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REVIEW

Enhancing Sugarcane Productivity through Scientific Irrigation Water Management in Western India

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Abstract Sugarcane productivity is declining in western India. To meet the domestic demand for sugar, jaggery, juice (beverage), and other diversified uses (ethanol, biomass, etc.), there is a need to enhance cane productivity to around 150 t ha^{-1} by the year 2030 from the present 78.3 t ha^{-1} in view of the constraint on the availability of more water for cane growing. Increased adoption of moisture stress management practices like deficit irrigation is required in view of the increased frequency of droughts and paucity of irrigation water. Drip irrigation along with proper irrigation scheduling have increased and sustained yields and hence, their increased usage is important. The prerequisite for irrigation scheduling through drip, the crop coefficient for semiarid Indian conditions area are now available. Emphasis needs to be on situation specific crop management practices. This includes integrated approaches to nutrient management, micro irrigation with fertigation, particularly with wide row planting techniques. Reclamation of salt affected soils and improving drainage in ill drained soils will bring dramatic yield increases and hence need special attention and investments. Intercrops and residue utilization will improve and sustain productivity.

Keywords Drip irrigation · Irrigation water management · Maharashtra · MPKV Rahuri · Planting technique · Sugarcane

Significant statement: In last few decades lot of agro technological interventations has been and developed by leading research organisation Mahatma Phule Krishi Vidyapeeth (MPKV) Rahuri. Especially in water management aspect much research has been done and this review is an attempt to summarize it.

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Introduction

Sugarcane (*Saccharum officinarum L.*) is one of the most important agro-industrial crops next to cotton grown in subtropical and tropical parts playing vital role in Indian agriculture. In India, it is a traditional crop grown since time immemorial. Cultivation of sugarcane in India dates back to the Vedic period. In fact, its westward movement was through India [1, 2]. There are mentions in literature that production of sugar from sugarcane began in India, followed by China, Persia (Iran), Egypt and Spain, and elsewhere around the Mediterranean [3]. India ranks 2nd after Brazil among sugarcane producing countries of the world and contributes 22.5–27% in area and production of world, respectively [4]. Sugarcane is cultivated in almost all the states, excepting the hilly regions. The major sugarcane producing states are Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu and Bihar that contribute about 80–85 percent of the total sugarcane production in the country.

Area, Production and Productivity in India

Sugarcane occupies about 3.7% of the total cultivated area (5.11 Mha) and contributes about 4.6% of the gross value of agricultural production in the country. The annual sugarcane production of the country is about 400.16 Million

tonnes (MT) and average productivity is 78.3 t ha^{-1} [5]. Wide fluctuation in production is a characteristic feature of the Indian sugarcane agriculture (Figs. 1 and 2). The demand for sugarcane is increasing due to increase in the per capita consumption of sugar by an ever-increasing population and diversification of sugarcane uses. Hence, there is a need for increasing production on sustainable basis. Taking into account the population growth, increase of per capita consumption of sugar and emerging alternative uses, the projected sugarcane requirement by 2030 would be around 600 million tonnes [6]. Considering that a maximum of about 5.5 million ha of land would be available for cane cultivation, increasing the yield to around 110 t ha^{-1}, i.e., an increase of 57.1% over the current level, is required. Nevertheless, yield improvement will remain an important goal in sugarcane production. The increase has to come largely through increased yields since it is difficult to find additional land for sugarcane (Fig. 3).

Area, Production and Productivity in Maharashtra

Sugarcane is one of the most important cash crops of Maharashtra influencing the economy of state. Maharashtra is the highest sugar producing state of India. Sugarcane industry in Maharashtra is second largest agro-based industry with higher investment. It has brought about desirable changes in social, economical, educational and political life in rural areas. The pace of growth of sugarcane cultivation in state has been massive over the past few years. The state has established its supreme position in Indian Sugar Industry by contributing 37% of total sugar production. Out of 485 sugar factories in India, 185 are operating in Maharashtra state [5]. The area under sugarcane during 2018–2019 in India was 5.11 Mha with total production of 400.16 MT and average productivity 78.3 t ha^{-1}. Whereas the corresponding figure of Maharashtra were 1.16 Mha with production 92.44 MT and average productivity 79.50 t ha^{-1} [4].

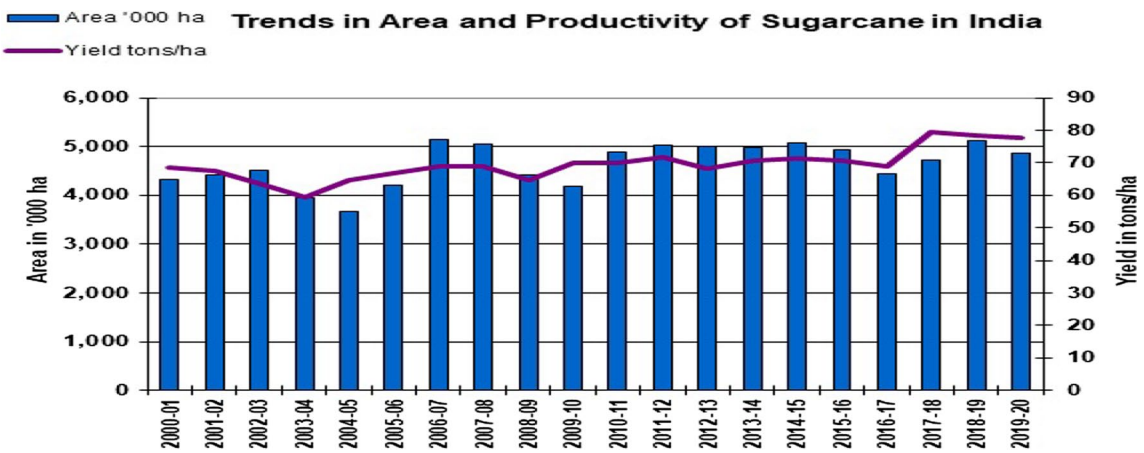

Fig. 1 Trend of fluctuation in area and productivity of sugarcane in India

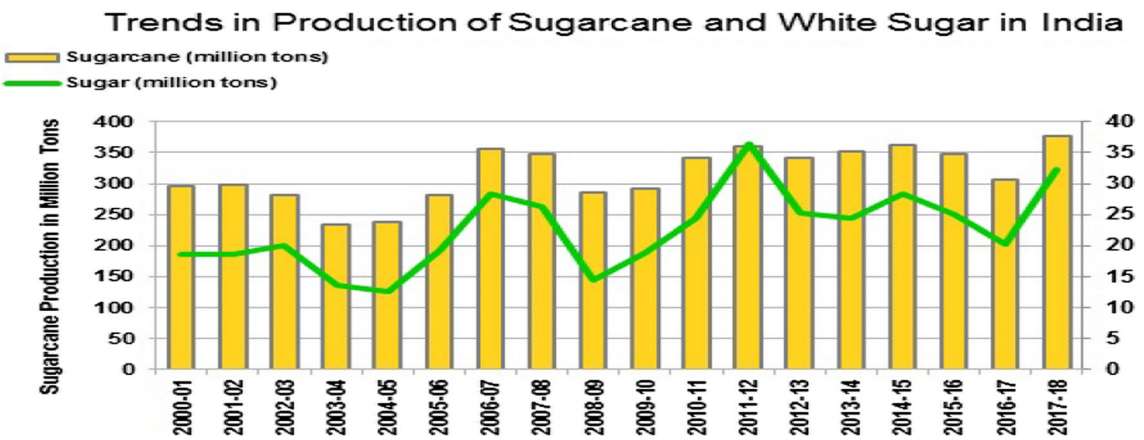

Fig. 2 Trend of fluctuation in production of sugarcane in India

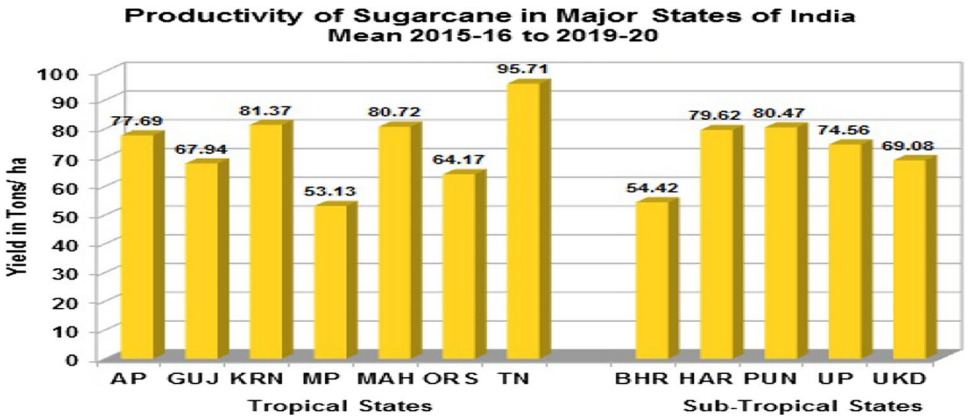

Fig. 3 Statewise productivity in major states of India (5 years average)

Suru (seasonal), *Preseasonal*, *Adsali* and *Ratoon* are the four sugarcane cultivation seasons prevalent in Maharashtra, *Ratoon* is most popular with 40% cane area under it, possibly since it has shortest duration at 11 months, fitting almost perfectly with the annual October to March cane crushing season. Same can be said about *Suru* (seasonal), having duration of 12 months and coverage of 20%, both methods requiring 22.5 irrigations, each of 7.5 cm depth. *Adsali* season has the highest yield and recovery rate, but only 10% of the sugarcane area is under this method, possibly since it has the longest duration at 17 months. It is most water intensive, requiring 32.5 irrigations. *Preseasonal* season, as the name suggests, is planted about 2.5 months before the season, and stands between *Ratoon* and *Adsali* in terms of duration, yield and recovery rate. In Maharashtra, the highest harvested cane yields by farmers for *Adsali*/*Pre-seasonal*; *Suru* and *Ratoon* have been 269, 217 and 202 t ha^{-1}, respectively. But there is wide gap between the average yields and potential yield. These production potentials can be achieved by adopting scientific irrigation water management and crop production practices.

Varieties

The sugarcane growing situations vary widely across the state. Sustained crop improvement work led Sugarcane Research Station (SRS), Padegaon, a more than 100 years old renowned institute of MPKV Rahuri has yielded improved cultivars. Some of them had occupied extensive areas and subsequently replaced by newer ones. At present, a large number of cultivars are available for each part of the States (Table 1). However, only a few of them occupy bulk of the area. In the state, Co86032 (Nira), CoM265 (Phule 265), Co-94012 (Phule Savitri), MS-10001 (Phule-10001), CoC 671 (Basant-1), VSI 434 and CoVSI 9805 (Sharad-1) are some of the leading varieties (Table 1).

There are vast stretches of sugarcane growing areas with several abiotic stresses like drought/moisture stress, excess moisture/water logging, soil and water salinity and alkalinity, soil acidity, and extremes of weather like hot summers and cold winters [6]. Since varietal response to such adverse growing conditions also varies, it is important to identify suitable varieties for each of the constraint situation. For example, cultivars CoM265 and Co86032 were found suitable under salt affected soils. Since, there is strong cultivar and environment interaction, growing situation specific high yielding cultivars is important to improve yields. There are changes in the sugarcane agronomy like wide row planting, paired row planting, etc. to facilitate mechanization, adoption of micro irrigation, etc. To take full advantage of the changed agronomy, specific varieties are required (Table 2).

Table 1 Brief information about sugarcane varieties for Maharashtra. Source: [23]

Variety	Characteristics
Co86032	Medium to late maturity, suitable for all three seasons and good ratoon
CoM0265	Medium to late maturity, High productivity and suitable for saline alkali soils
MS-10001	Early maturity, High productivity and sugar recovery, suitable for saline alkali soils
Co94012	Early maturity, High sugar recovery and good ratoon
Co92005	Medium to late maturity, suitable for jaggery
CoC671	Early maturity and high sugar recovery
Co.VSI-9805	Medium to late maturity and high sugar recovery
VSI434	Early maturity and high sugar recovery

Table 2 Spacing of sugarcane under different soil type and irrigation methods. Source: [23]

Soil type	Method of irrigation	Furrow spacing	Method of placement of set	Spacing between two sets
Coarse to medium textured soils	Surface	100–120 cm	Parallel to furrow	15–20 cm
Fine textured soils	Surface	120–150 cm	Across the furrow	15–20 cm
Coarse to medium textured soils	Drip (Paired Row)	75 cm × 150 cm	Parallel to furrow	30 cm
Fine textured soils	Drip (Paired Row)	90 cm × 180 cm	Parallel to furrow	30 cm
Nursery seedlings (All soil type)	Drip (Single row)	150 cm	Parallel to furrow	60 cm

Seed Rate

Single and two eye bud methods of planting are in practice. To avoid heavy risk of gaps in single eye bud and over population by three eye bud planting methods, two eye bud method is recommended. About 25,000 (for heavy soil) and 30,000 (for medium soil) two eye budded sets will be required to plant one-hectare area. Only upper half or two third cane should be selected for planting. While preparing set, care should be taken to maintain minimum distance (one third internode) above the eye bud and maximum distance below the eye bud (two third internode) so as to obtain high germination. Depending upon the soil type and method of irrigation, appropriate spacing should be adopted.

Nowadays, the use of transplanting is also becoming popular as it helps to save time during field preparation. MPKV Rahuri has recommended planting of 45 days old single eye bud poly bag settling of preseasonal sugarcane (Co-86032) at 90 cm apart by skipping one row after four rows and keeping laterals in alternate rows for higher yield and net returns. However, transplanting is not preferred over normal planting due to delay in maturity.

Nutrient Management

Application of organic manures for maintenance of soil at high fertility level is almost essential. Organic manures improve physical, chemical as well as biological properties of soil. Organic manures @ 20–25 t ha^{-1} are to be applied in different forms like Farm Yard Manure/Compost/Dung Manure. MPKV Rahuri recommended FYM (20 t ha^{-1}) + fertilizer @ 400 kg N, 170 kg P and 170 kg K ha^{-1} under drip irrigation for deep soils of Maharashtra. Press mud can also be used as an organic manure @ 5 t ha^{-1} particularly useful in saline alkali soils. Sugarcane trash can be used as a mulch and sprayed with 80 kg urea, 100 kg Single Super Phosphate and 10 kg decomposing culture ha^{-1} for better decomposition. Sugarcane trash can also be incorporated while making organic manure along with press mud and use of earthworms for preparing vermicompost.

Green manure crops like sannhemp and dhaincha can be grown as a sole crop and buried in the field at an age of 1.5–2 months (before flowering) followed by sugarcane crop. These can also be grown along with sugarcane by sowing in rows in between two rows of sugarcane and burring in soil at the time of earthing up. On an average, 20 tonnes of green matter and 90 kg nitrogen is added by growing green manure crop.

Intercropping

During the initial 3 months period of sugarcane crop, short duration leguminous intercrops which fix atmospheric nitrogen, improve phosphorus nutrition and help improve soil physical condition, can be grown. For the seasonal planted sugarcane summer groundnut, chick pea, onion, cucumber, watermelon, cabbage, cauliflower, Knol-khol, Fenugreek, coriander; for preseasonal potato, onion, garlic, cabbage, cauliflower, peas; and in Adsali summer groundnut, cowpea, soybean, vegetables are some of the suitable crops for intercropping.

Studies at MPKV, Rahuri has recommended plating of *Suru* sugarcane at a distance of 90–180–30 cm and cucumber as inter crop under drip irrigation for getting higher yield, higher monetary returns and maximum water use efficiency. In another study, *Suru* sugarcane + onion inter cropping system under overhead sprinkler or micro sprinkler and sugarcane + cucumber or water melon under drip method of irrigation are recommended [7].

Irrigation Water Management

Sugarcane is water-intensive crop and the challenge is, therefore, to produce more crop with less water. The major factors responsible for decline of sugarcane productivity in Maharashtra are mainly drought in sugarcane producing area and poor irrigation management [8]. In Maharashtra, sugarcane

occupies 4% of total cultivated area (1.02 Mha), but it uses 65% of total available irrigation water [9]. Sugarcane being a yearlong crop requires continuous supply of irrigation water throughout its growth cycle with differential phasic water requirement [10]. It requires 125 and 1400 tonnes of water to produce one tonne of cane and sugar, respectively [11]. Considering only dry matter production, it requires 322 g of water to produce one gram of dry matter [12].

In Maharashtra water is the biggest factor limiting crop growth, the supplemental irrigation is required to produce acceptable yields of sugarcane. Due to over exploitation of ground water resources, water for irrigation is becoming scarce and expensive. Further, irrigation in these areas is mainly given as flooding, which results in heavy conveyance and water application losses, and causes waterlogging, salinity and loss of nutrients through leaching [13]. It is one of the reasons for reduction in the cane productivity in Maharashtra in spite of development of many high yielding varieties. In addition, for various reasons the surface water supply is not regular. Farmers apply excess irrigation during canal 'on' periods whereas prolonged 'off periods' resulting in moisture stress leading to reduced crop yields and crop failure in extreme cases [14]. It is, therefore, utmost important to use a scarce water resource effectively and efficiently by adopting proper water management strategies when growing sugarcane.

Sugarcane Water Requirement

The consumptive water needs of seasonal (one-year) sugarcane is between 1600 and 2000 mm in Maharashtra State depending upon agro climatic conditions. After effective rainfall, the annual net irrigation requirement is only 1200–1600 mm. Considering 20% field application losses, 1400–2000 mm is enough under surface irrigation condition. However, farmer's water use is 3000–4000 mm [15]. It shows enormous wastage of water resource. The excess application result in water logging and salinity in the farm. Adoption of any one of the modern irrigation techniques such as straight ridges and furrows with gentle slope, contour furrows, leveled furrows, drip irrigation and a combination of sprinkler plus straight furrows can reduce these problems. Adoption of modern irrigation techniques and best management practices will save about 50% water use on farm and will almost double the sugarcane yield.

Sugarcane comprises of four growth stage viz. germination or emergence, tillering or canopy development, grand growth and maturity or ripening. The water needs of the sugarcane crop are not uniform during the crop growth from germination stage till its maturity stage (Table 3). Usually crop water needs are relatively small during initial stage and maturity stage. The crop evapotranspiration of tillering, grand growth and maturity stage determined by field water balance are 264, 887 and 137.4 mm, respectively, whereas total crop water requirement is 1339 mm [15]. Nursery planting of sugarcane can save initial 3 irrigation amounting 80 mm each. Further, nursery planting of sugarcane has distinct advantages like spare time for field preparation and healthy plant selection, etc.

Table 3 Stage wise irrigation requirement and frequency of sugarcane in western India

S. no.	Growth stage	Months (duration)	Quantity of water each irrigation (cm)		
		Seasonal/ratton	Preseasonal	Adsali	
1	Germination	1.5–2	1.5–2	1.5–2	6
2	Tillering	2–4	2–4	2–4	8–10
3	Early growth	4–6	4–6	4–6	8–10
4	Grand growth	6–10	6–12	6–14	10–12
5	maturity	10–12	12–14	14–16	7–8

The irrigation requirements vary between different growths stages due to planting seasons, crop age and weather conditions (crop demand and rainfall). The water requirement is high and more frequent for initial stage for *Adsali* rather than *Suru*. Soil factors such as texture, structure, and soil depth are also found to influence water requirement. If the soil is deep, water storage capacity is more. In shallow soils, water storage is limited and requires more frequent irrigations than deep soils.

Deficit Irrigation Scheduling

Deficit irrigation scheduling is another way of irrigation scheduling to sugarcane. With deficit irrigation, a controlled water application imposed on the crop, but the economic viability of crop production has to assured [9]. Supplying measured irrigation water through drip can saved water to irrigate additional cropped area for which water would normally be insufficient under traditional irrigation practices [16]. Based on the knowledge of crop sensitivity to water stress, it is possible to develop recommendations for irrigation scheduling to meet water requirements during stress-sensitive growth stages and to impose deficits during less stress-sensitive stages. Tiwari [17] recommended irrigation be scheduled at 100 mm CPE from January to April, at an interval of 20–22 days, 125 mm CPE from May to August, at an interval of 24–26 days and 75 mm CPE from September to December, at an interval of 26–28 days with 8 cm depth of irrigation. In addition, sugarcane trash mulch @ 6 t ha^{-1} (30 cm chopped sugarcane trash) at 45 days after planting is also recommended to reduce crop water requirement of sugarcane.

Dingre et al. [18] observed mid-season stage as most sensitive stage followed by development and end stage from deficit irrigation criteria. A water deficit imposed in end season only marginally affects the yield. A deficit irrigation strategy with no water deficit at development, 30% at mid-season and 60% at end stage was recommended as best deficit irrigation practices. The water requirement of sugarcane under deficit conditions is 1147 mm. However, quality parameters of sugarcane do not influence with water deficit [19].

Drip Irrigation in Sugarcane

Drip irrigation not only meets the crop water needs but also increased cane yield, number of millable cane, sugar yield, water use efficiency and nutrient use efficiency as compared to furrow irrigation. The Mahatma Phule Krishi Vidyapeeth (MPKV Rahuri) has made remarkable research in terms of use of drip irrigation methods for sugarcane. [20] reported 54% productivity gains (30 t acre^{-1}) and 58% water saving due to drip irrigation over flood irrigation. Likewise, water saving of around 45% with an average yield improvement of 25% has been achieved through drip irrigation [7]. In another study, MPKV Rahuri assessed impact of drip irrigation on sugarcane through various efficiency indicators under Farmer's Participatory Action Research Programme (FPARP) in 10 districts of western Maharashtra. The study revealed higher water saving (50.2%), input use efficiency (33.5%) and yield advantage (25.4%) through drip irrigation over the conventional furrow irrigation.

The farmers are supposed to save about 1260 kwh acre^{-1} of electricity used in lifting water from wells. Besides, the farmer could save the amount to be incurred through operations like weeding, interculture, and irrigation. Economic analysis of several studies conducted at MPKV Rahuri suggested that investment in drip irrigation in sugarcane cultivation was economically viable even without subsidy. The benefit–cost ratio raised upto 3.93 without subsidy. Further, the calculated values of net present worth indicated that the farmer could recover the entire capital cost of drip irrigation from the income of the two years even without subsidy [21]. Based on MPKV Rahuri recommendations, government and most of the sugarcane factories of state have decided to brought most of the sugarcane area under drip. At present, the sugarcane area under the drip in the state has now increased to the tune of 1.5 lakh ha [4].

Planting Techniques for Sugarcane

Important considerations while adopting the planting methods are to be perform with use of drip irrigation system. Sugarcane is normally planted in rows spaced at 75–120 cm in Maharashtra. The planting technique or crop geometry needs to change to facilitate efficient water application and to minimize the initial cost of the drip system. This is also necessary for smooth intercultural operations that were affected by interference of lateral lines in the field**.** There have been continuous and sustained efforts by the two major research institutes viz. MPKV Rahuri and Vasantdada Sugar Institute (VSI) to evolve and refine planting techniques to enhance sugarcane productivity in the state. These efforts were actively supported and complemented by the state government and R&D units of some leading sugar industrial units. This involves new planting techniques like paired row planting; skip row, alternate row or four row-planting techniques. It is experienced that these techniques found to reduce the cost on laterals to the extent of 50%. The changed planting patterns lead to change in moisture and nutrient distribution in soil and hence yield could get affect. Experiments conducted at MPKV Rahruri, showed that paired row planting at 75–150 and 90–180 cm under drip irrigation gave 19.92–12.97% higher cane yield with 54.50–54.24% saving in irrigation water over 100 cm spaced normal planting. The net profit cm^{-1} of water in paired row planting of 75–150 and 90–180 cm were Rs. 677 and Rs. 753 with benefit: cost (B:C) ratio of 2.09 and 2.18, respectively. An additional area of sugarcane (*Suru*) to the extent of 1.21 ha and 1.52 could be obtained under drip irrigation at 75–150 and 90–180 cm paired row planting, respectively. Under drip irrigation system, the planting of sugarcane (*Suru*) in medium to deep black soil with skipping one row after every four rows of 90 cm width and providing one lateral for each pair, emitters spaced at 75 cm [7].

On other hand, wide row method of planting has great potential to produce higher cane and sugar yields in state. Under wide rows, stalk number to shoot population ratio is higher, individual stalk growth is better, stalk population is more uniform and sugar recovery is higher. Wide row planting also facilitates easy labour movement within the field, permits mechanized interculture, saves cost, saves seeds and fertilizers, gives better ratoons and allows in situ trash management. At present, wide row planting at 150–240 cm is becoming a practice in some parts of state to facilitate mechanized harvest. MPKV Rahuri recommended 150 cm row spacing in deep clay soil in terms of getting maximum net income, water saving and maximum water use efficiency for seasonal (*Suru*) sugarcane under drip method. In addition, large spacing of drip irrigation laterals viz. 180–240 cm involves more profitable installation and should preferably form a part of mechanized harvesting.

Irrigation Scheduling Under Drip

The irrigation requirement through drip usually requires determining reference evapotranspiration rate using climatic

parameters like temperature, wind velocity, humidity, sunshine hours, solar radiation, etc. In scheduling of irrigation through drip, the major aspects like time of irrigation application and quantity of water to apply at each irrigation are considered. Studies conducted at MPKV, Rahuri have pointed out that the crop response to alternate day or three days irrigation in sugarcane grown in medium to deep clay soils is better than daily irrigation practices. Weeding and mulching reduces competition for moisture and increases irrigation interval. The equation for water requirement under drip can formulated as.

$$WR = ETc + ER \tag{1}$$

$$ET_C = ETr \times K_C \tag{2}$$

$$ETr = Kp \times Pe \tag{3}$$

If sufficient weather data is available, the ETr is to be determined using modified Penmann–Monteith equation, otherwise pan evaporation method with only pan data may be used (Eq. 3). The water requirement or volume of water to be applied for a period through drip irrigation can be worked out with the following single formula with the addition of emission uniformity of emitters.

$$Q = Ls \times Es \times ETr \times Kc \times Wp/Eu \tag{4}$$

Mobile App for Calculating ETr

The reference evapotranspiration (ETr) that eventually depends on weather parameters such as temperature, humidity, sunshine hours, wind speed and rainfall. The MPKV Rahuri has developed mobile application *'Phule Jal'* to estimate reference evapotranspiration by different methods, based on weather data. *'Phule Jal'* mobile application estimates the reference evapotranspiration (ETr) for the specific location by fetching the required input weather data from the 'Open weather service provider' in online mode. There is also arrangement to input the own weather data for estimation of evapotranspiration in offline mode. This is particularly important, if farmers have their own data/Automatic weather station.

Crop Coefficient for Sugarcane

Dingre et al. [15] determined crop factors (Kc) for Indian conditions by field water balance method (Table 4). The determined Kc values for tillering, grand growth and maturity stages of sugarcane are 0.70, 1.20 and 0.78, respectively. They suggested following 2nd order polynomial equation was fitted with crop coefficient as the dependent variables and ratio of days after transplanting to total crop period as the independent variable.

$$Kc_t = -4.695\left(\frac{t}{T}\right) + 5.566\left(\frac{t}{T}\right) - 0.360$$

The daily values of Kc from above equation is very useful towards efficient management of irrigation water in terms of making a Decision Support System, Soil Moisture based Crop Yield Modeling, Crop Water Requirement based Computer programme or Mobile Application, Automation of irrigation system in sugarcane growing regions.

Mobile App for Irrigation Requirement

MPKV has been developed mobile application *"Phule Irrigation Scheduler"* for scheduling the irrigation for different crops by surface, sprinkler and drip irrigation methods in real time. This mobile application estimates the reference evapotranspiration (ETr) by the different methods for the specific farm by fetching the required input weather. The crop coefficient (Kc) is multiplied by the reference evapotranspiration (ETr) to determine the crop water requirement (ETc) for the specific day. Further by integrating other information on crop and soil, location of farm, irrigation system, the precise irrigation water requirement and time of application are estimated.

Table 4 Estimated crop coefficients (Kc) of sugarcane for Indian condition

Period (days)	Kc	Period (days)	Kc
0–40	0.40	200–210	1.29
40–50	0.31	210–220	1.29
50–60	0.43	220–230	1.28
60–70	0.53	230–240	1.27
70–80	0.63	240–250	1.25
80–90	0.73	250–260	1.22
90–100	0.81	260–270	1.19
100–110	0.89	270–280	1.15
110–120	0.96	280–290	1.10
120–130	1.03	290–300	1.04
130–140	1.08	300–310	0.98
140–150	1.13	310–320	0.91
150–160	1.18	320–330	0.83
160–170	1.21	330–340	0.75
170–180	1.24	340–350	0.66
180–190	1.26	350–360	0.56
190–200	1.28	–	–

Table 5 Fertigation schedule for sugarcane recommended by MPKV Rahuri

Weeks	Nitrogen (Kg ha^{-1})	Phosphorus (Kg ha^{-1})	Potassium (Kg ha^{-1})
1–4 weeks	30	09	09
5–9 weeks	70	32	14
10–20 weeks	100	51	32
21–26 weeks	–	–	37
Total	200	92	92

Fertigation in Sugarcane

Fertigation is supplying plant nutrients through irrigation water. However, at present fertigation essentially refers to supplying fertilizer nutrients through drip irrigation. Fertigation helps in efficient use of nutrients in the water-soluble fertilizers (WSF). However, application of WSF through drip irrigation is not widely adopted by farmers due to lack of knowledge and unavailability of precise research information. [21] recommended application of 80% recommended dose of fertilizer (200:92:92 kg NPK ha^{-1}) in water soluble form in 26 weekly splits as per schedule through drip for sugarcane (Table 5). Application of fertilizers through drip resulted in significant increase in cane yield (41%) and water saving (56%) over surface irrigation.

Water Logging and Salinity

The over irrigated sugarcane agriculture has resulted in the development of the twin problem of waterlogging and soil salinization. Waterlogging/excess moisture is a serious limitation for sugarcane production in most of the canal-irrigated tracts [22, 23]. An estimated 4–5 lakh ha of sugarcane in the state experiences varying degrees of salt problem and nearly 1.1 million ha is waterlogged. In semi-arid areas the underground water is saline, the annual precipitation is less than the evaporation and thus soils have become salt affected. Rising water table with poor drainage has led to salinity build up in the canal-irrigated tracts. The problem is severe in certain districts of western Maharashtra. There are only a few scattered attempts to evolve management practices specifically for sugarcane. However, the reclamation measures recommended for salt affected soils and saline water irrigation would help alleviate the problem. Subsurface drainage is an effective tool to combat this twin problem of waterlogging and salinity. MPKV Rahuri at its Agricultural Research Station working for agricultural drainage related works have been developed mole plough to drain excess sub surface water. At Sangli on a clayey soil with high salinity and irrigated with saline water, a spacing of 4.5 m mole drain system of was found highly useful which gave about 30% higher cane yield.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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