MONITORING NUTRIENT MOVEMENT ON JOHNSONGRASS PLOTS IRRIGATED WITH SWINE LAGOON EFFLUENT

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INTRODUCTION

Animal production in Mississippi is a viable industry for producers in a single commodity enterprise or in a diversified system. In confined systems, such as those in the production of poultry and swine, generation of waste parallels the efficiency of animal production. As in any production system, an economical method for the disposal, recovery, or recycling of generated wastes must be found. Disposal of animal wastes in a way that is potentially harmful to the environment is not acceptable. Non-point sources of environmental pollution are now being targeted by the EPA as a means of further enhancing water quality in the nation's lakes and streams (USEPA 1984). Some states already have enacted regulations addressing the land disposal of animal wastes (e.g., Arkansas). This need not be a hindrance to the expansion of such industries in Mississippi, providing sound management strategies are developed. Land application of nutrients (nitrogen, phosphorus, potassium, etc.) should be based on environmental criteria that protect valuable water resources. However, this goal must be balanced with the economic constraints inherent in using the *best available technology* for land application.

In the swine industry, land application of swine lagoon effluent using irrigation techniques has gained widespread acceptance. Today's swine facilities typically use water flushed down alleys to remove manure and urine from the production facility. Wastewater from the facility is then treated in an anaerobic lagoon. Biological processes in the lagoon convert some of the manure solids into liquids and gases; therefore, irrigation is an ideal method of land applying the effluent from a lagoon treatment system. This technique allows valuable nutrients in the swine lagoon effluent to be used by crops. Since decreased inputs of inorganic fertilizers and irrigation water will be required, this type of system lends itself to sustainability. However, results from several studies have cautioned against overloading the agronomic ecosystems (Edwards and Daniel 1993; Vollenweider and Kerekes 1980; Sharply and Menzel 1987; Powers et al. 1975; Smith et al. 1987).

In the past, environmental concerns regarding the land application of lagoon effluent concentrated on the potential for excessive nitrate movement through soils. Recently, however, this concern has shifted to the movement of soluble phosphorous into groundwater (although there is no maximum contaminant level [MCL] for phosphorus in groundwater) and insoluble forms into surface water supplies. This shift in emphasis is primarily due to agricultural runoff being identified as a source eutrophication (nutrient enrichment) in certain lakes across the United States, e.g., Florida's Lake Okeechobee. However, general recommendations regarding land application of lagoon wastewater are difficult to develop, since soil type, topography, geology, and climatic variability can greatly affect the recommended quantity and spacial distribution of the waste.

Land disposal of animal waste requires some knowledge of the ability of the soil to adsorb or buffer exogenous applications of elements such as nitrogen (N), phosphorus (P), copper (Cu), and zinc (Zn). The ability for the soil to reduce the movement of soluble nutrients into groundwater is of great importance since remediation of groundwater supplies is sometimes impossible and always expensive. In particular, the movement of nitrate (a water soluble form of nitrogen) is of primary concern for human health.

Environmentally, the movement of nitrogen and phosphorus into ground and surface waters has drawn the most public attention. To facilitate the modeling of such systems, soil factors such as P adsorption capacity, N mineralization potential, and solute transport must be characterized. Nutrients removed in the harvested crop must also be accounted for in the nutrient balance model.

Mississippi processes a large number of hogs per day but gets a small percentage of its swine from within the state. Growth of this industry has necessitated increased shipping distances for hogs, many from as far away as Iowa. Over long distances, there may be a loss of weight and vitality. In extreme cases, animal mortality may occur during transport.

The potential expansion of contract hogs in the east-central region of Mississippi requires that swine waste disposal methods be economically and environmentally viable. The proposed research seeks to establish design criteria that will lay the framework for efficient management of swine waste.

Background

For most animal production facilities, the Department of Environmental Quality (DEQ) requires that a plan for waste treatment be submitted for their approval. In most cases, this plan is developed by the U.S.D.A. Soil Conservation Service (SCS). For the past two decades, lagoons were used as the Best Available Technology for treating animal waste. Prior to January 1, 1992, the effluent from these lagoons was considered treated by the DEQ and, consequently, it was allowed to leave the property. Currently, however, all animal waste treatment systems are designed as *no-discharge* systems. For these systems, excess effluent from the lagoon must be applied to land resources. For swine production, this is generally accomplished by honey wagons (for slatted floor - manure pits) or specially adapted irrigation systems (for alley flush systems). Nutrients in the wastewater are utilized by crops.

Sizing of these land application systems is based on the minimum number of acres required to spread the waste at such an intensity that: a) no runoff occurs; b) there are no excess nutrients released which may either contaminate the groundwater or cause algae blooms in watershed streams and lakes. The key nutrient in such designs has traditionally been nitrogen (N), which has been known to both contaminate groundwater (in the nitrate form) and cause algal blooms. Although phosphorous (P) has been recognized as a potential agent in algal blooms, its strong tendency to adsorb to soils has meant that most control of phosphorus has been addressed through erosion control.

The SCS has established a limiting nutrient standard for the application of animal waste and wastewater. This means that nutrients in excess of crop requirements cannot be applied on a continuous basis. Design criteria through 1991 only recognized P uptake requirements by the crop. An adjustment factor is now being employed which accounts for the soil's phosphorus adsorption capacity.

While the SCS has allowed for soil storage of phosphorus in their latest calculations, they insist that the ultimate correct decision, with regard to quantity of wastewater application, must be based on site-specific research findings.

This research is intended to develop realistic waste application rates under several potential management strategies. It should offer waste treatment alternatives which allow the growth of this new industry, while protecting the environment.

PROJECT OBJECTIVES

Following are the overall objectives for completion of the entire project as defined in the proposal submitted to the Appalachian Regional Commission.

1. To determine nutrient loading capacity of specific soils using effluent from a facultative swine waste treatment lagoon.
2. To determine yield response and nutrient removal of crops irrigated with swine lagoon effluent.
3. To determine influence of climatic variability, soil type, and management practices on irrigation scheduling.
4. Mathematically model the data observed in objectives 1-3. Incorporate mathematical models into a computer based decision support system.

Since funding was secured late in the year (September of 1993), implementation of the field plots has been hindered and is not in place at this writing. However, during the wet winter months, instrumentation and flow measurement devices have been developed. The field plots will be installed during the summer of 1994.

This report summarizes the basic experimental design and then describes progress made in the area of data acquisition, instrumentation, and flow measurement device development.

METHODOLOGY

Experimental Design

Forage Plots. Forage plots will be established to provide five treatments and four replications (5 x 4 randomized complete block design) for each of the two predominant soil types found in the region (Okolona and Vaiden), i.e., 40 plots total. These plots will be approximately 6 feet by 12 feet. Borders will be constructed sufficient to prevent cross-contamination between the plots. Samples of soil, forage (johnsongrass), surface water, and groundwater will be taken from all sites before initiating waste application to determine baseline values of parameters of interest.

Runoff Plots. In addition to the forty forage plots, ten runoff plots (31.3 x 13 feet) will be established. These plots will be on a single soil type and will have the same five treatments as the forage plots, but with only two replications (5 x 2 randomized complete block design). These plots (two for each treatment) will be equipped with flumes to measure volumetric runoff rate. Five plots will be fitted with automated runoff samplers to evaluate nutrient levels at various stages during the runoff process. A layout of the field plots is shown in Figure 1.

Plot Treatments. Five treatments will be studied on the research plots, including: (1) irrigation only; (2) irrigation with inorganic fertilizers; (3) 120 lbs N/acre (~ 250 gal); (4) 240 lbs N/acre (~500 gal); and (5) 360 lbs N/acre (~750 gal). The delivery of clean irrigation water and lagoon wastewater will be accomplished by using a 400 gallon slurry-wagon equipped with a spray boom. An in-line flow cell will monitor the total quantity of liquid applied to each plot.

Sampling

Wastewater Analysis. Lagoon wastewater samples will be taken at each irrigation event and analyzed for N (total, organic, and NH_4+), P (organic and ortho-), K, Ca, Mg, Na, Cu, Zn, EC, total suspended solids, total suspended volatile solids, and biological oxygen demand (BOD_5). Lagoon effluent will be applied to the research plots in a manner that maximizes application accuracy and uniformity.

Plant Material Analysis. Native johnsongrass response to various rates of effluent irrigation will be determined, both on the application site and on test plots. Yield response will be determined by harvesting the johnsongrass at optimal hay cutting stage. Harvested forage will be oven-dried (65 C^o) to determine dry matter yield. Elemental analysis of the dried forage will include NO_3--N, total N, P, K, Ca, Mg, Na, Cu, and Zn. These data will be used to develop elemental cycling removal rates by johnsongrass. Removal rates will be used in establishing design criteria. Mass balances of all these elements will be performed to determine their fate and the most limiting nutrient. These data will establish acceptable seasonal, annual, and total effluent application rates.

Soil Analysis. Soils at the research site will be tested for extractable levels of P, K, Ca, Mg, Na, Cu, and Zn using the Mississippi State soil test extraction method. This will establish baseline nutrient levels in the soil profile. Organic C, total N, inorganic N (NO_3-, NH_4+), soluble salts (electrical conductivity, EC) will be determined using Standard Methods (Page et al. 1982). Phosphorus adsorption and desorption isotherms will be developed for initial and final soil samples, as described by Stuanes (1984).

DATA ACQUISITION

The collection of data from runoff plots is difficult due to the extreme environmental conditions experienced in most locations. The measurement of open channel flow (runoff) also complicates the issue. A standard runoff plot usually includes surrounding the plot with borders, installing a flume to measure flow (runoff rate), and installing a wastewater sampler (to remove samples from the runoff at predetermined intervals). Cullum et al. (1992) describe current technology and equipment associated with measuring runoff parameters. His implementation includes: collectors, approaches, end plates, 0.5 foot H-flumes, FW-1 water-level recorders with potentiometers, runoff splitters, Isco composite wastewater samplers, and dataloggers. This arrangement requires a shelter (small 10 x 12 feet buildings) for each pair of runoff plots due mainly to the proximity of the FW-1 stage recorders which measure voltage drop across a potentiometer for float displacement (voltage drop precludes mounting the dataloggers long distances from the stage recorders). This configuration is a centralized data acquisition system where all signals from the plot are routed to a single multi-channel datalogger. While this system has its advantages, the cost associated with implementation can be rather expensive.

Remote Sensor-to-Computer Interface Modules

New remote sensor-to-computer interface (RSCI) modules (a computer and A/D converter at each sensor) allow distributed (decentralized) data acquisition at a favorable cost. The centralized datalogger requires leads from each sensor to be routed to the datalogger (which is typically mounted inside a small building). This can be messy and may lead to signal degradation. The RSCI modules, on the other hand, mount a CPU and A/D converter at each sensor and are connected to the host computer via a twisted pair of wires (a network). The modules communicate serially with the host computer using RS-485 communication protocol and can be 2000 feet from the host computer without the need for a repeater (signal amplifier). With these modules, the sensor output (voltage, current, RTD, etc.) is immediately converted to a digital signal and sent to the host computer via the RS-485 network. The RS-485 protocol allows multidrop communication with up to 256 modules (32 modules per repeater). Each subsequent RSCI module is connected using only the twisted pair of transmission wires. The RS-485 protocol allows each RSCI module to communicate with the host computer independently (just like a PC communicates on a local area network). The failure of one module does not hinder data retrieval from subsequent modules since the ASCII commands are broadcast over the entire network. The RSCI modules operate on DC power and have internal voltage regulation. They operate from 32° to 158° F. A typical RS-485 multidrop network is shown in Figure 2.

Cost. Due to the spatial nature of runoff plot research, the distributed data acquisition system provides advantages in data accuracy and cost effectiveness. A typical setup to monitor and control ten runoff plots (including a notebook host computer) will cost approximately $3,500. This configuration can monitor 80 channels. This compares very favorably to centralized data acquisition systems where a single data logger may cost $2,500 (not including remote communication capability) and typically only monitors 8 channels without the aid of a multiplexer.

Remote Data Acquisition. Since the modules are communicating with a host computer (typically a PC notebook), the host computer can be accessed remotely via remote communication software. This allows the signals from each module to be monitored from a remote location (namely your air-conditioned/heated office). This feature allows the condition of each runoff plot to be checked during actual runoff events. This feature is extremely important, given the propensity of most runoff equipment to fail during the very time you need it to be taking data!

In light of these arguments, a decentralized RSCI modular data acquisition will be employed for the runoff plots.

FLOW MEASUREMENT

Yoder Flow Tube

While there are many accepted methods and devices for measuring open channel flow, the cost and complexity of monitoring runoff flow rate has generally limited the replication in runoff data collection. Yoder et al. (1993) developed a flow tube which consisted mainly of a 4-inch PVC pipe suspended from a load cell. He developed the flow tube to monitor the flow rate from field plots under minimum tillage management (very little sediment in the runoff). While his design performed favorably in the laboratory, he has experienced problems when implementing the technology at the field level. The nature of load cells (temperature dependent and expensive) may limit their implementation in the harsh conditions experienced in runoff plot research.

Burcham Flow Tube

Because a cost effective, accurate, reliable method of measuring runoff flow rate is essential for continued advancement in runoff research, a new flow measurement device has been designed and is undergoing preliminary testing. The design utilizes a PVC tube, similar to the Yoder design, but does not use a load cell for measurement. With the Yoder design in mind and consultation with Dr. Filip S. To (Agricultural & Biological Engineering Department, MSU), it was determined that a linear Hall Effect sensor (LHES) might be suitable for this application.

Linear Hall Effect Sensor. Linear Hall Effect sensors produce an analog output voltage that is proportional to an applied magnetic field. In other words, they provide very accurate displacement measurement. Temperature sta-bilization and internal trimming circuitry provide a device that features high overall sensitivity accuracy with less than 5 percent error over its operating temperature range. The Hall effect sensor can be isolated magnetically from environmental hazards such as dust, dirt, light, water, or vapor. It has no contacts to wear, pit, or weld. Internal hysteresis circuitry eliminates contact bounce, a serious problem with mechanical switches which must interface directly with a microprocessor.

With the sensor selection complete, the flow tube of Yoder was modified to pivot at the point of water entry. The tube is mounted in a cantilever fashion using a spring and damper as shown in Figure 3. The linear Hall effect sensor is mounted in a sliding PVC tube and measures the linear vertical displacement of the tube (the limited rotation of the tube does not necessitate actual angular measurement, although this is possible). A small lip at the outlet causes the water to have a slight upward trajectory as it exits the tube. This transfers kinetic energy associated with the fluid velocity to a downward force component and, consequently, causes the tube to rotate. A flow versus voltage output resulting from preliminary testing of the Burcham Flow Tube (BFT) is shown in Figure 4. As can be seen in Figure 4, the flow versus voltage output is linear. The r^2 value of the plot is 0.98. The maximum flowrate tested was 10 gallons per minute.

Preliminary testing of the Burcham Flow Tube is promising. The BFT is constructed from readily available parts (PVC tubing, aluminum box tubing, springs, a damper using automotive antifreeze and a non-precision piston, a linear Hall Effect sensor, standard electronics). The estimated cost of constructing the BFT is approximately $50 without labor.

Field Implementation

Five of the runoff plots will be constructed with standard 0.5 foot H-flumes. The H-flumes will incorporate electronic stage recorders consistent with the distributed data acquisition system. These five plots will be equipped with Isco wastewater samplers.

The remaining five runoff plots will be equipped with Burcham Flow Tubes. Results of the standard H-flumes will be compared to the Burcham Flow Tube. These plots will be equipped with flow dividers directed to storage sumps to facilitate composite samples for manure nutrient constituent analysis.

All plot borders will be constructed using 5-inch PVC tubing buried in the soil to half the diameter. Trenches around the exterior of the runoff plots will divert external runoff away from the plots.

SUMMARY

Forage and runoff plots will be installed near Crawford, Mississippi, to determine the movement of manure nutrient constituents into the soil, into the plant, and in surface runoff. Plots will be constructed to provide five treatment levels. Forage plots will have four replications, while runoff plots will have two replications.

A distributed data acquisition system is being tested and will be implemented at the site. The system places a remote sensor-to-computer module at each sensor and communicates with a host computer via a RS-485 serial network. The host computer serves as a data storage device.

A 400-gallon slurry tanker will be equipped with a boom to apply wastewater. An in-line flow device will allow precise quantities of liquid (clean water or wastewater) to be applied.

Development of an alternative flow measurement device will proceed. The performance of the flow measurement device will be compared to results obtained from standard H-flumes equipped with digital-output stage recorders.

REFERENCES

Advantech, Inc. 1994. Solution Guide Volume 41. 750 East Arques Avenue, Sunnyvale, CA 94086.

Edwards, D.R. and T.C. Daniel. 1993. Runoff quality impacts of swine manure applied to fescue plots. Transactions of the ASAE 36(1):81-86

Isco, Inc. Isco Environmental Division. 1993. 531 Westgate Blvd., Lincoln, NE 68528-1586.

Page, A.L., R.H. Miller, and D.R. Keeney (ed.). 1982. Methods of soil analysis. Part 2. 2nd ed. Agronomy Monogr. 9. ASA, Madison, Wisconsin.

Powers, W.L., G.W. Wallingford, and L.S. Murphy. 1975. Research status on land application of animal waste. USEPA Rep. 660/2-75-010. U.S. Government Printing Office. Washington, DC.

Sharpley, A.N., and R.G. Menzel. 1987. The impact of soil and fertilizer phosphorus on the environment. Adv. Agron. 41:297-324.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987. Water quality trends in the nations's rivers. Science (Washington, DC) 235:1607-1615.

Stuanes, A.O. 1984. Phosphorus sorption of soils to be used in wastewater renovation. J. Enviro. Quality. 13:220-224.

U.S. Environmental Protection Agency. 1984. Report to Congress: Nonpoint source pollution in the United States. U.S. Government Printing Office, Washington, DC.

Vollenweider, R.A., and J. Kerekes. 1980. The loading concept as a basis for controlling eutrophication: Philosophy and preliminary results of the OECD program on eutrophication. Progr. Water Technol. 12:5-38.

Yoder, D.C., J.B. Wilkerson, R.E. Yoder, and D.W. Hamilton. 1993. Open channel mass flow measurement system. International Meeting of the ASAE, Hyatt Regency Hotel, Chicago, IL, ASAE Paper No. 933532.

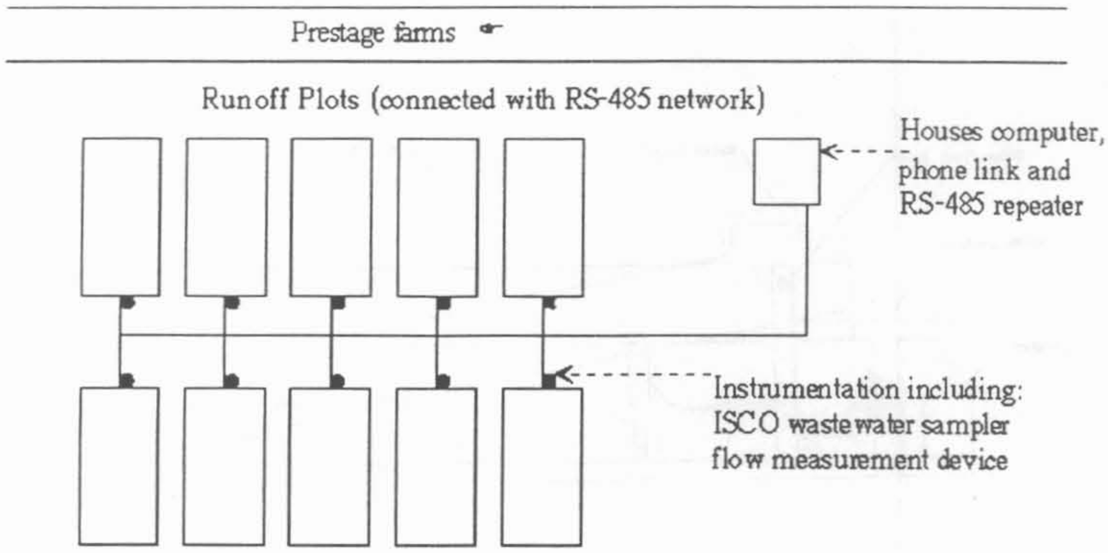

Figure 1. Runoff plot layout.

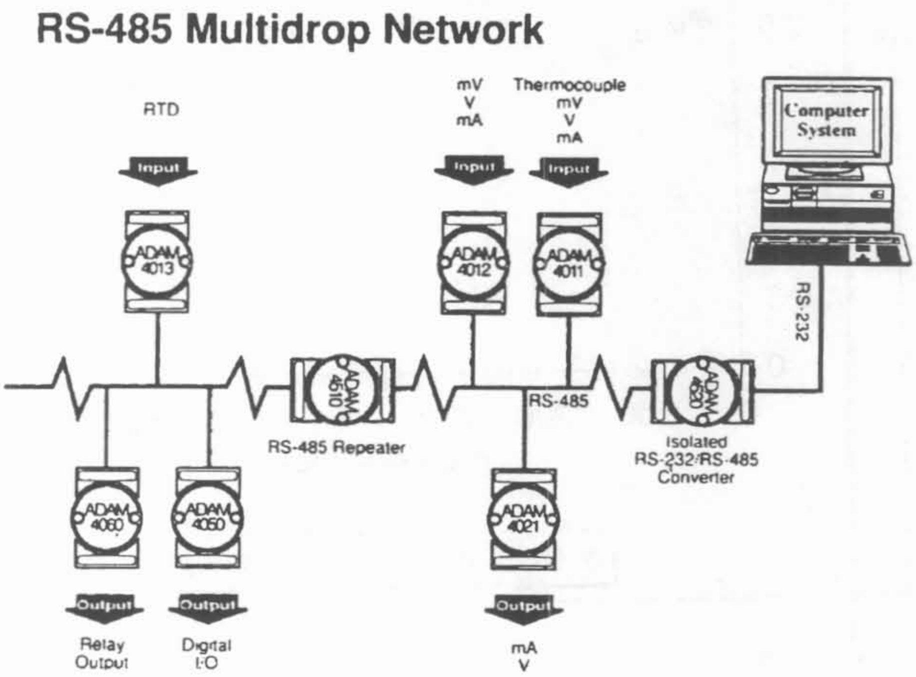

Figure 2. RS-485 multidrop network. (source: Advantech, Inc.)

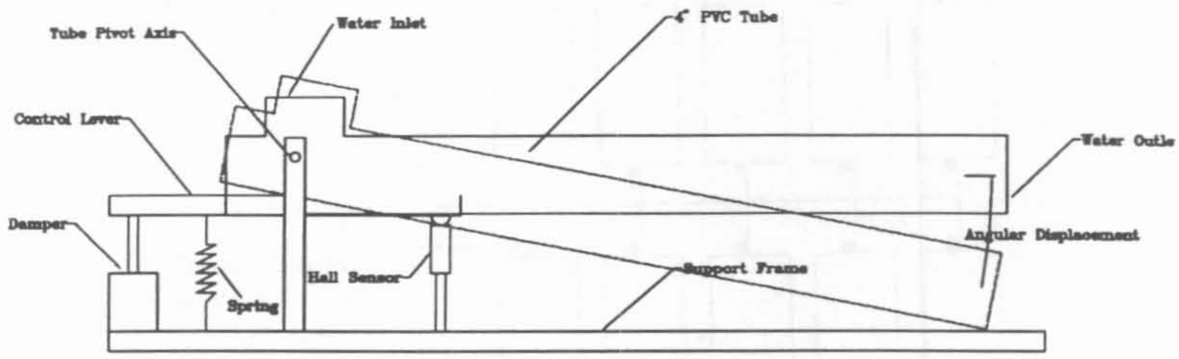

Figure 3. Schematic drawing of the Burcham Flow Tube.

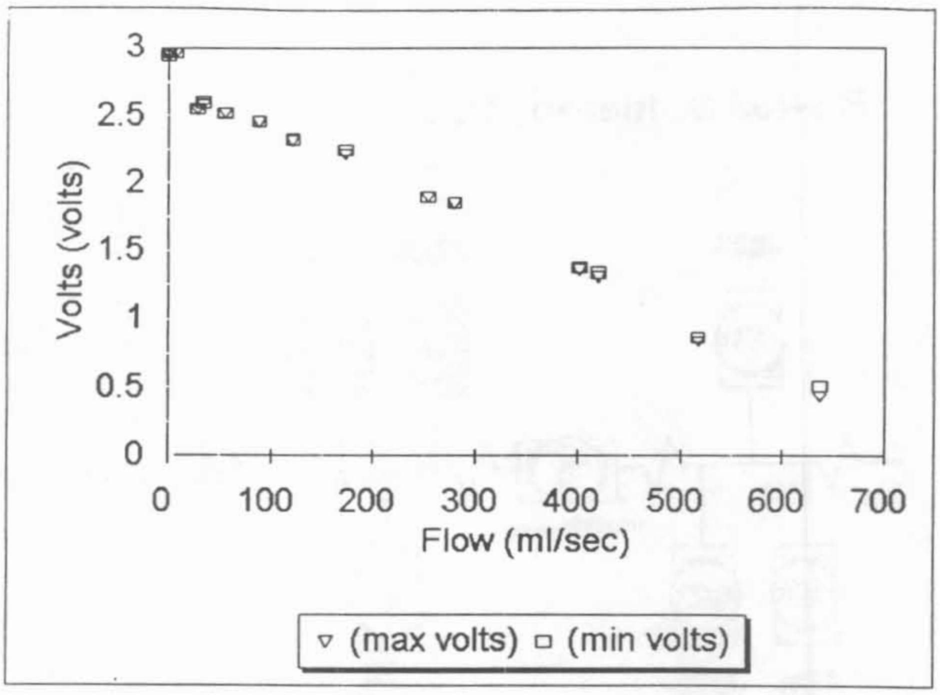

Figure 4. Plot of flow (ml/sec) versus Burcham Flow Tube Voltage (volts).