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ANALYSIS AND RECOMMENDATIONS ON IRRIGATION AND DRAINAGE FOR THE NORTH-ORIENTAL REGION OF BOLIVIA: VIEWS TOWARDS A RESEARCH PROGRAM

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Report prepared by

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Irrigation and Drainage Specialist

SERVICIOS TECNICOS DEL CARIBE

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ANALYSIS AND RECOMMENDATIONS ON IRRIGATION AND DRAINAGE FOR THE NORTH-ORIENTAL REGION OF BOLIGIA; VIEWS TOWARDS A RESEARCH PROGRAM

INTRODUCTION

In this report we will attempted to outline some recommendations directed towards a dual effort to increase grazing and other crop yields in the shortests time possible, and at the same time, advise administrators and field agricultural investigators of three experiment stations on ideas, concepts, and some specific research proposals. A viable effort is pursued, through short and longer terms steps, that can make more realistic this committment. To this end a realistic and simplified approach is attempted.

Naturally, the solution to the agricultural problems of North-Oriental Bolivia rest, only in part, on irrigation and drainage aspects. This is one area that needs to be reviewed within the whole effort. The fields of specialized training, infrastructure, settlement, etc., are beyond the scope of this report.

I sincerely acknowledge the gracefulness of Eng. Juan Bauzá, Technical Consultant for IBTA, whose dynamic attitude at all times made possible every trip to remote areas and experiment stations. In this sense, the generous cooperation that we always had from Eng. Angel Pérez, Director of IBTA in the Department of Beni, is also appreciated.

The sincere willingness of the research staff at all three experiment stations, in providing us with needed information, was

of great value in preparing this report. Finally, the cooperation of the office personnel of IBTA in Trinidad is gradly acknowledge.

The information for this report was compiled during the period July 16 to August 12, 1978. The final report was prepared and translated into English in Puerto Rico.

THE DRAINAGE PROBLEM IN BENI

Within some 213,564 Km^2 of extensive prairies, woodlands and lowlands, lie about 11.2 million ha. of savanna, between 190 and 240 meters of elevation. Within this area, about 1,800 "haciendas" suffer from yearly floods of various degrees of severity. Over 50 percent of these farms suffer from flooding of from 2 to 5 months, generally.This is the greatests restriction to the grazing and general farming capacity of these lands in conjunction with the defficient drainage.

The extremely high rainfall intensity in the river basins of the Beni,Mamore,and Itenez, born in the watersheds of the Departamento of Cochabamba and La Paz, leads to a major settlement problems in Beni, road construction, and for any type of agricultural development, even if it is of its present extensive nature. Due to the lack of watershed areas within the limits of Beni, the attention to agricultural development at the regional level excludes conservation and floods control programs. Because of the magnitude of the floods problems and urgency of its solution this hydrologic problem

needs to be approached at the national level. If to the benefits of hydro-electric power generation we add the savings that can be obtained during roads construction, and as a result of both - a more intensive settlement activity; it would then be questionable to refer to hydro-electric power generation as a too expensive proposition. Obviously, with an influx of population in response to better and more highways, and to greater power generation,agricultural development programs assume much greater possibilities of success.

In the central and oriental hydromorphic zone of about 5.7 millions ha. of lowand pastures with hetereogenic composition, it would be feasible to go along with plain grazing, were the local precipitation in 6 months and the irreversible slow drainage the only problems to cope with.Essentially, it would be an attempt to maintain the predominance of endemic grasses over the ciperaceous and arboreous species, through adequate rotation of the cattle, under a fencing system. That is as simple as it appears to be, the controlled lowland grazing can be headed to rapidly multiply the cattle population, without the irreparable loss of the younger animals during the flooding season.

The considerable rainfall between October and March, about 1,250 mm. as an average of seven meteorological stations in Beni, amounts to 75 percent of the mean annual precipitation in the sabanna. This much in six months of the year does not really represents a serious problem by itself if it were not because of the serious floods

caused by the Beni, Mamoré and Irenez Rivers, beginning late in November. Right after, between December and February, the most intense precipitation in 90 days proceeds, about 750 mm. over soils already saturated and flooded in sizable areas.This whole situation paralyzes the scarce agricultural activity in the savanna and of course, any progress in roads constructions is also halted. For the soils themselves, a progressive reduction in their hydraulic conductivity is implied, as greater amounts of fine silt and clay are carried in suspension and further deposited in the soil profile.

The rainfall characteristics of the plains in Beni, with an annual mean of about 1,700 mm., does not differ significantly from another area studied by the author in East-Central Puerto Rico, although there are different physiographic characters between both areas. Althoug it was not possible to evaluate the daily records in order to arrive at a more precise comparison, it could be estimated that the ratio between the three consecutive months of maximum rainfall and the least one in six consecutive months, with respect, to the mean annual precipitation, exhibits an index of rainfall distribution (DIS) 1/ of 1.66, slightly higher than the corresponding one for East-Central PuertoRico.The approximate mean for the maximum precipitation in three months appears to exceed the counterpart of the "wet" years for the given area in Puerto Rico. As the mean minimum precipitation for 6 months in Beni, is comparable to the mean for all

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1/ Capiel, M. & Antoni M.,1973. Two Rainfall Characteristics Indixes Proposed as Suitable for Agricultural Planning in Puerto Rico. Journal of Agriculture,University of Puerto Rico 57, No. 1:24.

years of the 180 day least rainfall in Puerto Rico, the mean DIS for Beni turns out to be somewhat higher. This brief analysis is offered to demonstrate that the character of rainfall in Beni is not unusual, and less so, responsible to any great extent for the yearly floods.

The incursion of sizable floods with millions of tons of silt and clay in suspension, which dimishes considerably the grazing area and the cattle population itself, may also be increasing the lagoons area. After the rains are over, for some time, the water table shifts irregularly as a result of the silt and clay deposition in strata arrangement.

It seems possible that perhaps, centuries ago the low permeability of these soils was less serious, as today we may observe signs of orderly soil cultivation in some areas of the savanna.

To the North-Oriental edge of Beni, between Riveralta and Guayaramerin, there are better drained soils, not subject to regular floodings, and with geater slopes (1.6%) in many areas. They vary in texture from sandy clay loams to loamy sands in their top soils. They are friable and have probably been subject to greater lixiviation. Yet, the rainfall pattern is similar to that of the rest of the Beni region, except in the Magdalena area. Approximately, 150,000 ha. of these reddish-yellow soils offer better possibilities of a diversified agriculture to succeed, specially in fruit crops-to be discussed later.

Analysis and Recommendations
Regarding Drainage

It has been mentioned that the drainage problem in most of the savanna is entangled with the overflows of rivers carrying enormous amounts of silt and colloidal clay depostis which every year add to the soil profile greater compactness. This makes it difficult to identify existing water table properly, with the relatively short intervals between floods.

In the lowlands or "bajíos", and even in some of the intermediate position grasslands which comprise the central hydromorphic zone of the east,[2/] the possibilities of more intensive grazing are scarce, as long as the flood problem is present. The prospect of improving the quality of the grasses is also limited, as long as the ratio between graminaceous to arboreal species remains low.The latter ones can withstand better flooding because of their greater ability to develop adventitious roots over water. The burning practice in hydromorphic areas does not appear to be an efficient one, and fencing might result in traps to cattle during flooding periods. The problem is really serious, at the same time that there is a great potential.

About 970,000 ha. of higher position savanna and forests, of which the Agricultural Experiment Station in Peroto is representative land, offer greater possibilities to more intensive grazing, and for other crops under proper management. Applied research should deal with this phase.Their texture varies from silty clay to nearly

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2/ Cochrane, T.T., 1967. Land Systems Map of Central Tropical Bolivia. Tropical Soils Department, Santa Cruz, Bolivia.

loamy sands, closer to the river beds. Their main management requirement is possibly to get rid of excess water before it causes serious problems to the soil aeration and to the soil nutrients availability.

Roots respiration is a natural and essential reaction in plants, for water and minerals uptake. It is the equivalent to the respiration in leaves as a reaction to photosynthesis. In both, the molecular oxygen consumption is required. If water saturates the soil voids, giving way to anaerobic conditions, growth and root activity are markedly suppressed. This condition is impaired as microbial activity compete for the limited oxygen. Crops however, vary in their tolerance to low oxygen diffusion rates, and on the basis of this soil environment plants ussually undergo a natural selection process.

It may be ironical to realize that when soil voids are saturated with water, moisture uptake is then drastically reduced. This is not only due to the low oxygen diffusion rates, but also to the toxicity brought about by high concentration of carbon dioxide under anaerobic conditions.

Adverse changes in the composition of the soil atmosphere is not the only factor which interferes with root growth and development. Due to either extended soil-water saturation periods, or as a result of soil compaction, that silt and clay fractions rearrangement in the soil profile provokes, both typical in the savanna. Mineral reduction is another adverse condition that needs to be solved for the sake of better land utilization for agriculture. It has been in-

formed that toxic concentrations of ferrous and sulfide compounds develop in the soil medium, in addition to the formation of organic compounds such as methane. It is also known that hydrogen sulfide has been found to inhibit phosphorus and potasium uptake, principally.

On the other hand, it has also been reported that the solubility of various minerals in flooded soils increases, including that of phosphorous and iron. Under extended periods these are leached to lower depths. When drainage is provided, or after a drought period, iron and phosphorus deficiencies may be exhibited in the top-soil. This may be an explanation to the low phosphorus content already found in most of the grasslands. On soils under paddy-rice cultivation, their podzol-like appearance, in many cases is due to the leaching of iron and manganese to lower depths.

All these detrimental effects, as an outcome to the restricted soil permeability, point out clearly to the need of undertaking, with priority, the drainage of around 4.7 million ha. of some 6.7 million that will continue exposed to the yearly floodings. Therefore, hydraulic works such as dams construction should be initiated, mostly outside the Department of Beni, but for the benefit of the nation as a whole. This is the reason why we mentioned earlier the need to approach the problem at the national level.

Drainage Systems and Design

There are various drainage systems to provide adequate surface and subsurface draining to the soil. The most familiar to us are:

1) Open drains
2) Underground concrete pipes
3) Plastic perforated pipes
4) Mole drainage

Only the first systems - open drains, appears to be the practical and economic one to recommend at this stage. The reasons are obvious, in addition to the fact that this system is an adequate one.

Open drains are not designed for peak flows at given short-time intervals because their construction would not be economical.At any rate, a good part of the input will stand on depressions, awaiting for evaporation.

The design capacity of open drains is influenced by such factors as rainfall intensity, area needed to be drained, topography and soil relief, vegetation, flood frequency, and protection desired.For the savanna of Beni, whose slopes are generally minimum, drops in the drains are not necessarily needed, althoug traps will be helpful to pick-up sediment.

As an average in the plains, open drains may have slopes of .01. The fall along the Mamoré River is considerably lower. For streams with appreciable amounts of silt and clay in colloidal suspension we may concede a velocity of 0.7 m/second. Assuming streams as high as 10 to 20 cubic meters per minute, the open drains can be constructed from 0.8 to 1.0 m. deep, 50 to 60 cm. wide at the botton, and side slopes 1:1. Under a flow of 8 to 11.5 cubic m/min. from run-off and sub-sufface lateral flow, drainage down to 60 - 70 cm. in the root-zone can be obtained. These estimates can fluctuate appreciably,depending on whether the 80 meter spacing between drains is adequate.

To focus as soon as possible the drainage problem, it is recommended that the following research study be carried out on grassland areas in the savanna, at intermediate positions with respect to elevation.

PROPOSAL FOR A RESEARCH PROJECT

Title: Effect of open drains on grazing

Objective: To evaluate the effect of open drains on the fattening capacity to cattle per ha., and on the performance of graminaceous species within the natural pastures.

Justification: It would not be advisable to initiate a crop production program in the savanna, under the present soil physical condition and the infrastructure of the region. Nevertheless, it is necessary and we think possible, to bring to a higher level of exploitation the actual operation of beef-cattle raising.This effort should be directed to, if possible, triplicate the present earnings by substantially increasing the carrying capacity of the grazelands. We will, at the same time, be taking a first step towards optimizing the physical structure of the soil, in benefit of its mechanical,chemical, and bilogic properties.

Procedure

1) Four parcels, 13.5 ha. each will be selected from an area not more than 2 km^2. and which will constitute the four replications of the experimental work to be done.Each replication will be 360 x 375 m, in size.

2) Along each side of the 375 meter lenght of each replication two drainage plots will be established, 160 m. wide. Thus, there will be left a strip in the center, 40 m. wide, which will serve as species sampling area.

3) The drainage experimental treatments will be : (a) with open drains 80 m. apart (2 dains along the 375 m. borders and one in the center), and (b) no drainage.

4) Each drainage plot will be further subdivided (lenghtwise) into two lime sub-plots or experimental units.These will consist of (a) liming with calcium corbonate at the rate of 5 metric tons per ha., and (b) no liming. In the drainage plot with drains(three) the drain on the center will separate the limed from not limed sub-plots. In the drainage plot with no drains a fence in the center will also separate the same sub-plots. Both drainage and lime treatments will be randomized within each replication and each plot, respectively.

5) Sixty-four cattle-heads, of similar age breed and size will be selected for this experiment.These will be separated into four groups of 16 heads each, so that the deviations from their mean age and weight will be minium within replications. In each one the cattle will be randomized within the drainage and within the lime plots.There will be four heads corresponding to each sub-plot or experimental unit.

6) The cattle weight will be taken at the beginning and end of each experimental year, during three years. In the center strip, divided crosswise (limed and not limed) the dry weight of 10 m^2 of species will be taken every 90 days.

ANALYSIS AND RECOMMENDATIONS ON IRRIGATION AND CLIMATOLOGICAL ASPECTS

Beni and Pando Regions

It has been attempted to describe some of the rainfall character in Beni, with some emphasis on the period of higher rainfall intensity. Only monthly values, of rather short period duration have been found available and for this reason any mayor conclusion related to drought incidence, or rainfall deficiencies in given periods, can only be generalized. Long term daily records allow an insight into the recurrence of short periods of drought, in the case of Nor-Oriental Bolivia, in March, April, October and November. In any one of these, fall or spring, 10 to 15 days of dry spell may provoke a serious saturation deficit in the atmosphere, affecting the water economy of annual crops mainly.

On the basis of monthly data, mean of seven weather stations, with records of from 10 to 19 years, between June and September, there is the least precipitation in 4 months, with an average of 218mm. At this time, although the daytime is shorter and the cooler south winds prevail, nevertheless the solar energy is less intercepted by moinsture in the atmosphere, and there is greater conversion to heat energy at the soil surface.This fact brings the daytime air temperature to values comparable with those during the summer. On the other hand,

there is a greater temperature span at this time of the year, and under irrigation, the farming of such crops as tomatoes, peppers, and sugar cane offer good prospects of success, to some extent, as a result of lower hightime temperatures. On the first two crops fruit formation is favored, on sugar cane the enzymatic conversion to sucrose during ripening can be better attained to optimum values. If the sugar cane is 12 month crop, the sugar yield prospects are still greater. Planted in September, with two or three irrigations if it were necessary, the initial growth would be insured until the summer rains. As the crops grows taller and more vigorous, with a concurrent increases in water consumption, the weekly rainfall also increases (this crop is recommended for the better drained Pando). Towards the end of May, when growth practically ceases to give way to maturation, rainfall intensity drops and the nightime temperature too; as required for the optimum maturity of the cane.

The interaction between soil moisture and atmospheric evaporative demands is obvious. As we focus plant water requirements, both factors are primarily involved. With respect to soil moisture in the savanna of Beni, once rainfall starts to decline, normally between April and May, not much is from there on known about the capillary rise. It should be adequate to supply the evapotranspiration of grasslands, at least for some time after.

It has been found that capillary rise attains a maximum value when the predominant fractions in the profile are silt of less than 0.65 mm., but greater than 0.01 mm.[3/] The reduction is quite drastic

3/ Work reported by Atterburg, according to Zuncker, F., Julious Springer, Bertin, 1930.

in either direction. It is not known to what extent does the colloidal clay brought in suspension with the floods, and accomodated within the soil profile, have interfered with the capillary rise. Little is also known about the water table fluctuation with rainfall or the lack of it. Yet, for plants, the rate of the capillary rise (is more critical) than the height it can attain.

The contribution that capillary rise may represent in satisfying the plant-water needs may be considerable when referring to the grasslands, and perhaps more in the forest community. The soil cover in either case helps to maintain a balanced capillary flux, to which the root system of the vegetation adjusts itself. However, with subsequent burning, land clearing, plowing, and pulverization of the top-soil, the micro-environment changes and such a flux is checked out.

At the Experiment Station in Perotó it was observed that where the land was cleared, plowed and pulverized, upon drying the aggregates became very hard. In addition to loosing any capillary contact, their direct exposure to the atmosphere causes the soil temperature in the top few mm. to rise fast. Soil moisture is thus lost far beyond what plants can extract, due to the very high moisture suction of the surrounding air, about 40 atmospheres of tension. Where irrigation has been applied, with evaporation the soil surface seals by leaving colloidal fractions and salts in the very top of the surface. The use of various kinds of mulch can help to prevent a great deal of the inconveniences, including poor seed germination in many instances.

Although today there exist a number of irritation systems, some of these have been introduced to cope with a limited water supply to satisfy the irrigation needs. However, for some time the introduction of irrigation systems and lay outs should depend on conventional methods in this region, including the Experiment Stations of Perotó, Riveralta, and Cobijas, this last in the Department of Pando. As the location of irrigation facilities and lay-outs may begin in the Experiment Stations, which appears to be desirable, the irrigation recommendations are directed to these research centers.

Perotó Agricultural Experiment Station

It is located in the 15°00' latitude, and 64°30' longitude on the province of Marban, about 100 km. to the South East of Trinidad. The soils are representative of about 3.5 million ha. in the somewhat better drained savanna. The soils remain saturated or flooded during three to six months. The previously recommended research on drainage is directed to this region.

Within 10 ha. agronomic trials are carried out with corn, sorghum, and watermelons, mainly. No source of irrigation water is yet available inside the research area. It is estimated that in the next 3 to 5 years, if an irrigation source is located in the vicinity, there will be under simultaneous experimental work with vegetables about 6 ha.

Between April and September the approximate water consumption may be estimated to be around 640 mm. If we concede a 60 percent

irrigation efficiency, as an average of the furrow, flooding and sprinkler methods of application, the total irrigation requirements can be roughly estimated to be around one meter per season of six months. Rainfall is not being considered, to leave it as safety factor, inasmuch as the irrigation efficiency may be lower.

The capacity of the lake at the South-West of the present experimental area appears to be ample. The 1.5 $km.^2$ of water surface would only drop about 4 cm. to supply the needed 60,000 cubic meters for 6 ha. during the season between April and September.

Land leveling, or at least surface smoothing should be carried out with a land plane like the Everman type. This would eliminate the surface depressions, including those left during land clearing. The irrigation runs may go from west to east with furrows parallel to the open drains, and the water distribution laterals in a south direction, perpendicular to the drains.

The irrigation canal from the lake to the experimental area in the Station can be constructed for a stream of 8 cubic m/min. This capacity should be adequate to distribute a depth of up to 80 mm. to one ha. in 4 hours, assuming an irrigation efficienty of 60 percent. On Appendix 1 of this report there appears a graphical description of the drainage and the irrigation ditches, turn-out and some useful equations relate to water flow.

The border system of irrigation will also be adequate to irrigate these soils, with the flooding strips of from six to 12m. wide.

It is not convenient when the cross-slope is greater than 0.3%. For experimental work this problem may be solved by using a similar system of flooding - the basin system. It does not require so much the mentioned minimum cross-slope, and lends very well to the irrigation of small experimental units.

The furrow method of irrigation is convenient to irrigate row crops, such as sorghum, corn and a variety of vegetable crops. However, for this system to be efficient the length of the furrows should not be less than 50 m. This implies that generally, the land should be leveled.For water distribution in the furrows, siphons or plastic pipes of from 4 to 8 cm. in diameter, that can deliver from 1 to 6 l/s, may be used. The flow in the furrows and their slope should be inversely related, and can be estimated from the simple equation;

$$f = 0.6/p$$

where (f) is expressed in l/s, and (p) in percent of slope.

The Experiment Station of Peroto, as well as the others, should attempt to meet an irrigation application depth of as much as 80 mm. to one ha. in from 4 to 6 hours. If this were not possible, it further implies the need to recur to land leveling in both directions, to allow for adequate furrow lenghts and border strip lenghts. With this much cover, the irrigation needs of experimental plots of as much as 6 ha. can be adeauately met simultaneously.

El Maral Agricultural Experiment Station

Located in the Province of Vaca Diez, about 42 km. from Riveralta. It comprises about 436 ha. most of the land is now in forest. The hydraulic conductivity of the soils is more favorable than in Peroto.The soil texture varies from sandy clay to loamy sand,generally yellowish red or reddish yellow.

Although more than 300 ha. of the farm lend well to agricultural research on crop production, this much land clearing is not recommended to any further extent than the present land use, at least until an additional source of irrigation water is secured.Right now it appears to be doubtful that the El Tigre and San Fernando streams within the farm can supply anymore than 10 ha. of irrigation water requirements, assuming that the water is diverted of from 4 to 6 hours, six days in the week, during a six-month water deficiency season. Thus, the need for a water storage pond and/or a deep well is evident, as the research work is evertually expanded to more than 10 ha.

Were adequate funds made available for land clearing and preparation of 10 additional ha., separated from the present location of the experimental work, it is recomaended to establish a reasearh orchard in citrus fruits, preferably oranges. A deep well would be needed whose ater yield would determine the actual size of the orchard itself, Since an adequate full program with oranges requires special management, mainly on pest control, the location of the orchard is recommended separate from the other experimental work specially away from vegetables crops.

For water application to the orchard, sprinkler irrigation is recommended. Land leveling is therefore not required. The well perforation can be located centrally with respect to the orchard, and connected directly to the irrigation system.

Cobija Agricultural Experiment Station in Pando

This Station is located about 30 km. south of Cobija, the capital of the Department of Pando. Its elevation is approximately 280 m.

The soils of this Northern region of Bolivia exhibit a marked contrast with those in Beni (with the exception of the Riveralta zone). They vary in color from reddish yellow to yellowish red, of sandy clay to loamy sand texture. They are generally friable on the first 30 cm. depth, and their water retention capacity appear to be more favorable than that of the alluvial soils of Beni. It may be estimated that on the 30 cm. of top-soil about 50 mm. of available soil moisture is retained.With the progressive compaction of the soils in Beni,their available water retention capacity may be in the order of 30 mm. in the first 30 cm. of soils.

The soils in this region lend to greater diversification of crops, among which can be mentioned, with good prospects, oranges, pineapple, corn, sugar cane, improved pastures, and farinaceous crops.

The Experiment Station maintains a collection of forage crops and leguminous species, which should be preserved and improved.Were a favorable impact in the infrastructure attained, such that the population would increase considerably, the dairy industry could be developed soundly. The same prospects would apply to the enlargement of a beef-cattle industry. Thus, this Experiment Station shoul con-

centrate efforts in developing efficient techniques in forage and grazing management. A research proposal is described further on this report.

From the limited hydrologic access to information it appears that this region of Pando has three considerably dry months - June, July and August, with a mean monthly rainfall of about 25 mm. We should also consider moisture deficient months May and September, with mean monthly values of 75 mm.

It appears that the Thornthwaite method of estimating potential evapotraspiration empirically, is not realistic for the winter in the Beni and Pando regions of Bolivia. The estimated monthly values in the winter only reach between 60 and 70 percent of the indicated values in mid summer (December, January and February). For reasons stated before, it should be acknowledged that a mean monthly difference of only 2.5°C between the mean air temperature of summer and winter months does not counteract the greater aerodynamic contribution to evapotranspiration in the inter months. The mean air temperature is only a rough estimate of the energy required for evaporation.

The Experiment Station should decide to gauge the stream crossing the farm, or better, install a permanent weir in a convenient location along the stream. In the Appendix a graphical description of this structure is given.

The sprinkler method of water application is also recommended for Cobijas in areas or locations where land leveling is too expensive or not feasible, mainly because of the general slope. The capacity

of the individual sprinklers may fluctuate between 0.5 to 1.2 l/s. Adequately designed and used, it may result in the most efficient water application method. In reasonably leveled locations, the basin method of irrigation can be the most adequate for the irrigation of small forage plots by flooding. For row crops, the furrow method is adequate if furrows can be made reasonably long.

Size of Stream and Timing

The capacity required for an irrigation system (volume in a given lenght of time interval), irrespective of its magnitude, it can be estimated if we know in advance: (a) area to be served by irrigation (b) total depth of application, and (c) time during which the irrigation will be in operation. That is, if we establish the equation:

$$V_t = 2.73\ AL/T$$

where V_t is the volume intensity or capacity required in liters per second, (A) is the area to be irrigated in ha. (l) is the depth of application in mm., and (T) is the time of application in hours. Thus we can verify that:

$$30\ l/s \times 1\ hr - 0.5 \times 22\ mm.$$

both sides of this equation reach around 110,000 cubic meters. Naturally, on the basis of this example, derived from the previous equation, we can arrive at any desired combination. For example, if (a) is 50 Ha. and (L) (depth) amounts to 44 mm., we have to raise the left side of the above equality by a factor of 200. In this case, if V_t is fixed, then the application time (T) should be 200 hrs. As such, the application can be made in 50 days (1 ha/day), 4 hours a day, or in 25 days, 8 hours per day.

No consideration has been given to irrigation efficiency, which generally fluctuates with the degree of land preparation and the irrigation structures available. It may be fixed between 50 and 70 percent. To this respect if V_t is fixed, we generally increase the time of application. Assuming that in the equation (T) turns out to be 4 hrs. and that the expected irrigation efficiency is 60 percent, then the time of irrigation ought to be increased to be 6 hours and 40 minutes.

It is important that the concepts and relationships between water requirements, area and volume of the stream be clear in the mind of those working in irrigation. In one report brought to my attention, in the Experiment Station of El Maral, it is mentioned that the potential evapotranspiration of the region is 14.39 cubic meters per ha-year, and that the irrigation requirements in the dry season amount to 3.93 cubic meters per ha.-year. The first figure implies that the potential evapotranspiration is 1.44 mm/year, the second one would only concede the irrigation requirements in the dry season to amount only 0.3 mm/year. Perhaps, the confusion airses from the fact that it is not clear that precipitation, consumpt time use, or evapotranspiration are all expressed in terms of a given depth, irrespective of area (volume/area = depth).

Meteorological Instrumentation

The three Experiment Stations visited (Peroto and El Maral in Beni, and Cobija in Pando) maintain meteorological stations for the collection and compilation of daily records on weather variability.

Needless to say, proper care should be exercised and adequate maintenance of equipment need to be given. Only in this way can information on precipitation, air temperature, relative humidity, open pan evaporation, wind speed, and solar radiation, can be secured. It is very convenient that some of this weather variables be recorded continously, such as relative humidity, air temperature, and intensity of solar energy.

The hidrothermographs located in the three stations are of good quality, German manufacture (Thies). However, it is essential to have a psichrometer at hand on every station, to be able to correct possible deviations which the relative humidity curve exhibits after some time. It is recommended to adjust both values of humidity and temperature weekly, after a new chart is installed.At this time, the psichrometer and the corresponding tables of air temperature vs. wet bulb depression, will give the correct relative humidity. The air temperature is corrected from the dry-bulb temperature. At 14:00 hour on the same day a verification can be made, when the temperature is highest and the relative humidity lowest, in the day. When visiting the Station of Peroto, it was observed that the relative humidity was way off the real value. As the psichrometer was out of order, no correction could be made.

The relative humidity is not an independent measure of the moisture content of the air, such as is the dew point temperature or the saturation vapor pressure deficit.This is due to the dependence of relative humidity on the air temperature. However, from the mean values of relative humidity (RH) and of the air temperature (T_a) , by referring to tables of the partial vapor pressure of the air (e_s) at various

Ta, we can calculate the saturation vapor pressure deficit (e_d) and the dew point temperature (T_d) by the following equations:

$$E_d = E_s - E_s(RH)$$

$$T_d = T_a \text{ at } E_s$$

Both E_d and T_d maintain a close relationship with transpiration rate of plants. It is important though, that the mean values of relative humidity and air temperature, obtained within a given interval, say one week, be correctly estimated. The mean relative humidity is best obtained with a planimeter, or by obtaining the mean of values from the curve every two hours. To obtain the mean value of air temperature, values of every 4 or 6 hours is enough.

Solar radiation (I_o), and open pan evaporation (E_o), are very useful as weather parameters to evaluate the dry matter yields of crops, and their consumptive use of water, respectively, at the same time, both indices maintain a close relationship, a fact which can be used to advantage in assessing one variable in terms of the other.

It is recommended to obtain another type of pyranometer, of the integrating kind. The one under present use at Cobija is not in operation, supposedly, because the instrument can not be oriented properly. The same kind of instrument is installed in El Maral. It appears to be working, yet the charts are sent to La Paz and no data is sent back on the nature of the radiation intensity. As the station in Peroto does not have any kind of instrumentation to measure solar radiation, it is recommended to acquire a SOL-A-METER [4/] whose approximate cost is $b12,000.

4/ Manufactured by Matric, Inc. 537 South, 31 Street, Mesa, Arizona, 85204, Tel. 602-832-1380.

As far as open pan evaporation, measurements, no tabulated data was obtained, although it was reported that the readings are being taken. It is important that this data be taken by the same agronomist always, if possible.There might be different criteria regarding the micrometer reading.The tank should be cleaned regularly, and when doing so, it should be no later than the 0730 hour, to insure a reliable reading the next day.

It is also recommended that anemometers be installed, to record the wind speed about 45 cm. over the base of the evaporation pan. The instrument can be fixed to the same platform of the tank. Pluviometric instrumentation appears to be adequate. For agricultural research, related with irrigation, the precipitation intensity, as recorded with pluvigraphs, is not required. Generally, the daily pluviometric values are sufficient.For soil erosion studies, drainage design for engineering purposes, this data is possibly helpful,and the Experiment Station may offer its cooperation.

Views on Agro-Meteorology

Daily pluviometric data is very useful, not only to keep a hydrological balance for irrigation purposes; also for, after a long term period of no less than 30 years, estimating the rainfall probabilities of weekly periods or so by the gamma function probability technique[5/] with the same daily rainfall data we may also attempt to characterize rainfall by such indices as (DIS) (Rainfall Distribution Index) and (DES) (Rainfall Deficiency Index), as reported before by the author. [1/]

5/ Thom, H.C.,1958, A note on the Gamma Distribution.Monthly Weather Rev. 86, No. 4: 117-122.

Regarding other climatic parameters, there have been found remarkable interactions between crop yields, quality, water use, and management with weather indices. In the tropics, the author found significant inverse correlations between forage yields (Pennisetum purpureum L) harvested every 45 days (frequent harvest) and its nutrients composition, a finding which could be traced to evaporative demands indices.[6/] Under space harvests (every 60 days) the inverse relationships was not significant.

Not all crops respond equally to weather, even if an optimum conditions is brought about to the plant-weather relations through convenient irrigation. Under greenhouse conditions it was observed[7/] that until flower initiation bean plants maintained a 1:1 relationship between transpiration and net solar radiation (r = .97) so long as soil moisture was adequate. After bloom this relationship no longer held, transpiratinn declining to roughly 40 percent of the net radiation. On the other hand, in this same study it was found that the transpiration rate of young coffee plants was always much lower than the net radiation, in addition to being poorly related to it.

On the North Coast of Peru, one of the regions in the world where rice yields are highest, Sánchez[8/] report that Variety IT-8 under com-

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6/ Capiel, M., 1978. Effect of various meteorological indices on the yield and nutrient composition of napiergrass(Pennisetum purpureum L). Jour. Agric. Univ. P.R. Vol. 62, No. 1:76-89.

7/ Capiel, M., 1973. A differential psychro test of plan-soil-weather relationships and water use. Jour. Agric. Univ. P.R.,Vol. 57, No. 1:42-55.

8/ Sanchez,P. et al. 1974. Influencias de la radiación solar sobre la respuesta varietal del arroz al nitrógeno en la costa del Perú. El Manejo de Suelos Tropicales,editado por E. Bornemisza y A.Alvarado, CIAT,Cali, Colombia.

plete exposure to solar radiation (about 490 langleys per day) exibited an outstanding yield response of 11.5 tons/ha. to the applied nitrogen of up to 300 kg/ha. Under restricted solar radiation of 57 percent (with plastic nets) rice yields were not only lower, also there was no response to the applied nitrogen. Nitrogen was applied in urea form, one half of it 30 days after transplanting, and the other half at the point of primordium initiation of the panicle.

Some other plant-eater research may be mentioned. However, some research proposals are next presented, instead. It is hoped that these will also be useful in interpreting better plant-water-weather relationships, to optimize crop yields.

RESEARCH PROPOSALS ON IRRIGATION AND AGRICULTURAL METEOROLOGY

1) Title: Response of corn to three irrigation regimes.

   Objective: To investigate the optimum water utilization by corn, under three water application regimes, based on the open pan evaporation and growth stage of the crop.

   Justifications: The eco-physiological aspects of corn, tied up with the water economy and growth should be investigated. Significant yield differences under similar fertilizing and soils justify this investigation. There is also much hearsay on critical periods of moisture demand by

corn, that needs to be verified. This investigation pursues to develop a better criteria with respect to the water requirements of corn in three experimental regions with different ecological characteristics (Peroto,El Maral,Cobijas).

Procedure

1) On a parcel 15 x 90 m. four blocks 15 x 20 m. will be established as replications of the following arrangement. Three irrigation plots, 5 x 20 m. will be randomly located within each replication. Ten meters are left so that between the replications, irrigation and drainage ditches be located at their heads and lower ends, respectively.

2) The three irrigation regimes will be established as follows: (a) water will be applied to the irrigation plots after an accumulated open pan evaporation of 80 mm. Any rainfall of 2mm. per day or over will be deducted from the accumulated evaporation; (b) water will be applied after an accumulated evaporation of 30 mm. deducting any significant rainfall in the same manner as before; (c) water will be applied after an accumulated evaporation of 80 mm. during growth, and until immediately before trasseling begins. From here on, and until the milky maturation of the kernels begin to show-up, water will be applied every time 30 mm. of evaporation accumulated.From the latter stage of kernel maturation and on it will be turned back to the more spaced irrigation of every 80 mm. of accumulated evaporation.No more than two irrigations will be applied on this last stage.

3) Irrigation will be applied by furrows 75 cm. apart.There will be six rows per irrigation plot, with plants left 30 cm. apart. The four center rows will be harvested for yield, and only 12 m. along each row, towards the center of the row.

4) The depth of water to apply on each irrigation will correspond with the accumulated evaporation in the case of the 80 mm. accumulated evaporation. The depth of application in the other, more frequent irrigation (every 30 mm) will be of 40 mm. After planting one uniform irrigation will be applied. The irrigation treatment regime will begin from there on.

5) Fertilization, variety, pesticide use, and other management details will be left to the decision of the research techncians.

6) Laboratory determinations will be made of the relative moisture content (CRH), or relative turgidity of the leaves at the 0900 and 1400 hours, weekly. Two disks 1 cm. in diameter will be obtained from each side of the central vein, on the second open leaf begining from the top.This will be repeated in six plants of the irrigation plots.Disks will be taken to the laboratory in petri-dish to be weighted, then placed for 2 hours in distilled water for saturation under light exposure, and again weighted. The differences in CRH between the 0900 and 1400 hours will be compared under the three irrigation regimes. Sampling will begin on the fourth week, and until after the last irrigation.

2) <u>Title</u>:The effect of irrigation, harvest frequency, and nitrogen fertilizatinn on the yield and quality of forage grasses.

Objective: To evaluate the best combination of irrigation, harvest frequency and nitrogen fertilization for optimum and economical yields of forage along the year.

Justification: The development of a dairy industry in both Beni and Pando should be investigated, simultaneously under intensive and extensive methods of forage harvests and of grazing management. The forage harvest systems has some advantages which may well popularize it. It can also be couppled with a rotaion system of grazing (with fencing), mainly connected with the younger cattle and with the rainy season. In the dry season, under irrigation, the forage-harvest system can also be very helpful. Finally, this system may help to keep under control desease problems.

Procedure

1) An experimental site, 52 x 58 m. in size, will be selected for a split-plot experimental design, The main treatment or plots 25 x 12 m. will be represented by two harvest frequencies, based on the accumulated solar energy (photosynthetic potential criteria), to be chosen from the following values, depending on the forage specie, and for ano more than two harvest-frequencies: 13,000 - 20,000 - 27,000-35,000 langleys (or cal/cm^2). For example, if napergrass (Pennisetum purpureum) were selected for the experiment, the two appropriate harvests frequencies would be 20,000 and 27,000 lys. This harvest-frequency criteria accounts for short days, when the forage is slow in growth. If there were no pyranometer available, the harvest frequency criteria

may rest on accumulated pan evaporation (with no adjustment for rainfall), of 160-240-320-400 mm. values which approximately correspond to the previously mentioned solar energy figures.

2) Two irrigation regimes will be chosen as sub-plots, 12 x 12 m. in size, and will also be based on the accumulated open pan evaporation. In this case: (a) irrigate after an accumulated evaporation of 40 mm. (significant rainfall substracted) and (b) irrigate after an accumulated evaporation of 80 mm.

3) The basic experimental units or sub-plots will be 6 x 12 m., to accomodate two nitrogen application rates of 350 and 700 kg. N/ha. year, divided into the estimated number of possible harvests, under both harvest frequency regimes.

4) Irrigation will be applied by flooding basins (6 x 12 m). One meter spacing will be maintained between the irrigation sub-plots, and 2 m. between the harvest frequency plots.

5) In addition to dry matter yields, the N, P, K, and fiber composition of the forage will be take for each experimental unit (sub-sub-Plots), which amount to 32, as there will be four replications (52 x 12 m).

3) Title: Compilation, analysis and evaluation of meteorological data.

Objective: To awake conscientiousness, formality, and scientific interest in the collection and analysis of the meteorological data, for a better interpretation of the response of crops to the environmental factors and to management.

Justifications: For the higher latitudes there exitss abundant literature on the influence of weather factors on crops yields. Such influence is sometimes expressed in plant nutrition, or in water uptake, by altering the soil-plant relationship. In other instances, and adverse effect of climatic factors has benn detected on crop management, as for example - pesticide control.

Procedure

1) Mean weekly values of air temperature (Ta), and wind speed (u), relative humidity (RH), solar radiation (I_o)and the total open pan evaporation (E_o),and total precipitation (P) will be calculated for each of the three experiment stations. The instantaneous values of air temperature and relative humidity must have been checked with a psycrometer right after placing a new weekly chart at the 0800 hr. on Mondays, and once more on the 1400 hour.

2) From the mean weekly values of relative humidity and air temperature, the mean values of vapor pressure saturation deficit (E_d) and dew - point temperature will be calculated, using the equations and tables mentioned before in this report.

3) From the mean weekly values of the weather parameters mentioned before, estimate the functional relationship of :

$$E_o = f\ (I_o\ , T_a,\ u,\ \ E_d \text{ or } T_d\ )$$

If there exists good correlation, it will permit us to estimate some missing mean weekly values of in terms of the calculated ones.

4) It iwll also be attempted to estimate I_o from the extra-terrestial solar radiation (I_e) available from tables, by the linear equation

$$I_o = a + b \; I_e/E_a$$

Values of I_e are given in the appendix for some latitutes. It will only be necessary to extrapolate to arrive at mean weekly values of I_e.

MEDIUM AND LONG TERM RECOMMENDATIONS

It would not be desirable to deepen into the solution of agronomic problems in North-Oriental Bolivia if this effort is not meritorious *per se*. A region that has been importing floods every year, gets adapted to live with them, leaving behind the growth of an infrastructure, without which a productive, efficient and diversified agriculture is just short of impossible.

The population of Beni and Pando is small and scattered and lacks adequate means of transportation and communication.

On the other hand, the substantial wealth of valuable forest, water resources, tillable land, and possibily mineral resources, await for a mayor population growth and civic, industrial, and trade centers, which in turn will stimulate production and consumption. Of course, infrastructure like the construction of more roads, school, health facilities, recreation facilities, housing and other government facilities and services will also be needed.

This report has focused on irrigation and drainage aspects which the Ministerio de Asuntos Campesinos y Agropecuarios, through IBTA, can give preferential attention, in an effort to impart greater prospects to the agricultural activity of this region.

In the longer view, other recommendations are generalized, some of which we know, are not covered by the realm of the authority of the Ministry.

Of Agronomic Extent

1) Establish adequate agreements with the Development Corporation of Beni (CODEBENI) and of the North (CORDENO) by which IBTA, after getting hold of a "technological package", product of their own research on a given crop, will coordinate with CORDENO or CODEBENI the establishment of a pilot farm on the given crop or crops. At this state the economic aspects of production and marketing will be considered.

IBTA could properly be entrusted the responsibility of coordinating with the Develpment Corporations the land clearing, land grading, and the irrigation and drainage set-up for the pilot demonstration farms. The San Carlitos Farm in Villavanceer appears to be adequate for a pilot demonstration farm.

2) On the basis of the results obtained with the drainage experiment recommended in this report, another study should be initiated in no less than 50 ha. as a grazing demonstration farm, within the limits of the Peroto Agricultural Experiment Station. This farm should not form part of the agreement with CODEBENI, inasmuch as it will be

subject to continuous modifications, based on experimental results. This farm may serve, in addition, to initiate experimental work with dairy cattle.

3) Establish in the Experiment Stations of El Maral and Cobijas experimental citrus orchards, with emphasis on citrus fruits. To this effect it is advisable for an horticulturirst to pursue graduate studies concentrating in this field.

The commercial cultivation of citrus fruits and their processing can, eventually, impact the agricultural economy of both regions. Its location in Cobijas can gain support with the project for an international airport in Cobijas. In El Maral, such a project can also gain support in the population growth taking place in the area of Riveralta-Guayaramerin, and in the prospect of better shipping facilities by way of Mamore-Madera - Amazonas Rivers.

4) It is recommended to discourage the indiscrimate land clearing of productive forests, just to give way to insolated plots for farming which eventually may be abandoned.The land clearing of "island" forest or "motacusales", which contribute to the hydrologic and ecologic balance of the savannas, have also been the shade refuge for the cattle. Once cleared, nature's hundreds of years work are destroyed in days.As no organized, adequate drainage can be provided to this isolated areas, eventually they will be abandoned and remain barren.

Beni and Pando possess an enormous undeveloped wealth in forest resources, which contain such fine wood as cedar, laurel,mara,

mora, itauba and others. The U. S. market alone, for this product is promising. The conservation and reforestation of this resource is essential and should be planned from now. The prospects for a stable lumber industry are good, once the transportation and technological problems are solved.

We must be aware of the fact that for years Bolivia will not be a densely populated region to any extent. From this point of view the local market for perishable crops must be carefully evaluated. The agricultural exploitation could be rather visualized as one for export. In this sense lumber products deserve a high priority because the resource is there.

5) Along the same line of thinking, paddy rice cultivation in commercial scale is worthwhile considering in Beni. It may have better possibilities in the winter, between May and September, under flooding irrigation techniques. There will be required around one million cubic meters for each 100 ha. This is equivalent to 18 m^3/min. 8 hours a day during 22 days a month, along the five months of rainfall deficiency.

6) For the "chacos" of Beni with 50 ha. of arable land, it is recommended to develop a research program at Peroto.The idea would be to develop a model for a 20 ha. farm intensively cultivated in crops such as rice, and corn. Although this type of farming deviates from what is recommended so far, subsistence production is essential to the farming community and to satisfy the population centers of Trinidad and other communities.

The irrigation requirements for an agricultural farming of this kind in 20 ha. are approximately 90,000 cubic meters, or a stream flow of 30 l/s. 160 hours of irrigation monthly (8 hours in 20 days), during 5 months.

On the Infrastructure

1) Establishment of vocational education and farm machinery centers that can aid to spread adequate technological information on farming practices and promote rural housing through mutual aid and self-help methods.

2) Establish better ties between higher education centers and the agricultural experiment stations.Establish communications with the librarians of this education centers, aimed to develop library facilities in the Experiment Stations. These ties may eventually locate graduate students in the experiment stations to work on their thesis problems.

At the National Level

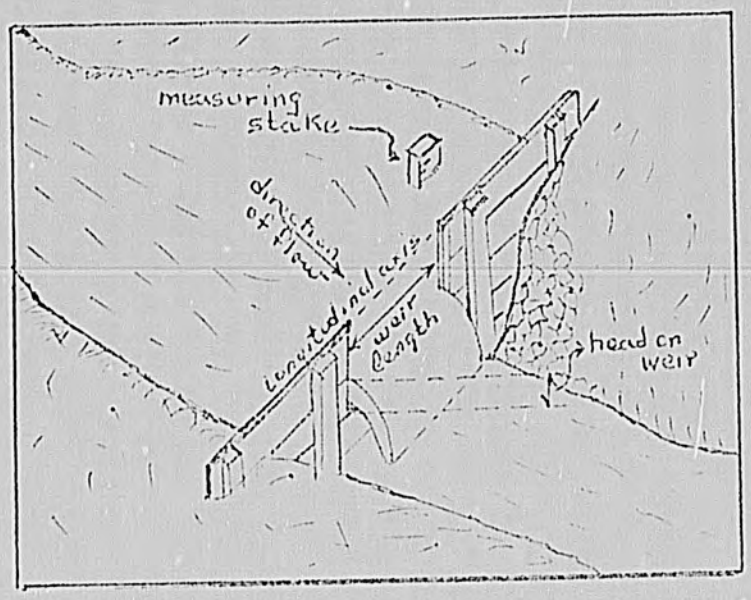
1) Efforts should be made with the Ministry of Public Works and Highways, directed to dig a general drainage canal on both sides of the road that goes from Trinidad to Peroto Experiment Station. The digging of these drainage canals, parallel with the road, will also leave a dike between the road and the drains.

2) It is recommended that a topographic survey be made to facilitate irrigation and drainage construction works, at least along the roadside areas, about 2 km. on both sides.

Appendix I

Crested Weir in Weir Pond
Installation Requirements

1. For 6 to 15 m^3/min the recommended crest length is 75 cm with a maximum head of 20 cm.



2. Weir will be set at lower end of pool, sufficiently long, wide and deep to give an even, smooth current (almost still water) of no more than 15 cm/sec.

3. Longitudinal axis be perpendicular to direction of flow.

4. Face of weir should be completely vertical.

5. Crest of weir should be horizontal (completely levelled).

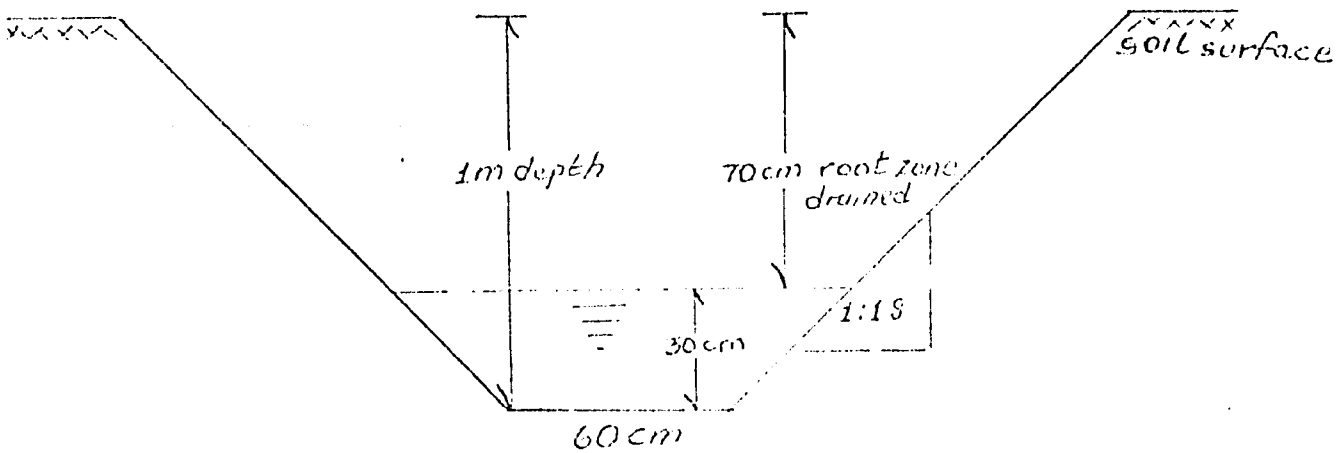
6. Distance of crest above bottom of pool should be 3 times the depth of water flowing over weir crest.

7. Measuring stake should be to one side of weir to be free from downward curve of water surface as it passess over curve.

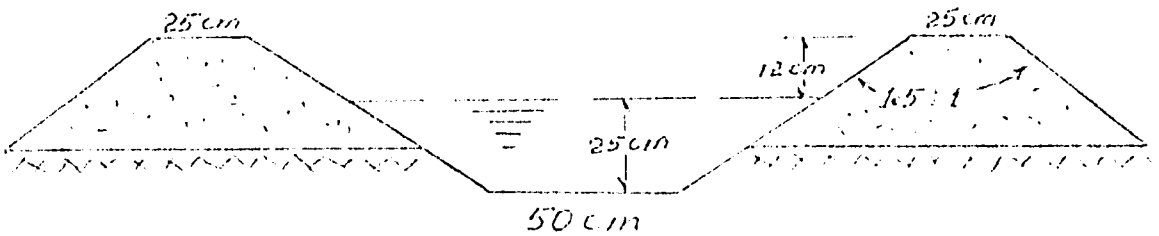
8. Crest should be high enough so that water falls freely.

9. Prevent erosion downstream below weir by placing loose rocks.

Appendix I



Open drain designed to carry freely up to 11 m^3/min.



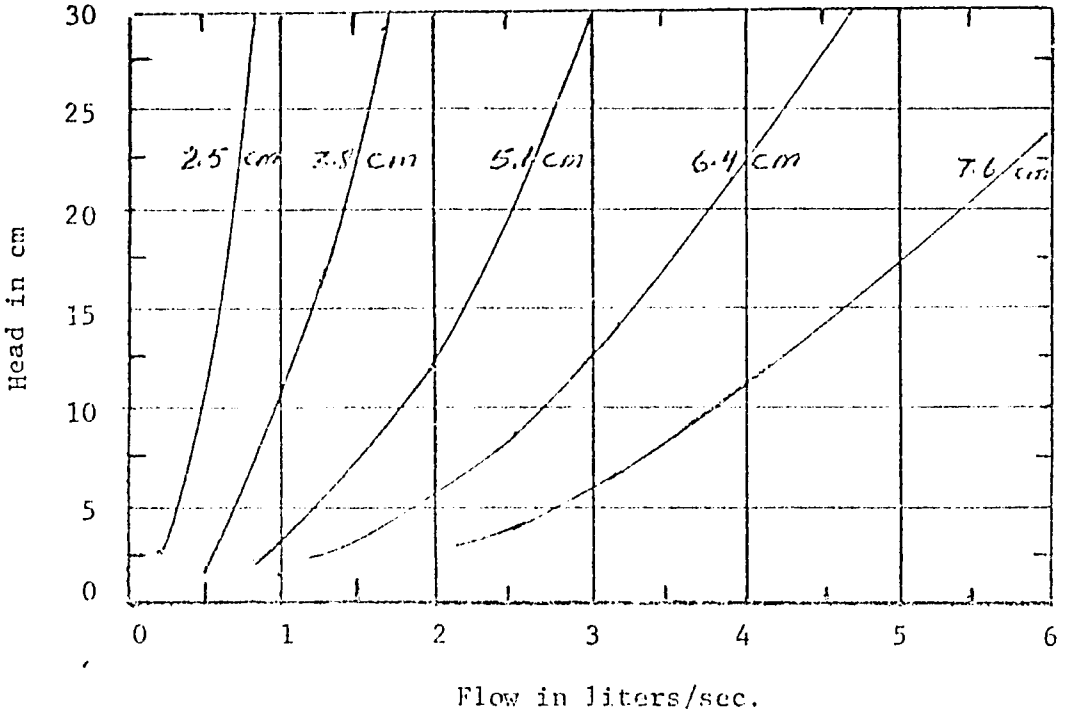
Irrigation ditch designed for a stream of not more than 9 m^3/min.

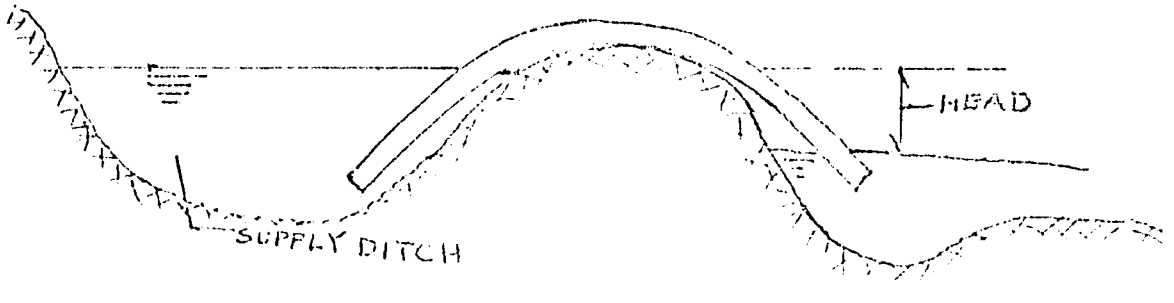
For channel flow: $Q = AV$

where Q = volume of flow in m^3/min.
A = cross sectional area in m
V = velocity of flow in m/min.

Appendix II

Flow through various sizes of siphons connected to a supply ditch.





From the equation given before: $V_t = 2.73\ AL/T$

if V_t, in l/s and L, in mm are fixed, and A = number of siphons x distance between siphons in meters x length of furrow in meters,

the time required to irrigate is

$$T = 2.73\ AL/V_t$$

If V_t in the turnout is not known, we can estimate it for the individual siphons from the above figure.

Appendix III

Radiación Extraterrestre en mm/día
Para Tres Latitudes en Bolivia

Lat	En.	Feb.	Mar.	Ab.	May.	Jun.	Jul.	Ag.	Sep.	Oc.	No.	Dic.
10	16.4	16.3	15.7	14.4	13.0	12.2	12.5	13.8	15.2	16.2	16.5	16.4
15	17.0	16.6	15.5	13.8	12.1	11.2	11.5	13.0	14.8	16.2	16.9	17.1
20	17.4	16.7	15.2	13.1	11.1	10.1	10.5	12.2	14.3	16.2	17.2	17.6

Langleys/día x 0.0172= mm/día

mm/día x 58.14 = langleys/día