Sustaining sugarcane productivity under depleting water resources

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Sugarcane is a high water-requiring (with an average of 20 megalitres of water/ha) crop and 80% of its water requirement is met through groundwater. The Central Ground Water Board has estimated that only 162 billion cubic metres (BCM)/yr of groundwater is available for future irrigation, out of which around 40 BCM/yr is available in the sugar-producing states. Sugarcane cultivation in 5.0 million ha area will require about 100 BCM of water/yr. NASA's Gravity Recovery and Climate Experiment Satellites reveal faster depletion of groundwater stocks, especially in North and Northwestern India (18 BCM/yr). Under the depleting groundwater scenario, productivity of high water-requiring crops like sugarcane can only be sustained using technologies economizing water and cultivating sugarcane varieties with relatively lesser water requirement. Drought-tolerant varieties could also be of advantage. Water-economizing techniques like drip irrigation, skip-furrow irrigation, trash mulching, irrigating at critical stages of growth and laser levelling of the fields have shown promise. Utilizing these ecofriendly and economically viable options and identifying areas (depending upon weather, soil and suitable varieties) where we can harvest reasonably good yields of sugarcane may go a long way in sustaining sugarcane productivity under conditions of depleting water resources. We can also enhance the yield of sugarcane (and sugar)/unit of water/unit area.

Keywords: Depleting water resources, drip-irrigation, laser levelling, skip-furrow irrigation, sugarcane.

Role of water in sugarcane

WATER is a universal solvent wherein many biochemical processes and diffusion of solutes take place in plant cells and regulates temperature in plants. Being incompressible it supports the plant structure. Turgidity of the cells, which is maintained by water, is essential for physiological and biochemical processes to occur and support growth. Lysimeter studies have revealed that a sugarcane crop requires 88–118 kg water/kg cane and 884–1157 kg water/kg sugar produced, in plant and ratoon crops respectively. Water/moisture content (%) in various morphological components is as follows: leaf laminae: 68–70; leaf sheaths: 78–80; stalk: 80–85 and roots: 70–75 (ref. 1). Bringing down the moisture content from 83% to 73% in the third, fourth and fifth leaf sheaths and from 84% to 74% in the eighth, ninth and tenth internodes during 2–5 months before harvest, enhanced accumulation of sugars. Critical stages are the stages of sugarcane growth during which it is affected severely due to water stress and the loss cannot be restituted by adequate water supply at later stages. These stages are: sprouting (germination), tillering and formative stage, ripening and initiation of sprouting in ratoons. Sugarcane seems to be under a peculiar situation so far as water management is concerned. The crop faces drought conditions in the formative phase (during summer months) and waterlogging in the grand growth phase (during monsoon). Under these situations water is to be managed judiciously, so that maximum benefit is obtained with minimum harm to the plant.

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Water requirement of sugarcane

Water requirement is the total amount of water needed for raising a crop successfully. In the case of sugarcane, it includes the amount of water for meeting the needs of evapotranspiration and metabolic activities (known as consumptive use), losses during application of water and water needed for land preparation as pre-planting irrigation. Water loss from the soil takes place through surface evaporation, transpiration by plants and percolation beyond the root zone. Under field conditions, water requirement is met effectively by rainfall, contribution from groundwater (if the water table is within the reach of the root system) and irrigation. It varies from place to place depending on weather conditions, texture of soil, and growth and development of crop stand (plant or ratoon crop), as shown in Table 1 (refs 2 and 3).

It has been estimated that, in India, on an average, sugarcane requires about 20,000 kl of water/ha for its cultivation[4].

Depleting water resources

In India sugarcane is an irrigated crop; and from 1980 to 2006 irrigation coverage has increased from 80% to 93% of the total sugarcane-cultivated area. Sugar-producing regions have more than 80% groundwater irrigation through deep-well pumping. According to an estimate by the Central Ground Water Board, Government of India (2005), only 162 billion cubic metres (BCM)/yr of groundwater is available for future irrigation, out of which around 40 BCM/yr is available in the sugar-producing states (this groundwater will be utilized for producing other crops as well). India's average water utilization for the 5.2 m ha of sugarcane produced is around 104 BCM/yr (20 BCM/m ha/yr)[4].

NASA's Gravity Recovery and Climate Experiment Satellites have revealed faster depletion of groundwater stocks in India, especially in the north and northwestern parts of the country (18 BCM/yr). These areas having 93% of sugarcane irrigated, produce around 60% of sugarcane. At the current level of water consumption for sugarcane (20,000 kl/ha), the major sugarcane-producing states including Uttar Pradesh, Maharashtra and Karnataka may possibly sustain their production level only up to 2013 (ref. 4).

The massive expansion of private sector tube-well irrigation schemes (in Bangladesh, India and Pakistan) has led to the rapid depletion of groundwater. With zero or negligible tariff on farm power in some states in India (no additional costs for extracting extra water) and inadequate canal water; the cultivation of crops with high water requirement (e.g. rice and sugarcane) in low-rainfall regions has led to over-exploitation of groundwater resources[5]. Depletion of groundwater levels over the years in some states is self-explanatory (Tables 2 and 3).

The Inter-Governmental Panel on Climate Change has projected that global mean annual surface air temperature is likely to increase in the range 1.8–4.0°C by the end of this century[6]. Rising temperatures associated with climate change will also affect water resources by decreasing snow cover and accelerating the rate of snow melt. Under the climate-change scenario, delayed and/or uncertain onset of the southwest monsoon will also have a direct bearing not only on rainfed crops, but also on water storage putting additional stress on water availability for irrigation[5].

The misery is further aggravated by urbanization of the cities. Take the example of Lucknow – the state capital of Uttar Pradesh. At present, according to an estimate of the State Groundwater Board, the city is extracting 500 million litres daily (mld) water from the ground through about 470 tube wells of the Jal Sansthan, 400 tube wells in multistoried buildings, 200 borings in various State and Central Government Departments and around 10,000 deep borings done by the people for commercial and domestic purposes by installing submersible pumps. This indiscriminate extraction had led to groundwater depletion at the rate of 0.73 m/yr. Over a dozen tube wells in

Table 1. Water requirement (WR) in various sugarcane-growing states of India

State	WR (ha-cm)
Subtropical India	
Bihar	140
Uttar Pradesh	160–180
Punjab	170–180
Tropical India	
Andhra Pradesh	160–170
Tamil Nadu	180
Karnataka	200–240
Maharashtra	
Plant cane (seasonal)	250
Plant cane (pre-seasonal)	300
Plant cane (Adsali)	350
Ratoon	300
Madhya Pradesh	270

Source: Srivastava and Johari[2] and Verma[3].

Table 2. Changes in the water table (m) during June 1984–1994 in Punjab

District	Average rainfall (m)
Amritsar	2.3
Jallandhar	2.5
Ludhiana	1.9
Ferozapur	4.5
Kapurthala	1.8
Patiala	4.8
Sangrur	5.1
Bhatinda	1.9
Faridkot	4.5
Fatehgarh Sahib	2.7

Source: Aggarwal *et al.*[5].

Table 3. Declining trend in groundwater levels in Uttar Pradesh (between pre-monsoon 1996 and 2006)

Decline in groundwater level (cm/yr)	No. of affected blocks
1–10	296
10–20	102
20–30	37
30–40	11
40–50	4
>50	11
Total	469

Source: Bhattacharya[4].

the city have gone dry and several more are working below their capacity. Housing colonies of Lucknow after the 1990s have been constructed after levelling water bodies/ponds, lakes, etc. Due to this, most of the rainwater is lost as run-off and their groundwater recharge is successively poor. The groundwater level, which used to remain 7–8 m below surface in the 1970s, has now gone below 20–35 m (ref. 7). More or less similar situation exists in most of the cities.

How to cope with the situation for a crop like sugarcane?

Sugarcane is an important cash crop, which not only produces 78% of the sugar worldwide, but also contributes to energy demands by cogeneration and alcohol as fuel and produces a large number of high-cost, value-added, useful products in addition to millions of farmers and labourers being engaged in its cultivation. However, we have to cope with the situation of depleting water resources using the technology for economizing water and effective utilization of limited water availability. This may be accomplished through the following interventions:

(i) Methods of irrigation economizing water: (a) skip-furrow/alternate furrow irrigation and (b) drip irrigation.

(ii) Preventing water loss as evaporation from soil surface – trash mulching.

(iii) Applying irrigation at critical stages of growth/ proper utilization of limited water availability.

(iv) Cultivation of less water-requiring/drought-tolerant varieties.

(v) Laser levelling of the field.

Methods of irrigation economizing water

Under conditions of depleting water resources, as described above, methods which economize water will be desirable. These not only produce the same quantity of cane with relatively less amount of water, but also utilize the available water to irrigate more cane area.

Skip-furrow/alternate furrow irrigation: In this method, instead of irrigating all the rows and inter-row spaces, one row is skipped (left out) and irrigation is given in alternate furrows. This method saves 30–40% water without impairing cane productivity[2]. Some of the recent data are discussed later.

Micro-irrigation/drip irrigation: Micro-irrigation is the frequent application of small quantities of water on, above or below the soil surface, by surface drip, subsurface drip, micro sprayers or micro sprinklers. Water is applied as discrete or continuous drops, tiny streams or miniature sprays through emitters or applicators placed along a water-delivery line near the plant. Micro-irrigation is characterized by low rate, frequent irrigation; water being applied near or into the root zone of plants and low-pressure delivery systems.

In drip irrigation, water is supplied directly to the root zone using a network of tubes and dippers/emitters nozzles placed along the water-delivery line. This involves precise control and manipulation of soil moisture temporally and spatially, which improves water economy, growth and ultimately crop yield.

In a Comprehensive Land Development Project in the East Godavari district of Andhra Pradesh in the five remote upland villages (Valu Thimnapuram, Anura, Kondapalli, Ramespeta and Surampalum) under 511 acres of sugarcane (belonging to 378 farmers), drip irrigation was installed with Rs 109.96 lakhs. Cultivation of sugarcane was taken up with less water usage under drip irrigation[8].

In Maharashtra, 400 ha of sugarcane area is under drip-irrigation system. Drip-irrigation required 940 mm of water/ha as against 2150 mm in conventional flood method of irrigation. The cane yield observed under drip method was 170 tonnes/ha as against 128 tonnes/ha using the conventional method. This resulted in a net saving of 65% in water use and also improved cane yield by 33% (Tables 4 and 5). In India, potential area under sugarcane suitable for drip irrigation has been identified as 2.50 m ha (refs 8, 9).

In Hawaii, in the dry central Valley of Maui, the Hawaiian Commercial Cane and Sugar Company has 37,000 ha of sugarcane under drip irrigation. This is perhaps the largest drip-irrigated farm in the world. It has led to efficient water and fertilizer use and consequently resulted in higher cane yield and sugar production[10].

In the Philippines, San Carlos Bio Energy Incorporated, Hacienda Vasconia, San Carlos City (equatorial humid climate with dry frost-free winter) installed subsurface drip irrigation in an area of 7.2 ha (with row–row spacing 1.5 m and plant–plant 0.15 m) with head control unit, main and sub-main pipes besides Drip Net PC integral drip line (16 mm diameter), with a lateral spacing of 1.5 m, emitter spacing of 0.5 m and emitter flow rate 1.0 l/h. Each crop row was irrigated with one drip line installed at 0.3 m below the soil[11]. This study gave the following results.

Improved cane yield: Conventional overhead sprinkler irrigation – 70.0 tonnes/ha (with 0.93 lakh number of millable canes (NMC)) and with subsurface drip yield increased by 90% (133.5 tonnes/ha with higher NMC; 1.3 lakhs).

Improved cane quality: Increase in sucrose content by 5.2%.

Water requirement and saving: Conventional overhead sprinkler irrigation – 13,000 m^3/ha (1300 mm/ha) and with subsurface drip – 3000 m^3/ha (300 mm/ha). The water saving by drip over centre pivot sprinkler is 70% or 10,000 m^3/yr/ha (the saved water can irrigate an additional 3.3 ha).

Table 4. Water-saving and productivity gains under drip vis-à-vis flood irrigation for sugarcane in India

	FIM	DIM	Saving/improvement over FIM (%)
Water consumption (mm/ha)	20,150	940	65
Cane yield (tonnes/ha)	128.0	170.0	33
Water use efficiency (yield/mm water/ha)	0.003	0.011	–

FIM, Flood irrigation method; DIM, Drip irrigation method. Source: Narayanamoorthy[8].

Table 5. Field survey results of DIM vis-à-vis FIM

			Benefit over FIM	
	FIM	DIM	In %	In value (Rs)
Cane yield (tonnes/ha)	112.44	138.36	23.05	259.20
Electricity consumption (kWh/ha)	2,384.99	1,325.25	44.43	1,059.74
Cost of cultivation (Rs/ha)	48,540	41,993	13.49	6,547.00

Source: Narayanamoorthy[8].

Table 6. Effect of alternate furrow irrigation and trash mulching on cane yield

	Cane yield (tonnes/ha)		
Irrigation type	No mulching	Trash mulching	Mean
Every furrow	97.42	110.45	103.94
Alternate furrow	105.01	114.47	108.74
Mean	101.21	112.46	

Source: Srivastava and Johari[2].

Table 7. Effect of irrigation at different stages of crop growth on the yield of sugarcane

No. of irrigations	Time of irrigation	Yield (tonnes/ha)
One	I (emergence)	48.81
	II (first-order tillering)	45.38
	III (second-order tillering)	47.05
	IV (third-order tillering)	56.59
Two	I + II	50.97
	I + III	49.78
	I + IV	60.00
	II + III	56.51
	II + IV	60.29
	III + IV	60.01
Three	I + II + III	64.20
	I + II + IV	69.75
	I + III + IV	59.52
	II + III + IV	64.66
Four	I + II + III + IV	66.31
CD 5%		11.12

Date of planting: 27 January 1973. Source: Anon.[14].

Higher net returns were observed by subsurface drip (US$ 919/ha) in comparison to overhead sprinkler irrigation.

Other benefits include saving on fuel expenses, improvement in fertilizer use efficiency, uniform internode length, thicker canes, less weed growth and uniform irrigation of sugarcane grown on undulated terrains.

Table 8. Effect of irrigation on cane yield under limited irrigation at Shahjahanpur (in spring-planted crop)

No. of irrigations	Time of irrigation	Yield (tonnes/ha)
One	I (mid-April)	54.4
	II (second week of May)	45.7
	III (first week of June)	27.2
Two	I + II	58.9
	I + III	47.6
	II + III	48.7
Three	I + II + III	64.2
CD 5%		6.2

Source: Modified from Saini and Singh[15].

Using scarce water resources in sugarcane cultivation in a sustainable manner brought a larger area under cane cultivation; the drip irrigation of sugarcane appeared to be an ecofriendly and economically viable technology. It led to higher productivity and increased sucrose content and ultimately increased income for the farmers. Subsequently, nearly 217 ha of sugarcane area was brought under subsurface drip irrigation during 2008.

Drip irrigation combined with fertigation, besides saving water also saves about 25% of the fertilizer requirement and provides fertilizers right in the root zone, at the proper time and in the right quantity, thereby enhancing productivity[12].

Preventing water loss as evaporation from soil surface – trash mulching

Use of trash mulch (10 cm thick cover spread in inter-row spaces) after germination in plant crop and at the time of initiation of ratoon crops, is a most practical way to increase the effectiveness of irrigation by reducing evaporation loss from the soil surface. It maintains the soil moisture at a higher level for a relatively longer time compared to uncovered soil surface. Skip furrow along

Table 9. Effect of irrigation methods on sugarcane yield, water-saving and water-use efficiency

Agronomic measure	No. of demonstrations	Cane yield (t ha^{-1})			Water applied (cm)			IWUE (kg ha^{-1} cm)		
		D	FP	Increase (%)	D	FP	Saving (%)	D	FP	Increase (%)
TM	10	75.9	54.9	38.2	42.5	59.6	28.7	1786.4	921.5	93.9
SF	14	82.8	63.7	30.0	48.7	63.9	31.2	1700.2	996.9	70.6
ICGS	9	82.8	63.4	30.6	46.0	55.3	16.81	1800.0	1146.5	57.0

D, Demonstration; FP, Farmer's practice; IWUE, Irrigation water use efficiency; TM, Trash mulching; SF, Skip-furrow method of irrigation; ICGS, Irrigation at critical growth stages. Source: Anon.[17].

Table 10. Economics of some agronomic measures on sugarcane production (plant cane)

Parameter	Demonstrated agronomic measure			
	Farmers' practice	TM	ICGS	SF
Cost of production (Rs ha^{-1})	56,721.0	43,034.0	58,790.0	54,831.0
Cane yield (t ha^{-1})	65.7	75.9	82.8	82.8
Gross return (Rs ha^{-1})	91,980.0	106,288.0	115,920.0	115,920.0
Net return (Rs ha^{-1})	35,259.0	63,254.0	57,130.0	61,089.0
Benefit : cost ratio	1.62	2.47	1.97	2.11

Source: Anon.[17].

with trash mulching was more advantageous. In Belgaum, Karnataka[13], this gave an additional 9.5 tonnes of sugarcane/ha (Table 6).

Applying irrigation at critical stages of growth

As mentioned earlier, critical stages are those during which sugarcane is affected severely due to water stress and the loss cannot be restituted by adequate water supply at later stages. These stages are: sprouting (germination), formative stage or tillering, ripening and initiation of sprouting in ratoons. In case of limited water availability, one may sustain sugarcane productivity by irrigating at critical stages of growth.

Studies at the Indian Institute of Sugarcane Research (IISR), Lucknow, have indicated that even with the availability of one irrigation and if used at third-order tillering, reasonably higher cane yield could be obtained[14].

Studies at Shahjahanpur/Lucknow, have indicated that if there is water sufficient only for one irrigation, it should be given in third-order tillering (Table 7)/mid-April (Table 8). If one can afford two irrigations, then these may be given at mid-April and second week of May. If water is available for three irrigations, these may be beneficially given in mid-April, second week of May and first week of June (Table 8)[15].

Under subtropical conditions, in ratoon crop, subsequent to irrigation at its initiation, applying one pre-monsoon irrigation with half dose of manure and administering the remaining half of the manure at the onset of monsoon gave higher cane yield[16].

Results of field demonstrations conducted by IISR, Lucknow[17], on the effect of irrigation methods on sugarcane yield, water-saving and water-use efficiency are given in Table 9 and economics of these methods is presented in Table 10.

Cultivation of less water-requiring/drought-tolerant varieties

Depleting water resources create conditions analogous to drought. Thus, relatively less water-requiring or drought-tolerant varieties could be a plausible solution to sustain sugarcane productivity under such conditions. The drop in yield in such varieties under lower moisture regimes remains low, and they sustain productivity by yielding comparatively higher under limited supply of water. The All India Coordinated Research Project (AICRP) on sugarcane has released varieties as drought-tolerant/less input requiring/for rainfed conditions/widely adaptable varieties based on multi-location testing in diverse agro-climatic conditions (Table 11).

Drought-tolerant and/or less water-requiring varieties have also been developed/identified[18] in various other sugarcane-growing countries: B 41227, B 43337, B 59162, B 6311, B 6427, Co 213, Co 331, Co 421, Co 775, Co 1148, Co 1200, D 141/46, D 140, F 177, M 134/32, M 13/56, Mex 5481, Mex 5532, Mex 5618, Mex 57473, N 12, NA 5679, NCo 310, PM 72, PPQK, PR 980, PR 1048, SP 701143, UCW 5465 (ref. 19); Sertao (for semi-arid northeastern parts of Brazil); F-134 (for drier areas of Kwangtung, China); Guitang 11, 94-42, YT 86-368; FA 81-745, M.T. 77-208 (China); ROC 1, ROC 4, ROC 6,

Table 11. Sugarcane varieties released by the AICRP (sugarcane) in India in recent years

Variety	Year of release	Cane yield (t/ha)	Sucrose (%)	Maturity group	Reaction to disease	Tolerance to stress
Peninsular zone (Madhya Pradesh, Gujarat, Karnataka, Kerala, interior Andhra Pradesh and plateau region of Tamil Nadu)						
Co 94008 (Shyama)	2002	119.8	18.3	Early	MR–red rot	DR, salinity, WA
Co 8371 (Bhima)	2000	117.7	18.6	Mid–late	R-smut	DR, WL
Co 87025 (Kalyani)	2000	98.2	18.3	Mid–late	R-smut	DR, WL
Co 87044 (Uttara)	2000	101.0	18.3	Mid–late	R-smut	DR
CoM 88121 (Krishna)	2000	88.7	18.6	Mid–late	R-smut	DR, MQL
Co 91010 (Dhanush)	2000	116.0	19.1	Mid–late	R-smut	DR, RF
Co 99004 (Damodar)	2007	116.7	18.8	Mid–late	MR–red rot	DR, salinity
Co 2001–13 (Sulabh)	2009	108.59	19.03	Mid–late	MR to red rot, smut and wilt	DR, salinity stress
Co 2001–15 (Mangal)	2009	112.99	19.37	Mid–late	MR to red rot and smut	DR, salinity and lodging
East coast zone						
CoC 01061	2006	110.8	17.4	Early	MR to red rot	DR
North central zone (eastern Uttar Pradesh, Bihar and West Bengal)						
Co 87263 (Sarayu)	2000	66.3	17.4	Early	R-smut, red rot	WL, RF, LIC
Co 87268 (Moti)	2000	78.9	17.5	Early	R-smut, red rot	DR, WL, High soil pH
CoSe 96234 (Rashmi)	2002	64.1	17.9	Early	MR–red rot	Stress conditions, in general
CoSe 96436 (Jalpari)	2002	67.1	17.7	Mid–late	MR–red rot	WL
CoLk 94184 (Birendra)	2008	76.0	18.0	Early	MR to red rot	DR, waterlogging.
Northwest zone (Punjab, Haryana, Rajasthan, western and central Uttar Pradesh)						
CoH 92201 (Haryana-92)	2000	70.0	18.2	Early	R-red rot	LPC
CoS 95255 (Rachna)	2002	70.5	17.5	Early	MR–red rot	LPC
CoPant 90223 (Pant 90223)	2000	73.3	18.5	Mid–late	MR–red rot	DR, WL, LT
CoPant 93227 (Pant 93227)	2002	75.4	17.3	Mid–late	R-red rot	LIC, sub-optimal environments
Co 86249 (Bhavani)	2000	104.2	18.7	Mid–late	R-smut, red rot	WA
Co 98014 (Karan-1)	2007	76.3	17.6	Early	MR to red rot	DR, waterlogging
CoPant 97222	2007	88.2	18.2	Mid–late	MR to red rot	DR, waterlogging, salinity
CoH 119	2005	82.8	17.5	Mid–late	–	DR

DR, Drought tolerant; WL, Waterlogging tolerant; RF, Suitable for rainfed conditions; WA, Suitable for wider adaptability; LIC, Suitable for low input conditions; MQL, Maintains juice quality longer; LPC, Suitable for late planted conditions, and MR, Moderately resistant.
Source: O. K. Sinha, Project Co-ordinator, AICRP (Sugarcane), Lucknow.

ROC 9 (Taiwan); N 11, N 12, N 21 (South Africa); LF 82-2122 (Fiji) and M 1186/86 (Mauritius).

Based on weather, soil conditions and suitable varieties, agro-ecological zones for sugarcane (ZEA Cana), have been identified in Brazil for producing sugarcane crop with relatively lower amount of water (www.unica.com.br/download.asp?mmdCode=8A1CFBDE-9A8B-4419).

Laser levelling of the field

Laser land-levelling is a technology for resource conservation. With respect to water management, it reduces water and time required to irrigate a unit area of the field, leads to relatively uniform distribution of water in the field and maintains a uniform moisture regime for growth and development of the crop. In the rice–wheat system, a study involving 71 demonstrations in western Uttar Pradesh, where laser land-leveller was used, which indicated that 61 farmers could save nearly 5–10 ha cm water for wheat crop and 10–15 ha cm for the rice crop. Overall, this led to a saving of 33% in irrigation water used. It improved irrigation efficiency (application efficiency from 60% to 88% and distribution efficiency from 80% to 92%). It enhanced water productivity (kg grain m^{-3} water) from 0.49 in traditional land-levelling to 0.61 in laser land-levelling for rice and from 1.02 in traditional land-levelling to 1.22 in laser land-levelling for wheat. Its use also enhanced nutrient use efficiency by 110% for nitrogen, 100% for phosphorus and 228% for potassium[20]. Besides, use of laser land-levelling improved weed-control efficiency and improved crop yield (7.3% in rice and 6.1% in wheat). Use of laser land-levelling in sugarcane may also confer these advantages and we may economize water use in its culture.

Although laser land-levelling is beneficial, there are certain limitations associated with it such as high cost of the equipment/laser instrument and need for a skilled operator. It may be less efficient in irregular and small-sized fields.

Utilizing these ecofriendly and economically viable options will go a long way in sustaining sugarcane productivity and economizing water under conditions of ever-depleting water resources. However, to cope with such a situation, we have to develop less water-requiring varieties of sugarcane and also identify areas for producing sugarcane with relatively lesser amount of water, based on weather, soil conditions and suitable varieties.

1. Shrivastava, A. K., *Sugarcane at a Glance*, International Book Distributing Co., Lucknow, 2006, p. 257.
2. Srivastava, S. C. and Johari, D. P., The irrigated sugarcane in India. AICRP (Sugarcane), Indian Institute of Sugarcane Research, Lucknow, 1979, p. 36.
3. Verma, R. S., *Sugarcane Production Technology in India*, International Book Distributing Co., Lucknow, 2004, p. 628.
4. Bhattacharya, A., Bio-fuel production and water constraint: an effective utilization of water shed projections in India, ISSF, Mumbai, 11–13 January 2010.
5. Aggarwal, P. K., Joshi, P. K., Ingram, J. S. I. and Gupta, R. K., Adapting food systems of the Indo-Gangetic plains to global environment change: key information needs to improve policy formulation. *Environ. Sci. Policy*, 2004, **7**(6), 487–498.
6. Aggarwal, P. K., Managing impacts of global climate change. *The Hindu Survey of Indian Agriculture*, 2010, pp. 64–65.
7. Anon., The 'waste' side story. *The Times of India*, Lucknow, 15 June 2010, p. 2.
8. Narayanamoorthy, A., Impact assessment of drip irrigation in India: the case of sugarcane. *Dev. Policy Rev.*, 2004, **22**(4), 443–462.
9. Anon., *Agricultural Research Data Book*, ICAR, New Delhi, 2008.
10. Drip irrigation credited for sugarcane industry survival; http://www.accessmylibrary.com/article-1G1-10910141/drip-irrigation-and-hawaii.html
11. Sugarcane success story, The Philippines, 2008; http://www.netafim.com/article/sugarcane-philippines
12. Nair, N. V., The challenges and opportunities in sugarcane agriculture. *Co-op. Sugar*, 2011, **42**(5), 43–52.
13. Hunsigi, G. and Parmeshwarappa, N., In Paper presented at the Regional Seminar on Command Area Development of Malaprabha and Ghatprabha Projects, Dharwad, Karnataka, 1975.
14. Anon., Annual Report, Indian Institute of Sugarcane Research, Lucknow, 1973, p. 23.
15. Saini, S. K. and Singh, D., Management of irrigation water in sugarcane. In *Sugarcane Planting Techniques and Crop Management* (eds Yadav, R. L. and Yadav, D. V.), Indian Institute of Sugarcane Research, Lucknow, 2007, pp. 57–61.
16. Anon., Annual report of research work conducted on sugarcane in Uttar Pradesh (Shahjahanpur), Sugarcane Research Station, Shahjahanpur, UP, 1960–61, pp. 67–68.
17. Anon., Annual Report, Indian Institute of Sugarcane Research, Lucknow, 2008–2009.
18. Shrivastava, A. K. and Srivastava, M. K., *Abiotic Stresses Affecting Sugarcane: Sustaining Productivity*, International Book Distributing Co., Lucknow, 2006, p. 322.
19. Tew, T. L., New varieties. In *Sugarcane Improvement through Breeding* (ed. Heinz, D. J.), Springer Verlag, New York, 1987, pp. 559–554.
20. Jat, M. L., Chandna, P., Raj Gupta, Sharma, S. K. and Gill, M. A., Laser land leveling: a precursor technology for resource conservation. In *Rice–Wheat Consortium Technical Bulletin Series 7*, India: Rice–Wheat Consortium for the Indo-Genetic Plains, New Delhi, 2006, p. 48.

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