IRRIGATION DESIGN CRITERIA FOR SUGARCANE

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Abstract

A method for determining irrigation design criteria for sugarcane based on physical properties of soil, climatic data and crop management practices is explained. Practical methods of acquiring data are described and reference is made to sources from which data are easily available. Certain assumptions are made and the effects of these on design criteria are discussed. A case study is made to illustrate the sequence in which successive decisions need to be made. The use of the design criteria by planners and operators of irrigation schemes is explained and the importance of energy conservation and the efficient utilization of natural resources is emphasized.

Introduction

The agronomic criteria used in the design of an irrigation scheme must be carefully considered. Insidious waterlogging and accumulation of salts in over-irrigated soils can be attributed not only to poor irrigation management but also to incorrect assumptions regarding the moisture holding capacity of the soil, movement of water in the soil and the combined effect of the water requirements of the crop and average climatic conditions.

The failure of an irrigation scheme to supply a crop's water requirements results in water stress and loss of yield. This occurs when the requirements of the crop are underestimated and when water is lost as runoff because application rates exceed the intake rate of the soil, particularly on steep slopes or due to deep percolation. Knowledge of soil moisture and crop interactions, an accurate estimate of the water requirements of the crop, local rainfall and evaporation records are the basic requirements for the design of an irrigation scheme and are also necessary for the efficient scheduling of irrigation.

Once the design criteria have been determined, planners and irrigators have the necessary information for the design and operation of an energy efficient irrigation scheme appropriate to the crop and the environment. Under good management a well designed scheme will be capable of producing yields that are close to the climatic potential for the area.

Design Criteria

The design criteria needed by irrigation planners include the

- irrigation cycle or frequency,
- precipitation or application rate,
- irrigation requirement per cycle,
- annual water requirement per hectare.

Information on the soils to be irrigated, the topography and the cropping practices is best obtained by on site investigation. Climatic data in the form of long term means are rarely available for the specific area to be irrigated but records can usually be obtained from a local meteorological station.

Irrigation cycle or frequency:

An estimate of the total available moisture (TAM) of the soil, ie the amount of water in millimetres available to the crop, is used in conjunction with the water consumption of the crop to calculate the cycle time of an irrigation scheme and to estimate rainfall efficiency.

The main physical factors affecting the availability of soil water to the sugarcane plant are the available moisture capacity (AMC) of the particular soil; the depth of the soil profile or effective rooting depth of the crop and the distribution of roots within this depth.

Estimates of the soil factors can be made in the field by examining a soil profile which is exposed in a suitable inspection pit. Identification of the soil form and series facilitates the determination of the physical properties of the soil. The South African Sugar Association Experiment Station Bulletin No. 19, Soils of the Sugar Industry, is a valuable aid as it describes 23 soil forms and the method of identifying them, based on soil parent materials and geographical soil systems. Soil form and series identification using diagnostic horizons is detailed in the Department of Agriculture publication Soil Classification, a Binomial System for South Africa, which could also be useful.

An inspection pit should expose the soil profile to a depth of about 1,2 metres or to an obviously limiting horizon. Limited depth of a soil profile, caused by rock in various forms, or a fluctuating water table with its associated leached or plinthic horizons and anaerobic conditions, is normally recognisable

TABLE 1

Available moisture contents of profiles of nine soil series

Soil form	Soil series	Depth (cm)	Available moisture content	
			0,1 to 1 bar (FAM) (mm)	0,1 to 15 bar (TAM) (mm)
Arcadia	Rydalvale	0– 30	9,9	33,6
		30– 90	28,8	70,2
		Total	38,7	103,8
Inanda	Inanda	0– 89	79,3	124,6
		89–132	23,2	43,0
		Total	93,5	167,6
Cartref	Cartref	0– 30	15,6	33,0
		30–120	54,0	78,3
		Total	69,6	111,3
Glenrosa	Williamson	0– 45	23,0	46,0
Longlands	Waldene	0– 25	30,2	50,0
		43–110	34,0	69,4
		Total	64,2	119,4
Estcourt	Estcourt	0– 22	16,9	29,9
		22– 80	20,5	40,7
		Total	37,4	70,6
Hutton	Shorrocks	0– 18	20,2	27,0
		18–100	51,7	93,5
		Total	71,9	120,5
Shortlands	Shortlands	0– 30	15,6	33,0
		30–120	33,3	73,8
		Total	48,9	106,8
Hutton	Clansthal	0– 30	16,2	25,5
		30–120	61,2	86,4
		Total	77,4	111,9

and diagnostic. The moisture in the soil above these limiting layers is accessible to plant roots, the amount being subject to the available moisture capacity (AMC) of the soil.

The moisture release characteristics of the soils in the South African sugar industry have been studied in detail and the findings have been published by a number of authors. The available moisture contents of nine common soil series are shown in Table 1 (Johnston[2]).

The attractive force or tension, measured in kilopascals (kPa) between water molecules and the surfaces of soil particle together with the ability of gravity and the osmotic action of plant roots to overcome this tension, is used to assess the moisture release characteristics of a soil. It is accepted that plant roots can remove water from soil up to a tension of 1 500 kPa. Water held in the soil at tensions less than 10 kPa is normally removed from the unrestricted soil profile by gravity and is not considered available to the plant. The amount of water held between these limits, viz: 10 and 1 500 kPa, will vary mainly with the size of the soil particle. Soils with fine particles such as clay and silt have a higher surface area for a given volume than sandy soils and hence they have a higher moisture holding capacity.

Figure 1 shows typical moisture release curves for soils with different particle sizes or textures.

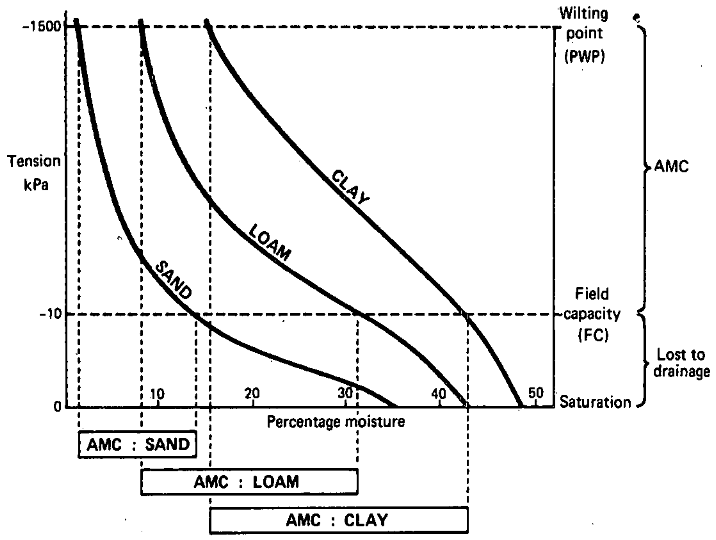

FIGURE 1 Soil moisture characteristics for three soil texture classes.

To obtain an accurate measure of the available moisture capacity (AMC) of the soil, soil texture should be determined and the soil form and series should be identified. Soil texture can be examined and sampled in the field by using a soil auger but accurate textural classification can only be done in the laboratory. Texture is likely to vary with depth and samples should be taken at 300 mm intervals down the soil profile. Particle size fractions of sand, clay and silt can be distinguished by moistening the soil with water to the consistency of a thick pliable paste and rolling it between the fingers. The relative amounts of the different fractions or the texture of the soil can, with training and experience, be estimated fairly accurately.

Typical AMC ratings for common textural classes are given in Table 2.

TABLE 2

Expected AMC values for a range of soil textures

Textural class	Clay content %	Expected AMC mm/m
Clay	>55	>160
Sandy clay	31-55	131-160
Sandy loam	16-30	101-130
Loamy sand	7-15	81-100
Sand	0- 6	<80

Changes in texture within a soil profile affect the total AMC. The procedure for determining the AMC of profiles is to estimate the proportion of the effective rooting depth represented by each AMC or textural class and to average the results. All these factors have been taken into account in the AMC ratings given in Bulletin No. 19 and they may be used with confidence when soil form and series have been identified.

The rooting depth of the crop is the next consideration in the estimation of soil TAM. The effective rooting depth multiplied by the AMC (expressed in millimetres per metre) gives the TAM of the soil. The effective rooting depth is the depth of soil in which the majority of effective moisture absorbing roots are found.

Experiments carried out on a Clansthal sand at Mount Edgecombe (Thompson *et al*[3]) using neutron probes showed that over a period when runoff and deep percolation were unlikely to occur, 96% of the plant's water requirements on an adequately irrigated plot were supplied from the top 600 mm of soil. On a Windermere clay soil, 97% of the plant's water needs were supplied from the top 300 mm under similar conditions. Relatively short cycle irrigation is desirable but the additional capital and operating costs incurred with short cycle irrigation has resulted in recommendations that a rooting depth of one metre be used to estimate TAM for surface and overhead sprinkler irrigation schemes when the soil is more than one metre deep.

Precipitation or application rate:

The rate of water intake by a soil is the most important factor to consider when determining application rates for overhead irrigation schemes or contact time for surface schemes. The intake or infiltration rate of a soil determines the size, capacity and to some extent the spacing of overhead sprinklers. In surface irrigation systems, the optimum length of run and furrow gradient for a given stream of water is determined by the infiltration rate of the soil.

Textural classification and the soil profile can be used as a guide to estimate the infiltration rate of a soil. When the soil is dry, the infiltration rate is relatively high but as cracks and other spaces are filled with water and when certain clay soils begin to swell, the intake rate decreases to the steady or terminal intake rate.

Economic and management considerations dictate fairly long application periods and the terminal rate is therefore used for the design of surface and overhead irrigation systems. Terminal infiltration rates for the soils described in Bulletin No. 19 were obtained by tests and observations both in the field and in the laboratory. The intake rates for five soil textural classes are given in Table 3.

TABLE 3

Typical values of 'final' infiltration rates of some classes of soil texture

Soil type	Infiltration capacity mm/h
Sands	20
Sandy and silty soils	10–20
Loams	5–10
Clayey soil	1- 5
Sodic clayey soils	1

Measuring infiltration rate in the field by using ring and furrow infiltrometers requires so many tests that it becomes impractical. The coefficient of uniformity for a number of these tests carried out at Cedara was 13 for the Balmoral soil series, 7 for the Shortlands series and 23 for the Zwagershoek series (Turner[5]).

The effect of the land slope on the infiltration rate is being investigated by the Experiment Station as part of runoff and erosion experiments using a rainfall simulator.

The recommendations made by a sprinkler manufacturer for reducing the precipitation rate with increasing slope to avoid runoff from irrigated lands, are given in Table 4. These figures apply to bare soil and it is reasonable to assume that only half of the recommended reduction is necessary for cane which is fully canopied or for fields which have a trash covering.

TABLE 4

Recommended reduction in precipitation rate for slope

Slope	Recommended % reduction in precipitation rate
0– 5 percent grade	0
6– 8 percent grade	20
9–12 percent grade	40
13–20 percent grade	60
Over 20 percent	75

Once the soil parameters have been determined, the TAM and infiltration rates for a field are averaged if the differences are small but when they are large, special attention by the irrigation planner is needed.

Water requirements of the crop:

If the soil is regarded as a water reservoir, the volume it can hold and rate at which it can be recharged can be determined from the criteria already discussed. The rate of water abstraction or the crop's demand and the part played by rainfall can now be considered.

The well established relationship between evaporation from a standard Class A evaporation pan and the evapotranspiration of sugarcane as reviewed by Thompson,[4] is used to determine the water requirements of the crop.

Crop factor:

The five growth stages of the sugarcane crop, viz: pre-emergence, quarter, half, three quarters and full canopy, are used to determine the canopy factor. The crop's water requirements (E_t) can be calculated on a daily basis by applying the canopy factor to the daily evaporation (E_o) figure. The relationship between canopy or stage of growth, the crop's water requirement and Class A pan evaporation has been established (Thompson[4]) and is given in Table 5.

TABLE 5

Evapotranspiration ratio

Canopy factor	0	¼	½	¾	Full
Percent of E_0	40%	55%	70%	85%	100%

Evaporation data:

Long term average E_o figures are available from meteorological stations maintained by the Experiment Station throughout sugarcane growing areas. Differences between these figures and farm figures are usually not significant.

Cropping practices:

Canopy factors can be forecast easily for an irrigated field which is harvested regularly during a particular month. When an irrigation scheme is planned for fields with similar soil criteria but which are to be harvested in different months, the average monthly canopy or crop factor must be calculated.

In Table 6, the E_t/E_o ratios that can be expected from a farm on the north coast with fields harvested throughout the milling season, April to December are compared with a single field always harvested in August.

The E_t requirements and TAM of the soil are used to determine the nett irrigation application and the cycle when full irrigation is required. Because sugarcane is grown in the summer rainfall areas of South Africa rainfall must be included in the determination of irrigation requirements for economic reasons.

Rainfall:

Long term mean rainfall figures from the Experiment Station's meteorological stations are used. A portion of the rainfall must be assumed to be unavailable to the plant because of runoff, deep percolation and evaporation. In the fully irrigated areas of the sugar industry, rainfall is assumed to be 70% efficient but in the rainfed areas where the crop's water requirements are met by rainfall alone, its efficiency is higher.

Irrigation requirement:

Using the soil reservoir concept again, a nett monthly irrigation requirement (I_e) can be computed. The difference between water consumption by the crop (E_t) and effective rainfall (R_e) is the nett deficit (I_e) which has to be supplied by irrigation. Variations in the crop's water requirement and effective rainfall will therefore cause the monthly irrigation requirement to vary. To ensure that the crop's water requirements are always met, the capacity of an irrigation scheme should be designed according to the greatest monthly deficit (I_e) or month of highest irrigation demand. This figure is used in feasibility studies to calculate the number of irrigations required per month.

Quantity and frequency of irrigation:

The irrigation cycle, nett application rate and quantity can now be determined. Gardiner[1] suggested that growth is unrestricted within the soil moisture tension range of 10 to 100 kPa. The percentage depletion of TAM at a tension of 100 kPa varies with the texture of the soil. The approximate depletion of AMC at the 100 kPa tension level for three soil textural classes is given in Table 7. This percentage of the AMC is known as the freely available moisture (FAM).

TABLE 7

AMC of various textural classes of soils and percentage depletion at a soil moisture potential of −100 kPa and their FAM values

Soil type	AMC mm/m	% depletion AMC at −100 kPa	FAM mm/m
Sandy soil	60	75	45
Clay loam	140	50	70
Clay	160	30	48

The irrigation cycle can be based on the number of days it takes to deplete the FAM at the daily I_e calculated from the greatest monthly I_e figure. The FAM is then the nett irrigation requirement per cycle.

Case Study

The procedure for determining the irrigation design criteria for a 10 hectare field on a farm situated about two kilometres east of Tongaat is discussed.

TABLE 6

Comparison of E_t/E_o ratios expected from a north coast farm harvested throughout the milling season with a single field harvested in August

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Whole farm av. monthly E_t/E_o ratio	0,74	0,85	0,90	0,94	0,90	0,85	0,77	0,70	0,66	0,63	0,62	0,65
Single field monthly E_t/E_o ratio	0,85	1,0	1,0	1,0	1,0	1,0	1,0	0,40	0,40	0,55	0,55	0,70

TABLE 8

Computation of required effective irrigation (I_e)

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Evaporation E_o	Day mm	6,1	5,9	5,4	4,2	3,4	2,7	3,0	3,7	4,2	5,1	5,5	5,9	–
	Month mm	188	167	166	125	104	82	93	115	125	157	164	184	1 671
E_t/E_o ratio		0,85	1,0	1,0	1,0	1,0	1,0	1,0	0,40	0,40	0,55	0,55	0,70	–
Evapotranspiration E_t	mm	160	167	166	125	104	82	93	46	50	63	90	129	1 275
Rainfall R	mm	130	132	113	61	65	17	33	52	96	97	116	103	1 015
Rainfall efficiency	mm	70	70	70	80	80	95	90	90	80	80	70	70	–
Effective rainfall R_e	mm	91	92	79	48	52	16	30	47	77	77	81	72	762
Effective irrigation I_e (Deficit E_t-R_e)	mm	69	75	87	77	52	66	63	(1)	(27)	(14)	9	57	513

Assessment:

The crop is burnt and harvested annually in August after a drying-off period of two months. The irrigation scheme is to operate 24 hours per day on six days of the week.

Land slope:

The slope of the field is 8%

Soils:

Parent material maps show that the field is on Dolerite derived soils of the Shortlands form, Glendale series. The clay content of the field varies from 30 to 50% and the texture is sandy clay. An AMC of 130 mm/m was estimated for the soil and throughout the field the unrestricted soil depth was 1,1 m. The TAM of the soil is therefore 130 mm as the maximum rooting depth is taken as 1 m and of this, 50% or 65 mm is the FAM. The infiltration rate of the Shortlands soil form is about 6 mm per hour. On account of the 8% slope this should be reduced by 10% to give a nett application rate of 5,4 mm per hour.

Climate:

The farm is situated close to the Tongaat weather station whose long term mean records have been used to compute the required effective irrigation (Table 8). The deficit figures in August, September and October indicate that rainfall generally exceeds the crop requirements during this period.

Irrigation frequency:

The estimated peak deficit (I_e) occurs in February and is 4,5 mm per day so the FAM of 65 mm will be depleted in 14,4 days. The grower chooses to irrigate for 6 days of the week therefore the irrigation cycle should be designed for 12,3 (14,4 × 6/7) working days. For practical purposes this is considered a 12 day cycle.

Irrigation application:

The nett irrigation application per cycle is 65 mm and at an irrigation efficiency of 80%, the gross application is therefore 81,2 mm.

Recommended design criteria:

The irrigation design criteria recommended for this field are:

Irrigation cycle	: 12 working days
Irrigation application per cycle	: a maximum of 6,7 mm/h
Sprinkler stand time	: a minimum of 12 hours (81,2 ÷ 6,7 = 12) for a solid set irrigation system and proportionately less for portable and dragline systems
Water requirement for 10 hectares	: 51 300 m³/annum, which satisfies the annual deficit of 513 mm/ha

Conclusion

The correct agronomic criteria for designing an efficient irrigation scheme can only be obtained by investigating the resources and data pertaining to the soil, climate and requirements of the crop in the area under consideration. These data are readily available in the form of recorded results, recommendations and long term means while on site investigations of the various soil characteristics is necessary to determine the most important criteria. The available soil depth, soil texture and terminal infiltration rate have a pronounced effect on design criteria and must be carefully considered. Estimates of the canopy factor have to be made throughout the year to determine the overall water requirements of the crop; the effect of these estimates and the assumed rainfall efficiency are evident.

The case study typifies a successful method which is used to determine design criteria for irrigation in the sugar industry. Once approximate criteria have been determined, they can be supplied to the irrigation planner on a Scheme Design Data form (see Appendix), which he can then use to design an irrigation scheme.

REFERENCES

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APPENDIX

SCHEME DESIGN DATA

1. Soil type	:	____________	
2. Total available moisture	:	____________	mm
3. Infiltration rate	:	____________	mm/h
4. Estimated peak use at full canopy	:	____________	mm/day
5. Irrigation efficiency	:	____________	%
6. Total water per application	:	____________	mm
7. Sprinkler stand time	:	____________	h minimum
8. Water duty, per cumec for 24 h/day, 7 days/week	:	____________	ha
9. Irrigation frequency	:	____________	days
10. Estimated annual application	:	____________	mm