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EFFECT OF IRRIGATION, FERTILIZATION, AND OTHER CULTURAL PRACTICES ON WATER QUALITY

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FOREWORD

The Water Resources Research Institute has provided the administrative coordination for this study and organized the interdisciplinary team that conducted the investigation. It is the Institute policy to make available the results of significant water related research conducted in Idaho's universities and colleges. The Institute neither endorses nor rejects the findings of the authors. It does recommend careful consideration of the accumulated facts by those who are assuredly going to continue to investigate this important field.

ABSTRACT

A farming unit in an intensively cropped, furrow irrigated agricultural area of the Boise Valley in southwestern Idaho was instrumented for two cropping seasons to measure the quantities of water entering and leaving the area. Surface and groundwater samples taken from the unit were analyzed for nutrient and solids content. A computer program was developed and used to compute a nutrient, total solids and water budget for the unit based on water measurements, climatic measurements, cropping data and chemical analyses.

Excessive amounts of water applied to onion crops were responsible for a portion of the applied water entering the groundwater through deep percolation carrying with it part of the nitrogen applied as fertilizer. However, the other crops, sugar beets and beans, were found to use shallow groundwater for part of their consumptive use requirements. The only materials which were lost from the farm in appreciable quantities in the surface runoff were found to be total solids and the associated phosphorous except when nitrogen was added to the irrigation water as fertilizer. Sediment ponds installed on the farm were found to be effective in removing sediments and phosphorous from the surface runoff.

Key Words: furrow irrigated; surface runoff; groundwater; nutrients; solids; digital computer model; nutrient and water balance; sugar beets; beans and onions; nitrogen added to water as fertilizer; sediment ponds.

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In addition the authors wish to thank J. Preston Jones, Charles E. Brockway and Fred J. Watts for reviewing this report.

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INTRODUCTION AND OBJECTIVES

At the present time little factual information is available about the kinds and amounts of materials that are added to surface and groundwater as a result of irrigation water applied to agricultural land.

In many cases the approach to the study of eutrophication of water has been to assign values to identifiable sources such as industries and sewage treatment plants and attribute the remainder to agriculture. In so assigning, agriculture has been held accountable for everything from feedlot runoff to naturally decomposing plant materials.

The objectives of the research conducted on this project were to determine the quantities and the nature of inorganic materials in the surface runoff and groundwater on an intensively farmed, gravity-irrigated area and to determine the effects of irrigation, fertilization and cultural practices on these quantities.

The Boise Valley in southwestern Idaho is one of the major agricultural areas in the state. It was selected for this study because conditions existed which might be conducive to serious contamination of both the surface and groundwater supplies in the valley. Some of these conditions are: (1) Most of the farms in the valley are gravity irrigated; (2) commercial fertilizers are heavily used in producing the high-value crops grown in the valley; (3) many of the soils contain indurated hard-pan layers which impede downward water movement; (4) relatively low irrigation efficiencies are common; (5) high water tables exist in most of the valley increasing the potential for groundwater contamination and (6) the rapid population growth that the Boise Valley is experiencing makes water quality problems critical.

The farm selected for this study is located northeast of Nampa, Idaho, in an area of intensive irrigated agriculture. It is operated by one of the more progressive farmers in the area, and was selected because all water entering and leaving the farm could be accurately measured. The portion of the farm selected for this study was divided into three fields totaling 94.5 acres (38.2 hectares). All of the fields had been leveled for efficient furrow irrigation. A map of the study area is presented in Figure 1.

The soil on this farm is classified in the Purdam series in complex association with Power and Sebree series. The Purdam series is a moderately deep, medium textured, level to moderately sloping soil that has a cemented duripan at a depth of 20 to 40 inches. These soils are extensive in the Nampa-Caldwell area of Canyon County. There are 39,334 acres of Purdam in complex associations with Power and Sebree series in the area.

High water tables are present under a large portion of this area. A drainage well located on the study farm was pumped continuously during the latter part of the irrigation season to lower the water table in the area. Even with continuous pumping, the water table under some areas on the farm was observed to be at a depth of less than three feet.

Three sources of irrigation water were used on this farm. They included Boise River water, artesian water and water from a drainage well. The water from the artesian well, which was about 400 feet deep, was of excellent quality although it was warm and had a sulfur smell. The water from the drainage well, which was about 75 feet deep, was generally better in quality than that delivered from the Boise River, but of poorer quality than the artesian water.

All of the delivery ditches on the farm were concrete lined. Water was transferred from the delivery ditches to the fields by means of siphon tubes. Two sizes of tubes, 1-inch and 1 1/4 inch, were used depending upon the crop and the duration of irrigation set.

Drainage ditches carried the surface runoff from the farm. Prior to the 1971 season, a settling basin was dug at the lower end of Field C. This proved to be quite effective in trapping sediments; and, before the start of the 1972 season, a settling pond was dug at the lower ends of Fields A and B as illustrated in Figure 1. Concrete structures installed at the outlet end of each pond allowed the water in the pond to be maintained at any desired depth.

The farm was divided into two parts by the ditch in the center. Sixty and one half acres (24.48 hectares) were included in the north part while the south part totaled 47.4 acres (19.15 hectares), 13.4 acres (5.46 hectares) of which were not included in the study.

Sugar beets (Beta vulgaris L.), green lima beans (Phaseolus limensis), and white onions (Allium cepa L.) were the three crops grown each year. During the 1971 season, 33.5 acres of onions, 27 acres of beets and 34 acres of beans were grown. These crops

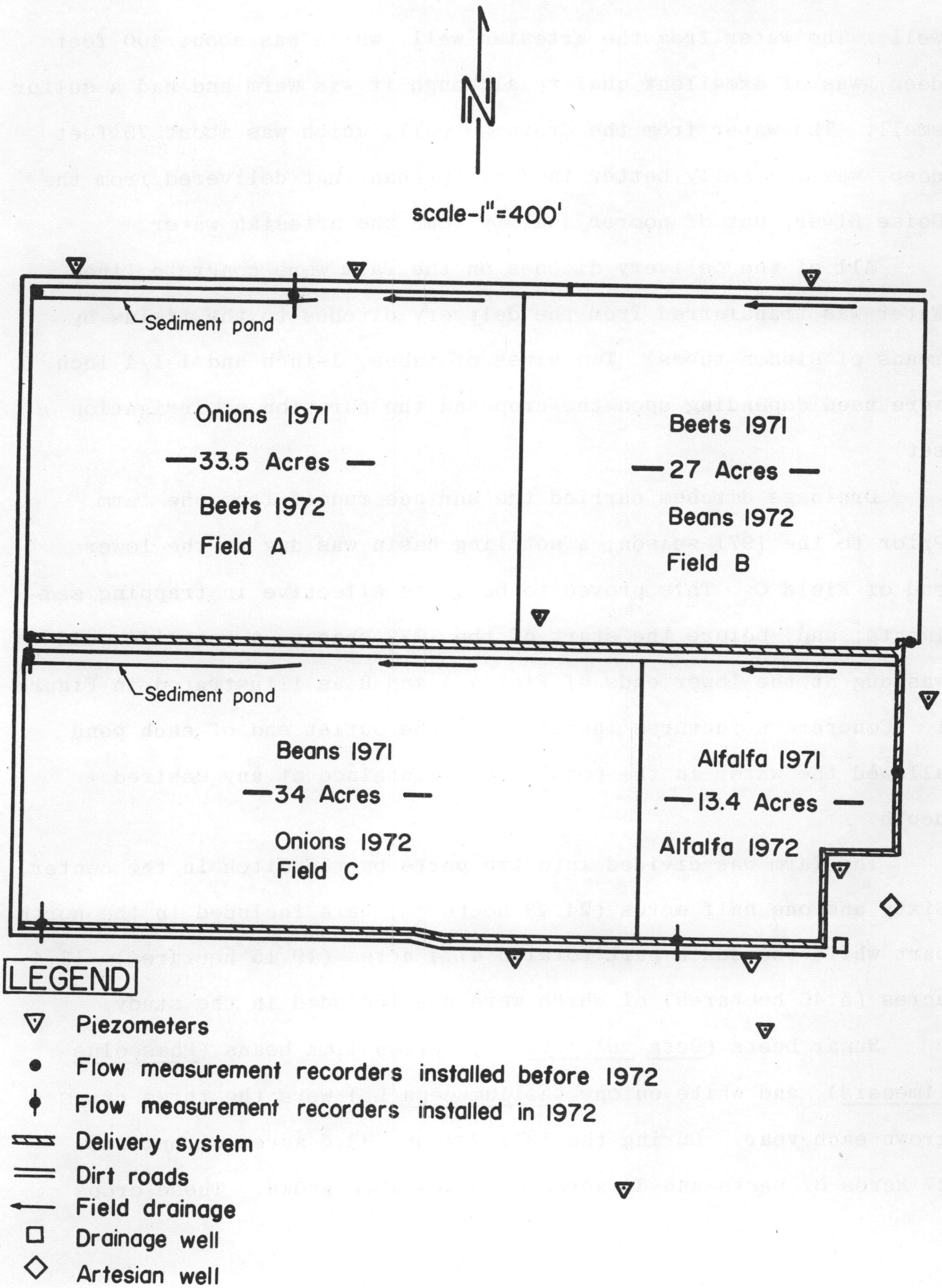

FIGURE 1: Site map

were rotated in 1972 so that there were 33.5 acres of beets, 27 acres of beans and 34 acres of onions.

Beets and onions are generally planted in April in this area. Beets are harvested during October while onions are harvested during the first part of September. The variety of beans grown have a short growing season and are harvested green. They are planted in May and are generally harvested by the third week in August.

The farmer on this tract applied commercial fertilizer several times during the year. The first application was plowed down in the fall. The crops were later side dressed and some crops were given supplemental nitrogen through the irrigation water.

The focus of this study was the establishment of a mass budget for an irrigated farm. This budget included: water, three forms of nitrogen, two forms of phosphorus and total solids. This balance was developed for all the fields in the study area. A balance for settling pond at the end of Fields A and B was also conducted in order to evaluate its effectiveness in removing nutrients and solid materials from the runoff water.

METHODS AND PROCEDURES

Developing a mass budget for the study farm depended upon: (1) continuous measurement of headwater and tailwater flows; (2) the collection and analysis of periodic headwater and tailwater samples; (3) the collection of climatic data for estimating evapotranspiration; and (4) the collection and analysis of groundwater samples.

Several different devices were used during the two-year study for measuring headwater and tailwater flows. Figure 1 shows the locations of all measuring devices.

<u>Headwater</u>

When the study began in 1971, Cipolletti weirs were used to measure all the water entering the north supply ditch which supplied water for Fields A and B of the study area. Steven type-F recorders were attached to stilling wells for obtaining a continuous record of stage. During the peak of the 1971 irrigation season, the two-foot Cipolletti weir that was installed in the ditch delivering water to Fields A and B had to be removed to prevent flooding upstream. As a result, continuous measurement of headwater became impossible and for the remainder of the season small 60^{o} fiber glass-trapezoidal flumes were installed in individual furrows and used to estimate irrigation applications. These flumes were placed in several rows during an irrigation set. From these measurements, an average application rate was estimated. Periodically the Cipolletti weir was reinstalled to check the small flume data. Generally the two measurements varied less than five percent. Before the start of the 1972 irrigation season, a specially fabricated weir was installed to measure the water delivered to the north fields.

No attempt was made in 1971 to install controls in the south ditch. In 1972 a large 45^{o} trapezoidal fiberglass flume was installed to measure the water entering the ditch and a two-foot rectangular weir was installed to measure the excess water leaving the ditch. Both of these weirs were equipped with stilling wells and stage recorders for continuous record.

Tailwater

In 1971 all the runoff from the north fields was measured through a six-inch Parshall flume. The Parshall flume was used because it was easily installed in an erodible channel, required a relatively small head loss, was accurate with up to 90 percent submergence and was not subject to siltation. The Parshall flume was also equipped with a stage recorder.

During 1971 it was impossible to measure all of the runoff from the south field; and, for this reason the data from Field C were incomplete for 1971. In 1972 the settling pond outlet was equipped with a concrete structure in which a two-foot Cipolletti was installed to measure all flows leaving the pond.

When a settling basin was dug at the lower end of the north field it was desirable to measure the inflow and outflow of the pond. A six-inch Parshall flume was installed above the basin and a two-foot Cipolletti weir with an adjustable crest was installed in the concrete outlet box. Both were equipped for a continuous record of flows. These two controls made it possible to establish water, nutrient and sediment balances for the pond.

Evapotranspiration

The establishment of a water budget required the determination of the amount of water lost to evapotranspiration. Many procedures for estimating evapotranspiration losses have been developed. These procedures are generally based on the correlation of measured evapotranspiration with one or more climatic factors. The climatic factors used for estimating evapotranspiration in this study were: maximum and minimum daily temperatures, solar radiation, two-meter wind speed and daily relative humidity. These factors were input into the Penman equation to obtain daily evapotranspiration estimates.

In 1971 a recording thermometer and a rain gauge were installed for an on-site record of temperature and precipitation. In 1972 a recording hygrothermograph was installed making both temperature and relative humidity measurement possible. The missing parameters for estimating ET were obtained from Boise and Kuna.

<u>Deep Percolation</u>

Eight 12-foot piezometers were installed prior to the 1971 irrigation season. Two others were on the site before the project began. The locations of the ten piezometers are shown in Figure 1. These piezometers were used to monitor fluctuations in the water table. Also, water samples taken from the piezometers were used as an estimate of the quality of water reaching the water table from deep percolation.

In an attempt to improve this estimate, a system of soil solution samplers was designed and installed during 1972. These samplers consisted of five tensiometer type samplers placed at one foot intervals to a depth of five feet. Each sampler was connected to a separate collection chamber by nylon tubing. The sampler tubes were made from one-half inch nominal PVC pipe and a three-inch long ceramic tip. The collection chambers were made from eight-inch lengths of two-inch diameter PVC pipe. Samples were obtained by evacuating the system with a hand vacuum pump a few hours after the irrigation of a field was completed. Whenever possible the samplers remained under vacuum for 12 hours. The samples collected were of the soil solution normally held under tension in the root zone. The samples obtained from a five-foot sampler were used to represent the quality of deep percolation water.

Sampling

One-liter grab samples of the head and tailwater were usually taken several times during each irrigation set. Runoff samples were collected at each control on the drainage ditch or settling pond. Samples were collected three or four times a day unless fertilizer was being added to the headwater in which case samples were collected hourly for the first four hours of the set and at about four-hour intervals thereafter.

Because headwater sample quality tended to vary less than that of tailwater samples, headwater samples were collected less frequently than tailwater samples. All peizometers were sampled at least every two weeks. These were pumped dry and allowed to refill before collecting a sample. This eliminated the possibility of detecting non-typical changes which might have taken place in the water while standing in the piezometer tube for long periods of time.

All samples were immediately frozen and later transported to the laboratory for analysis.

Analysis

At the lab each sample was analyzed for NO_3 nitrogen, NH_4 nitrogen, organic nitrogen, soluble phosphorus, total phosphorus and total solids. The methods used in making the analyses were essentially those given in APHA Standard Methods and by EPA. Nitrate-nitrogen was determined by the phenoldisulphonic acid method after first removing the chlorides with silver sulfate. The samples were filtered through 0.45 micro-millipore filters for soluble phosphorus and digested with sulphuric acid and ammonium persulfate for total phosphorus. The phosphorus was determined colorimetrically in the filtrate and digestion mixture by the amino-napthol-sulfonic acid method. Total solids were determined by weighing the residue after drying a sample for 24 hours at 110^{o} C. All analysis results were reported by constituent concentration in parts per million (ppm) by weight.

Data Processing

All of the raw data collected for an irrigation season were processed by a model 360/40 IBM digital computer, using a computer model developed by John R. Busch.

This model is designed to establish a water balance and a chemical mass balance on an irrigated tract for several chemical constituents. Two-hour time increments are used for all computer calculations. If the data for every two-hour period are not available, the model will fill in the missing data by linearly averaging between given data points.

The program first calculates the head and tailwater rates in cfs from the weir data and establishes the surface water balance. These data are then printed out. The flow data are then multiplied by the appropriate factor to generate volumes in acre inches per acre. These values, minus corresponding ET data and changes in soil moisture storage, allow deep percolation losses to be estimated. Because of the high water tables that existed under the study area, it was necessary to have the model either add water to or withdraw water from groundwater depending upon the amount of water in the root zone at any time.

The water balance data in inches of water on, water off, and water applied are printed out for each two-hour period. Next, daily and cumulative values for inches of water applied, water to ET, water to deep percolation and water present in the root zone are printed out.

Once the values for water volume have been printed out, they are no longer needed in that form in computer storage and are converted from acre inches per acre to pounds per acre. At this point the chemical concentration data are read in. The data for chemical concentration and dissolved solids are multiplied by the corresponding flow data and an appropriate factor to give quantities for the mass balance in pounds per acre. The corresponding mass values for headwater and tailwater for each two-hour period are used to obtain values for the amount of material gained or lost by the field during that period. These data along with cumulative totals are then printed out for each two-hour period and each day.

When this is complete, the deep percolation and corresponding data are combined to determine nutrient losses from deep percolation. The complete mass budget is then printed out.

The pond balance program is a modification of the mass balance model. This program calculates the difference between the quantities of water and materials entering and leaving the pond to obtain values for the amounts of water and constituents retained in the pond. The pond balance data are also calculated and presented on a two-hour time interval and daily basis.

RESULTS AND CONCLUSIONS

The results of this two-year study are contained in 500 pages of computer print-out tables. Water and mass budget values are listed for each two-hour period and for each day for both the 1971 and 1972 seasons. Similar data have been obtained for the north sediment pond water for the 1972 season. The mass balance has been divided into (1) the water balance, and (2) the nutrient and sediment balance for the purposes of this report. Each of these will be considered separately even though they are functionally related.

Water Balance

The water diverted for beet irrigation averaged 3.73 inches per irrigation in 1971. It was increased to 4.95 inches in 1972. This was the result of changing from 12-hour sets in 1971 to 20-hour sets in 1972. However, the average amount of water entering the soil was nearly identical both years with 2.53 inches applied per irrigation in 1971 and 2.54 inches applied per irrigation in 1972. As a result of the increased diversions in 1972, the average runoff increased from 1.20 inches in 1971 to 2.41 inches in 1972. It is interesting to note that the data showed a decrease in the deep percolation (DP) losses in 1972. This decrease is probably even greater than the data indicated because the last two sugar beet irrigations could not be included in the 1971 study period. The data showed the highest DP loss from beets during the 1971 study to occur during the last irrigation for which data were obtained. In 1972, the highest DP losses occurred during the last two irrigations. If this was the trend during the two missed beet irrigations of 1971, then the actual difference between the 1971 and 1972 deep percolation would be greater. This decrease in DP is probably due to less permeable soil conditions for the field planted to beets in 1972. This also may explain why more water had to be diverted in 1972 to attain the same application as 1971.

The deep percolation values indicate that beets planted on this farm will obtain needed moisture from groundwater between 25 and 40 percent of the time. It is probable that with the high water tables in this area, some sub-irrigation is always taking place. In 1972 the beans obtained thirty percent of their total seasonal moisture requirement from sub-irrigation. Unfortunately, there are no data for the 1971 bean crop to use for comparison with the 1972 data. Therefore, it is not known if this is always the case on this farm.

Onions had the greatest water application of the three crops grown. An average of 5.78 inches of water was diverted per onion irrigation in 1971 and an average of 6.20 inches was diverted in 1972. The average application rate was 3.47 and 3.54 inches respectively. Onions were irrigated in twenty-four hour sets and understandably had the highest runoff and deep percolation losses of the three crops. The data showed total seasonal deep percolation losses from onions for 1971 and 1972 to be 5.44 and 6.05 inches respectively. This deep percolation from onions may be important to the rotation scheme for this farm. Onions in the rotation may be valuable in preventing salt buildup in the soils because there was minimal deep percolation and thus minimal leaching of salts from beets and beans.

For all crops except beans the highest deep percolation losses occurred during the first and last parts of the season.

Sediment and Nutrient Budget

Three forms of nitrogen and two forms of phosphorus were considered in the chemical portion of this mass budget.

Nitrogen budget

In every case the data indicated more nitrate and ammonium nitrogen entered the farm with the irrigation water than was removed with the runoff water while the concentrations of the nitrogen forms was about the same in the headwater as the surface runoff. Generally, the total amount of organic nitrogen entering and leaving the farm was nearly equal. A small net loss of organic-N from onions and beans was probably the result of organic matter and plant debris being picked up and carried from the field by the runoff water and the organic matter associated with the sediment lost from the fields. This fact is supported by the data for the pond balance which indicates about one-half of the organic nitrogen lost from beets and bean irrigation was retained in the settling pond.

Liquid nitrogen fertilizer was applied to beets and onions through the irrigation water several times in 1971. The farm operator added the fertilizer to the irrigation water very early in the irrigation set and fertilizer addition was stopped when surface runoff started. The results show that the concentration of nitrogen in the surface runoff was highest when the early surface runoff flow rates were low and that the concentration dropped to the background level very rapidly after the fertilizer injection into the headwater was stopped. Thus, the total pounds of nitrogen lost by surface runoff was kept to a minimum. The maximum use of fertilizer in the irrigation water was obtained when the fertilizer was applied at the beginning of the set when soil infiltration rates were the greatest.

It was apparent that the overall nitrogen application efficiency was related to the water application efficiency. A portion of the fertilizer applied in the irrigation water was carried in the water lost to surface runoff and DP. Thus, the study indicates that the irrigator would save more than water by increasing his irrigation efficiencies. He would retain soluble nutrients that are valuable to him as a farmer and at the same time reduce the potential pollution of the water for downstream users.

Ammonium nitrogen generally was found in very low concentrations in the headwater unless nitrogen fertilizer was being added. However, the concentrations of ammonium and organic nitrogen in the water delivered from the irrigation canal tended to increase during the later part of the irrigation season. This increase was probably a result of the irrigation company's moss treatment program in the supply canals. Decomposing moss results in various nitrogenous compounds being released into the water. Because both organic nitrogen and ammonium nitrogen tended to increase and decrease together lends support to the theory that a portion of the ammonium nitrogen present was the result of decomposing matter in the water.

Since onions were the only crop that had significant deep percolation losses, they were the only crop that showed a loss of nitrate from the root zone. By using the five-foot solution sampler data, a loss of nearly 54 pounds of nitrate per acre was indicated for the 1972 season. This is about five times the loss shown when the twelve-foot piezometer sample data are used. It is difficult to say which is the best estimate. In the model developed for this study, it was assumed that the soil on the study site was uniform in fertility and depth and uniform in physical characteristics. This, of course, is never true of any natural soil. The data from four five-foot samples were averaged to obtain an estimate for the nutrient load in the deep percolation water from each field.

The headwater data for total phosphorous and total solids showed that the rate of application of both constituents remained essentially constant for the duration of an irrigation set. The amounts of total phosphorous and total solids lost in surface runoff were greatest as runoff began and then declined rather sharply. The amounts of total phosphorous and total solids lost in the surface runoff from each crop differed quite markedly as did the percentage of gross applied water lost to surface runoff. The onions lost more water to surface runoff than did the sugar beets and beans; and, likewise, there were more solids and phosphorous lost from the onions than from the sugar beets or beans.

The sediment pond was found to be effective for removing the bulk of the solids eroded from the fields. It was particularly effective in removing the larger particles. Since much of the total phosphorous is associated with the sediments, the phosphorous load in the runoff water was also lowered by the removal of the sediments in the pond as was the organic nitrogen.

SUMMARY

As described in the results and conclusions, the objectives of the proposed study were met. The quantities of water and inorganic materials entering and leaving an irrigated farm were determined for two irrigation seasons. In addition, subsurface water samples were obtained to determine the quality of water lost to deep percolation. The data obtained indicate that physical conditions in conjunction with varying cultural practices do influence the quantities and nature of inorganic materials leaving a gravity-irrigated farm.

The related publications describe in more detail various aspects of the project. The forthcoming thesis by R.D. Carlson outlines in detail the procedure used for data gathering and analysis and presents a complete summary of the analyzed data.

PUBLICATIONS RESULTING FROM THE PROJECT

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2. Busch, J.R., D.W. Fitzsimmons, G.C. Lewis, D.V. Naylor and R.D. Carlson, 1972. Cultural Influences on Irrigation Drainage Water. Age of Changing Priorities for Land and Water, Irrigation and Drainage Division, American Society of Civil Engineers, pp. 45-56.

3. Carlson, R.D. A Water, Nutrient and Sediment Budget for an Irrigated Farm in the Boise Valley. M.S. Thesis in preparation. Department of Agricultural Engineering, University of Idaho, Moscow, Idaho.