspection and expedite the permit.

Meeting conditions 4, 5, 6, and 8 are dependent on finding a suitable 33-acre site.

If the Kirton Ranch site assessment proves unsatisfactory then steps to finalize the Buck Island Ranch site selection will include:

A. Confirming the willingness of MAERC to host the project.
B. Inspecting the NRCS detailed soil survey conducted on the ranch in 1998.
C. Selecting a specific site with minimal ditch, fence, and access problems.
D. Testing the soil to confirm suitable background P concentrations.
E. Securing the DEP permit for residuals application (Appendix 3).

Demonstration Plots Layout

The layout of the demonstration project plots will be selected based on a combination of site constraints and project needs. Site constraints may include available land, ditching patterns, soil variability, roadways, residuals permit conditions, etc. The dimensions selected for the plots will affect several project factors including ditch construction and maintenance costs, fencing costs, runoff variability as dictated by rainfall patterns, runoff magnitude as affected by ditching density, harvesting patterns and costs, and residuals application patterns and costs.

Table 4 summarizes the plot dimension options and their implications for ditch and fencing construction/maintenance. If a geometric configuration for all 51 plots in 3 blocks is selected as shown in Figures 1 and 2 then overall site dimensions can be determined from the plot dimensions. Assuming three separate blocks of 17 plots each then the most viable options for plot sizes appear to be those in the 70' to 100' width range. Plots narrower than 70 feet become highly inefficient relative to ditch & berm requirements, while widths greater than 100 feet represent site selection and rainfall variability problems.

Table 4. Plot dimension options and implications for ditch and fencing costs.

Plot Width	Plot Length	Plot Perimeter	Ditch Inefficiency	Site Width	Site Length	Site Perimeter	Fence Inefficiency
40	545	1169	98%	780	1784	5127	9%
50	436	971	65%	950	1457	4814	2%
60	363	846	43%	1120	1239	4718	0%
70	**311**	**762**	**29%**	**1290**	**1083**	**4747**	**1%**
80	**272**	**705**	**19%**	**1460**	**967**	**4854**	**3%**
90	**242**	**664**	**12%**	**1630**	**876**	**5012**	**6%**
100	**218**	**636**	**8%**	**1800**	**803**	**5207**	**10%**
110	198	616	4%	1970	744	5428	15%
120	182	603	2%	2140	695	5669	20%
130	168	595	1%	2310	653	5925	26%
140	156	591	0%	2480	617	6193	31%
148	148	590	Square	2608	593	6401	36%

The entire project site (approximately 32 acres) will be surrounded by a fence of sufficient integrity to exclude cattle and also prevent invasion by wild hogs. Hogs have the potential to seriously disrupt the field experiment through their rooting activity, which can leave the plots in a condition similar in appearance to a freshly plowed field.

The earthworks, which define each plot, will be constructed by a subcontractor using methods appropriate to delivering berms and ditches of the desired dimensions of the earthworks. Interior plot ditches and border berms will be initially established at an approximate depth and height of 12 inches relative to the local land surface datum.

The linear feet required for ditches and berms are minimized when the individual plots are square in shape (148 feet by 148 feet). Any deviation from this shape results in an increase in the linear feet of ditches and berms. This is quantified in Table 4 as "ditch inefficiency" calculated as the ratio between the increased ditch length and the minimum possible ditch length (square scenario). Similarly, the linear feet of fencing required for the project is based on the individual plot dimensions combined with the block configuration, as shown in Figure 1. Assuming 3 blocks of 17 plots each, a relationship can be drawn between the individual plot dimensions and the required fencing perimeter. The fencing is minimized when the 32 acre project site is square in shape (1181 feet by 1181 feet). The increase in the perimeter is quantified in Table 4 as the "fence inefficiency" calculated as the ratio between the increase in fence length and the minimum possible perimeter.

Runoff water from the demonstration plots will be carried away from the immediate area by a ditch that will continue downslope for a distance that achieves the required drainage but does not infringe upon any nearby streams or isolated wetlands. The Kirton Ranch topography has sufficient slope to allow the runoff water to be removed, thus avoiding any potentially problematic backwater effects at the individual demonstration plot flumes.

Figure 1. Potential arrangement of plots.

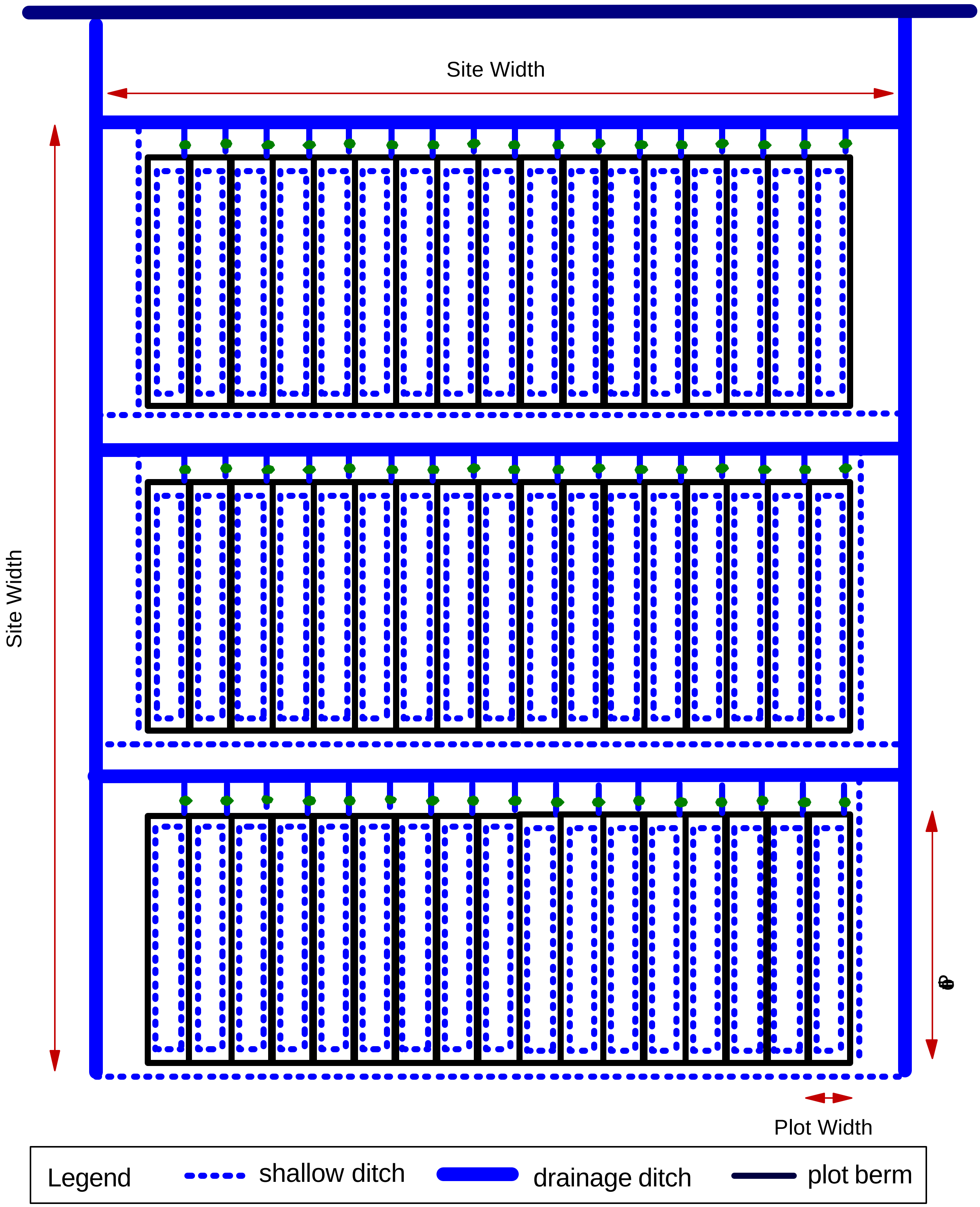
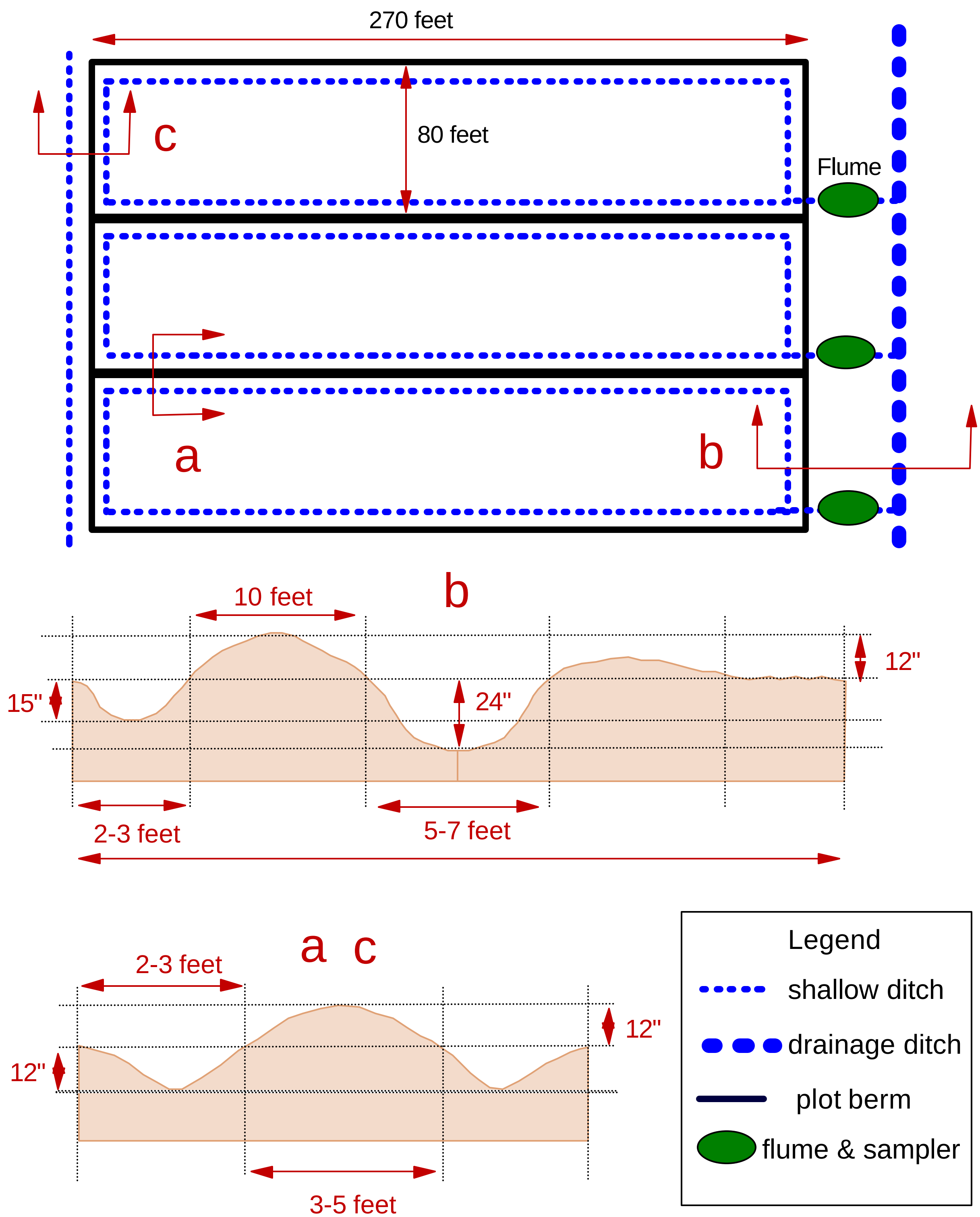


Figure 2. Detailed plan of plots, berms and ditches.



Characterization of Wastes and Soil

Laboratory analyses will be conducted on at least 5 Class B residuals, 1 chicken manure sample, 1 Al-WTR, and 15 representative soil samples. The soil samples will be collected from multiple depths (3) at multiple locations (5) to ensure accurate assessment of the experimental study site. These samples will be analyzed for total solids, pH, conductivity, organic carbon, total and extractable Fe, Al, Ca, Mg, and P. A chemical fractionation procedure will be used to determine the forms and distribution of P in the waste materials and soil. Phosphorus will be fractionated into organic and inorganic forms. The inorganic P will be separated further into labile P, Fe/Al-P and Ca-P by extractions with 1M KCl (O'Connor and Sarkar, 2000), 0.1M NaOH, and 0.5 M HCl., respectively (Hieltjes and Lijklema, 1980). The labile or available P pool in the materials will be evaluated further using iron-oxide strip as performed by Sharpley (1996) and established by Sharpley (1993) and using Mehlich 1 reagent (Sparks, 1996). Phosphorus sorption and desorption properties of the soil and Al-WTR will be determined using batch incubation (Reddy, et al, 1980).

Collection of these samples will be performed by Southern DataStream technical staff operating under SOPs approved by the cooperating UF-IFAS faculty (Dr. George O'Connor and Dr. Tom Obreza) with supplemental input from other cooperating faculty (Dr. Don Graetz and Dr. Rosa Muchovej). The Southern DataStream technical staff will be required to demonstrate competency in the sampling methods to the participating faculty prior to commencement of sampling tasks. Laboratory analyses will be performed by the UF-IFAS Soil Chemistry Laboratory (CompQAP 970022).

Residuals Selection and Application

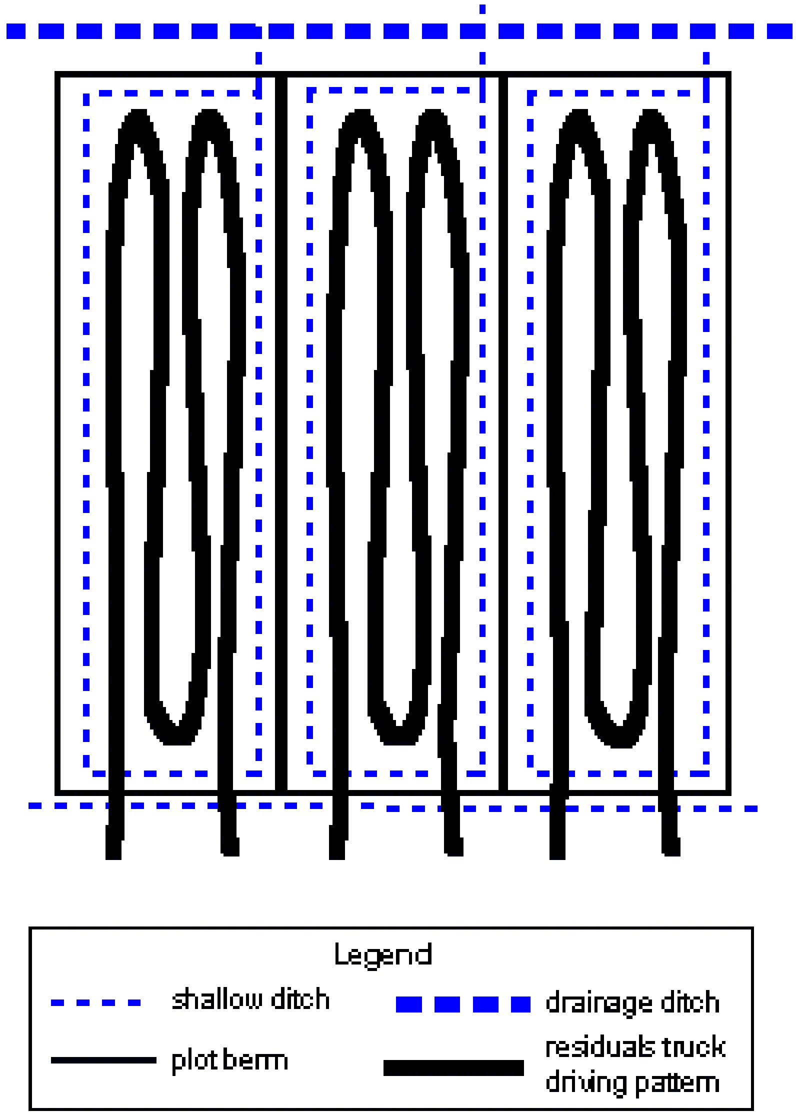
The residuals selected for this project will be based on local practices and product availability. This decision may remain open until completion of the site construction. Three materials will need to be selected: the waste water plant residual (biosolids), the water treatment plant residual (Al-WTR), and the chicken manure.

There will be four application rates of the biosolids and chicken manure. The first is the zero control and the second is the agronomic P rate. The other two are the "below-P" rate and the "above-P" rate. Determination of the specific agronomic P rate is dependent on the actual hay crop grown at the selected site and the availability of phosphorus in the residuals and soils. The below-P rate will probably be half to a third of the agronomic P rate. Assuming a P requirement for a bahiagrass hay crop of about 20 lbs/acre and a biosolids P content of ~2%, yields a biosolids application rate (based on P) of 0.5 tons/acre. EPA currently allows an assumption of 50% availability of biosolids-P, so the intermediate rate could be 1 ton/acre. The biosolids rate based on N would be approximately 5 tons/acre. This would represent a reasonable above-P application rate. The resulting biosolids treatment levels would be 0, 0.5, 1, and 5 tons/acre. A similar analysis will be performed on the chicken manure product selected for use on the project.

The selection of the single application rate for the water treatment residual will have to be based on analysis of the specific material selected for use in the project. The P sorptive capacity of Al-WTR is a function of material age, pH, particle-size fraction and surface area, and the availability of P. Ippolito et al. (1999) found that co-applying the City of Fort Collins (CO), Al-WTR and biosolids at ratios of 8:1, will adsorb all soluble biosolids P in the blue grama and western wheatgrass study. Beyond this ratio Al-WTR could adsorb all biosolids available P as well as some plant-available P.

Application of the residuals to the hay field plots will represent a significant challenge for a commercial hauler given: (1) the relatively small dimensions of the individual plots, (2) the relatively low application rates of the residuals, and (3) the random nature of the treatment assignments to plots with in a block. Ensuring that the hauler applies the proper amount for each plot and does so with good rate precision will require close supervision and a cooperative hauler. Funds have been allocated in the project budget to allow use of special precision application equipment for this task. A buffer zone of at least 5 feet will be established between the application zone and the edge of plot shallow runoff collection ditches. Figure 3 provides an example application pattern for the demonstration project plots.

Figure 3. Residuals application pattern.



Flow Measurement and Samplers

Each demonstration plot will be equipped with a flow-integrating sampler. One of two designs will be used for these samplers. The first design option is a paddlewheel system originally developed by Bottcher and Miller (1991) and recently modified by Dr. Del Bottcher of Soil and Water Engineering Technology, Inc. The second sampler design option is a concept developed by Southern DataStream. It is composed of a Parshall flume combined with a passive head-driven sampler. Both the paddlewheel sampler and the DataStream sampler are specifically designed and adapted to meet the surface water sampling requirements of Florida pasturelands. The paddlewheel samplers have been employed by other SFWMD studies in the Okeechobee region. The primary advantages of the paddlewheel systems are (1) their lack of dependency on external power and control systems, (2) their ability to take and store a flow-integrated sample, (3) flow capacity appropriate for very small research plots, and (4) flow estimates of 20% accuracy based on a simple linear relationship between sample volume and total flow. The paddlewheel responds to flow passing through its rectangular flume by rotating and, with each rotation, picking up a small volume of water and delivering this aliquot to a composite sample collection container.

Observed disadvantages and limitations associated with the paddlewheel samplers include: (1) a nonlinear relationship between flow rate and sampling rate, (2) a tendency of the system to clog and/or jam as the result of vegetative debris in the runoff water, and (3) difficult access for cleaning the internal flume throat section, (4) tight internal clearances required to induce sampling at low runoff rates resulting in the potential for paddle contact with the walls and subsequent sampler malfunction, and (5) inadequate sample container isolation resulting in external contamination from dust, debris and insects. Efforts are being made to introduce design modifications that will reduce these sampler operational limitations.

The samplers will be augmented by secondary flume measurement systems on three of the plots. These data will also be transmitted to an Internet web site through the telemetry system. These data will provide a basis for evaluating the performance of the samplers in acquiring proper flow-weighted water samples. The real time nature of the data delivery system will provide immediate notice of flow events at the project site, thus enabling the field sampling team to collect grab samples during select runoff events. The flow samplers will be placed in small ditches connecting the internal plot perimeter ditch to the external collection/removal ditch. These units will need to be stabilized to avoid damage during wind storms. Another threat to flume/sampler systems is backwater. The current monitoring project at MAERC (Buck Island Ranch) has been plagued with severe backwater from Harney Pond Canal. Efforts will be made to prevent similar problems in the new project.

A weather station and flowmeter counter will be established at one of the flow-integrating sampler sites. The weather station will consist of a tipping bucket raingage and datalogger. Rainfall is an extremely variable parameter for the region and a useful parameter in evaluating runoff and nutrient loading data. All flume samplers proposed for use in the project will be equipped with sensors to monitor sample acquisition rate. All sensors will be connected to a central data-logger and telemetry system that will transmit the resulting data in real time from the flume/sampler sensors and weather station.

Ground Water Wells

Two shallow ground water wells will be installed on each plot. The screens of these two wells will be placed at different depths, separated by the first aquiclude (i.e. spodic horizon). Depth to the spodic horizon in typical Okeechobee soils is approximately 3 feet. A soil of this type would be therefore best monitored using wells placed at depths of 3 and 10 feet with the screen lengths being 1.5 and 5 feet, respectively. Installation of the 2-inch diameter PVC wells will be accomplished using auger methods best suited to the depth of the wells. Appropriate sands backfill will be used over the screen lengths to minimize introduction of sediments into the wells and water samples.

Water Sample Analysis

As outlined in the RFP, water sampling will consist of both composite samples collected bi-weekly during flow periods, surface grab samples collected at the time of composite sample retrieval, and ground water samples collected monthly and after at least 4 rainfall events. During the rainy season, the occurrence of flow events may require sample retrieval from the field more frequently than bi-weekly. Ground water samples will be analyzed for TDPO4, OPO4 and Total Al. Surface runoff grab samples will be analyzed for TDPO4, TPO4, OPO4 and Total Al. Surface water composite samples will be analyzed for TPO4 only. Ground water and surface grab samples will be tested in the field for pH, specific conductance, and dissolved oxygen with an additional temperature recording made on the surface grab samples. It is expected that a total of 2720 samples of each of the three types will be required to meet the sample collection guidelines of the project. These sample sets will include all QA/QC required equipment blanks, field duplicates and split samples. The technical staff will also invite the SFWMD Water Quality Monitoring staff to subject Southern DataStream to one of their standard water quality field audits.

Water quality sampling and analysis will be conducted in the context of approved laboratory CompQAPs, an approved QAPP, and effective SOPs (Standard Operating Procedures). The water analysis contract lab used in this project will possess a FDEP CompQAP as will the Southern DataStream field sampling team. Southern DataStream is producing and will soon file its Comprehensive Quality Assurance Plan with FDEP outlining its methods for sample collection, processing, field equipment and measurements, field filtration, storage, and shipping. Each of these component tasks will be governed by effective SOPs as distributed by FDEP or as developed by Southern DataStream for tasks not addressed by existing SOPs.

Water quality analysis will be conducted by Dr. Donald Graetz utilizing the UF-IFAS Analytical Research Laboratory (ARL). Dr. Graetz and UF-ARL were selected based on their current involvement in similar projects. The Southern DataStream technical staff is very familiar with procedural preferences of Dr. Graetz (chain of custody, shipping requirements, etc.). Maintaining Dr. Graetz as the contract lab liaison will eliminate start-up errors often associated with new lab-client relationships.

GROUNDWATER		
FREQUENCY	SOURCE	ANALYTE
Monthly and Event-basis	Well	TDPO4
	Well	OPO4
	Well	Total Al

SURFACE WATER		
FREQUENCY	SOURCE	ANALYTE
Event-basis Composite (bi-weekly min.)	Flow-integrating Sampler	TPO4
Event-basis (bi-weekly min.)	Grab	TDPO4
	Grab	TPO4
	Grab	OPO4
	Grab	Total Al

Soils and Vegetation Analysis

Soil samples will be taken at incremental depths to represent A (0-5 cm), E, and Bh horizons twice a year and analyzed for pH, total P, extractable Al and Fe and for available P using various tests, as Mehlich-I and Fe-oxide strip paper, for correlation with plant P uptake. It is estimated that a total of 680 samples will be collected and analyzed during a two-year period.

The bahiagrass crop will be cut and bailed five times per year, approximately once every 45 days during the growing season. Up to 570 plant samples will be collected to determine dry matter yield, total P and Al content over a period of two years. These analyses will be conducted by the UF-IFAS Soil Chemistry Laboratory.

SOILS		
FREQUENCY	SOURCE	ANALYSES
Semi-annually	Soil Sample	pH
		Total P
		Available P
		Extractable Al
		Extractable Fe

VEGETATION		
FREQUENCY	SOURCE	ANALYSES
5 harvests per growing season	Pasture grass	Dry matter yield
		Total P
		Total Al

Public Education and Workshops

Two public workshops will be held in conjunction with this project. The first will be held in October, 2000 to introduce the public to the demonstration project and solicit input and cooperation in its conduct. The second public workshop will serve to disseminate project results and seek feedback from stakeholders.

Hosting the first workshop will be the four primary agency cooperators in this project (SFWMD, FDEP, FDACS, and UF-IFAS) and the project contractor, Southern DataStream. The workshop will be held in Okeechobee at either the SFWMD auditorium or at the local agricultural education facilities. Targeted for attendance at this workshop will be the regional agricultural producers, environmental interest, residuals generators, and waste haulers. Notices will be distributed to these groups through appropriate means.

The Okeechobee workshops will be conducted by Southern DataStream and the participating UF-IFAS faculty. Southern DataStream will assume final responsibility for the execution of the workshops. However, the public education workshops will be available to IFAS for incorporation into faculty extension programs in other parts of the state.

Management Plan

Southern DataStream project supervision will be performed by Dr. John Capece under the direction of the SFWMD project manager. Providing day-to-day field and data support under the direction of Dr. Capece will be senior technician, Mr. Ed Rawlinson. Mr. Rawlinson will be assisted by a series of short-term (6-12 month) student interns provided by another project subcontractor, Intelligentsia Intellitemps, Inc. During the first year of the project, an environmental engineer, Dr. Claudia Perlongo, will provide technical and academic support for the project. Dr. Capece and one or more UF representatives will participate in the preliminary orientation and site selection meetings. Mr. Rawlinson and the student intern will conduct the sampling and service visits to the project site. Dr. Capece will substitute upon any absence of Mr. Rawlinson and will participate in any special repair visits requiring additional technical expertise.

Supervising the activities of the primary subcontractor (University of Florida IFAS) will be two faculty members of the Soil and Water Science Department, Dr. George A. O'Connor (Principal Investigator) and Dr. Thomas A. Obreza (Co-principal Investigator). The UF faculty (or their technicians and student assistants) will train and/or provide on-site direct supervision of soil, waste, and vegetation sampling.

Project Reporting and Tasks Schedule

Southern DataStream shall be responsible for producing and delivering all reports associated with this project to the SFWMD (Table 5).

Table 5. List of tasks, deliverable, and due dates.

Task	Deliverable	Weeks	Date
	Project Execution Date	0	13-Jul-00
1	PROJECT WORK PLAN		
1.1	Draft Work Plan	9	20-Sep-00
1.2	Final Work Plan	12	**5-Oct-00**
2	FATE & TRANSPORT OF P IN SOILS		
2.1	Initiate lab characterization	12	5-Oct-00
2.2	Begin construction	16	**2-Nov-00**
2.3	Complete lab characterization	24	28-Dec-00
2.4	Complete construction	28	**25-Jan-01**
3	EDUCATION OF LANDOWNERS		
3.1	Initial Workshop	12	Oct-00
3.2	Final Workshop	154	Jul-03
4	REPORTING ACTIVITIES		
4.1.1	Quarterly Report	36	**22-Mar-01**
4.1.2	Quarterly Report	49	**21-Jun-01**
4.1.3	Quarterly Report	62	**20-Sep-01**
4.1.4	Quarterly Report	88	**21-Mar-02**
4.1.5	Quarterly Report	101	**20-Jun-02**
4.1.6	Quarterly Report	114	**19-Sep-02**
4.2	Year 1 Annual Report	75	**20-Dec-01**
4.3	Year 2 Annual Report	127	**19-Dec-02**
4.4	Draft manuscript	150	29-May-03
4.5	Draft final report	150	29-May-03
4.6	All data, spreadsheets and programs	156	10-Jul-03
4.7	Final report	156	10-Jul-03
4.8	Final manuscript	156	**10-Jul-03**

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