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SCIENTIFIC CORRESPONDENCE

My Experiences on Physiological Research on Sugarcane in India

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Abstract In tropical India where crop subjected to moisture stress at formative and elongation phases unlike sub-tropic records significantly low sugar recovery, especially during early stages of maturity, being more obvious in late maturing varieties. The optimum level of sett moisture for rapid and high germination was assessed to be in the range of 72–74 %. Sprouting of bud and early growth were influenced more by sett moisture than soil moisture. Physiological basis for varietal improvement under stress environment has been described and need for breeding the physiological traits conferring to environmental stress has been suggested. The major factors which contribute to sugar losses in standing crops and post harvest period have been briefly described and also measures to minimize inversion losses in milled juice have been indicated. Investigations on basic aspects of control of flowering made it possible to inhibit flowering under field conditions through defoliation, chemical spray and withholding irrigation, resulting in an increase in cane and sugar yield. The leaf area ratio showed negative and significant correlation with cane yield but positive with sucrose content. The use of leaf area index for selection of genetic yield potential has been suggested. Studies on gibberellic acid relationship of growth hormone and inhibitor with bud and root sprouting of stubble in ratoon under low temperature condition have been suggested. Farmers in sub-tropic unlike tropic are not able to timely provide essential production inputs and as a result harvest poor yield. Similarly, in sugar mills, adoption of varieties, especially low yielding, early rich sugar varieties get top priority compared to crop management particularly in sub-tropic. These are the reasons for a big gap between actual and potential yield in sub-tropic, indicating a great scope for improving yield in sub-tropic through effective measures.

Keywords Sugarcane · Ripeness-to-flower · Photoperiodic stimulus · Drought resistance · Growth characteristic · Plant–water relationship · *Saccharum officinarum*

Introduction

In developing country like India, the importance of research is not realized to the extent as that of developed countries. But it is true that the progress made in sugar industry is primarily because of contribution of scientific

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research which brought about the first successful green revolution in sugarcane in 1920s followed by other crops in late 1960s.

In India, the pioneer works on sugarcane were carried out at sugarcane research institute Shahjahanpur particularly in the discipline of plant physiology where basic researches on growth and sucrose development (Mathur 1941), certain methods for improvement of germination and final yield (Mathur 1940), nitrogen and carbohydrate metabolism of sugarcane (Varma 1948) and studies on effect of nitrogen on the yield and composition of sugarcane (Varma and Varma 1954) were carried out. Most of the sugarcane production technologies including varieties for North India, especially Uttar Pradesh were developed at this station between mid 1930s and 1950s.

My long and active association in various capacities with the sugarcane research Institute of the state of Uttar Pradesh and Indian council of Agricultural Research inspired me to write this correspondence which is supposed to contribute to the improvement in production and thereby growth of sugar industry. Findings of my research work carried out at above research Institutes on various aspects of sugarcane physiology are summarized below.

There is a large variation in germination in different parts of sub-tropical India which records almost half of tropical India. Field experiment were, therefore, carried out at Shahjahanpur to understand the role of soil moisture on germination of sugarcane setts (Varma and Singh 1965). The results revealed that emergence as distinct from germination was influenced more by sett moisture than soil moisture. During early stages of growth, high soil moisture reduced the germination but later on germination increased progressively with increase in soil moisture. Germination, however, could not be achieved above 60 % even under high soil moisture. Further, studies carried out at Lucknow on the effect of soil water potential on germination of sugarcane setts (Singh and Srivastava 1974a), revealed that sprouting of buds and roots and their growth were maximum at 0 atm. The osmotic potential although suppressed the bud sprouting, it was inhibited only at 10 atm, being more magnified at 20 and 30 atm. Under high water potential, bud sprouted earlier than sett roots, but reverse was the case at high moisture stress. The growth of sprout was significantly reduced at 5 atm and there was practically no growth at 20 and 30 atm. The sprouting of bud and its early growth were influenced more by sett moisture than soil moisture. It was observed that in general, setts which do not germinate beyond 15 atm water potential can be made to germinate and growth of shoots and roots that was limited at 5 atm may be improved at as low as 30 atm provided the continuous period of high soil moisture stress is interrupted by no moisture stress (Singh and Srivastava 1970). It was further observed (Singh and Srivastava 1969) that bud can germinate up to 10 atm nodal water potential even in the absence of any external water intake, provided there is no loss of internal tissue moisture. Buds at 18 atm could germinate only on absorption of water by nodal tissues, indicating that nodes desiccated up to 18 atm can be made to germinate if they are pre-soaked and planted under soil with adequate moisture. The critical nodal water content of sugarcane required for the onset of bud germination was found to be 70 %. The optimum level of sett moisture needed for rapid and high germination was assessed to be in the range of 72–74 % (Singh 1975a) in a review paper, methods of improving germination of sugarcane under north Indian conditions (Singh 1970b), the two phases of germination namely sprouting and growth of sprouts (emergence) which are mainly influenced by internal and external, factors, respectively with pre-planting treatments depending on their nature, influence the first phase or second phase have been described. Work on germination of sugarcane setts carried out in the past with suggestions for improving germination and future line of research has also been mentioned.

Sugarcane suffers from moisture stress at one or another stage of its growth. It was therefore, felt necessary to undertake work on various aspects as indicated below. These are drought endurance in relation to transpiration, the size and number of stomata (Singh and Varma 1965), physiological indices of water deficit in sugarcane plants and their measurement (Singh 1967b), the time lag between wilting and death under drought condition (Singh 1964) and physiological significance of soil moisture beyond permanent wilting percentage (Singh 1967a). Results revealed that drought resistant varieties had low shoot–root ratio, the interval between wilting and death was longer in these varieties and their period of survival beyond wilting point of sunflower was considerably more than that of susceptible varieties. The soil moisture available below the permanent wilting percentage was not enough to support the growth of plants. Nevertheless, it proved to be of much importance for their survival. It was also observed that there was no relationship between the transpiration rate and number and size of stomata and same was true with association between drought resistance of cane varieties and their number and size of stomata. However, pre-mature closure of stomata is one of the sensitive indicators of water deficit in many plants and, therefore, use of closure of stomata as an indicator of developing water deficit before visible wilting has been used by several workers. Various factors including drainage, being a problem in the state of Uttar Pradesh, Bihar and in some parts of Punjab responsible for low yield in sugarcane and means to enhance cane yield and quality has been reported (Singh 1968).

While reviewing the strategies for ameliorating drought problem in sugarcane, it was found that the scope and intensity of drought problems in different states of India are different (Singh 1990). Moisture stress imposed at various stages of growth indicated that stress at formative as well as elongation phase reduced the sucrose per cent juice, whereas at maturity phase, it was improved. Results of experiments reported by a number of workers on the two approaches namely manipulation of crops on their environment for effective utilization of available soil moisture and development of crop plants capable to withstand unfavourable condition have been discussed. Different breeding approaches for drought resistance which is a major objective of research programme in both national and international institution have been reported and also future line of work for rain fed and deficient irrigation conditions to enhance the productivity has been out lined. It was noticed from the experiment that both the cane yield and juice quality decreased in April and May planting. This decrease was compensated to a great-extent where nitrogen was raised from 75 to 150 or 225 kg/ha. Nitrogen doze of 150 kg/ha improved the sucrose percent juice more in April than that of February and March planting (Singh and Dua 1990).

Under Shahjahanpur conditions in north India, where seed setting is poor because of low temperature prevailing during crossing season in winter for getting high seed setting in sugarcane flower, different methods for covering the flower in selfing as well as crossing are used. In order to develop a suitable method experiments were undertaken. Studies to find out variation in minimum and maximum temperature during day as well as night hours in open field, crossing lattern and modified crossing lattern in November, December and January under Shahjahanpur conditions (Singh et al. 1992) showed that the minimum temperature during December, January was almost the same in open field, crossing lattern and modified crossing lattern, whereas the maximum temperature under above conditions differed significantly, being higher in modified crossing lattern followed by crossing lattern than that of open field. The role of alka then used in modified crossing lattern in relation to rise in temperature and seed setting during winter months has been discussed. Further, results of experiment conducted to study the variation in fluff germination between crossing lattern (covered with a bag of cotton markin cloth) and modified crossing lattern (entirely covered with a bag of alka then sheet of 400 guage) methods under Shahjahanpur conditions (Singh et al. 1993) revealed that germination was significantly higher in crossing lattern than that of modified crossing lattern method. Possible factors responsible for the differences in germination between the two types of lattern used in the study have been discussed.

Studies conducted, at Shahjahanpur during early stages of growth for picking out desirable seeding clones in F1 population after hybridization (Singh and Singh 1994, Singh et al. 1995) revealed that number of green leaves and leaf area of the first opened leaf for HR Brix and length and diameter of stalk and shoot/clump for yield potential could be considered as useful selection indices in seeding selection during early stages of growth for economic breeding programme. These above attributes were highly heritable and less influenced by environment. The results further suggested that studying of characters particularly heritability should be studied during early growth stages when expression of the characters is less influence by environment.

Studies on physiological factors affecting varietal deterioration in sugarcane (Singh and Singh 1995) suggested that besides, diseases, pests and soil and environmental factors, gradual loss in vigour and yield ability over long period of commercial cultivation caused by factors that remain till to day a mater of great speculation, is the cause of varietal deterioration. Singh and Srivastava (2002) reported the factors which contribute to sugar losses in standing crops and post harvest period and also measures to minimize inversion losses in milled juice have been briefly reported. The major aspects of post-harvest losses are biochemical which caused by invertase enzymes dextran sucrase of microbial origin (mainly *Leuconostoc mesenteroides*).

Singh (2010) suggested the need for improving genetic yield potential that depends on physiological manipulation of bio-mass production, a comprehensive knowledge of the relationship between physiological traits of growth and yield, the plant model for efficient photosynthesis, canopy interception of light and its utility, uptake of CO_2, water, nutrients, partitioning of assimilates and reduced dry matter is necessary. Singh et al. (1976) reported that in single irrigation series, April 15 was highly yield productive followed by May 10. In two irrigation cycle, April 15 and May 10 was significantly superior to other combinations and was at par with three irrigations given on April 15, May 10 and June 5. Irrigation on June 5 was the least productive. Work on soil, plant and environmental indices of water deficit in sugarcane plant in regulating irrigation has been reviewed in this paper (Singh 1970a) where importance of above factors as indices of water deficit in regulating irrigation for optimum yield has been discussed.

Findings on post stimulatory growth inhibition by in gibberellic acid (GA_3) treated young shoot of sugarcane (Singh 1975b) indicated that spray of GA_3 at different concentration accelerated the initial shoot elongation which continued up to the age of 8 days in all concentrations. This was followed by rapid fall which was more and also lasted longer in plant treated with 100 PPM than 10 PPM. In GA_3 soaked setts, inhibition in shoot elongation caused by GA_3 was noticed only at 4th day which became more pronounced during subsequent period, especially at 100 PPM. The inhibition was more in soaked setts than sprayed ones. Plants developed from inhibited shoots caused by GA_3 spraying were found to grow at faster rate and also produced more shoots and roots at the time of recovery. It was found from the field experiment on the control of flowering in sugarcane (Singh and Srivastava 1973; 1974b) that spray of Paraquat (Gramoxone) and Diquat (Reqlone) to the photoperiodically sensitive spindle leaves during floral initiation period that occurs during the third and fourth week of September at Lucknow suppressed the flowering significantly. The crop in which flowering was suppressed by chemical spray gave high sugar yield in and after March but not earlier.

Studies on floral initiation in sugarcane at Coimbatore (Lat. 11°N) revealed (Singh and Reddy 1975) that in early flowering variety Co853, it occurred between July 8 and July 20, whereas in late flowering variety Co419, it was noticed between July 14 and July 30. Floral initiation and rate of inflorescence development were much faster in Co853 than Co419. The range between weekly mean maximum and minimum temperature during the critical inductive photoperiod was 4–10 °C and relative humidity was 76–78 % when majority of the stalks initiated flowering. It was observed (Singh 1975c) from the studies on floral initiation in sugarcane hybrids at different months of planting at Coimbatore that irrespective of date of planting from November to May, floral initiation in a variety occurred more or less at the same time, being delayed in April and May planting. In ratoon crops, the majority of varieties initiated flowering when ratooned up to the first week of June. The second week of July to the third week of August was found to be photoperiodically sensitive period for initiation of flowering, the photoperiodic stimulus being stronger between July 20 and August 12. Floral initiation occurred up to 20–25 days later in late than early flowering varieties.

Further, it was noticed (Singh 1976) that effect of cutting leaf spindle during the second week of July and third week of August, when advance initiation takes place in late flowering varieties in majority of the stalk, were more effective in suppression of flowering. Early and mid-late flowering varieties with wider range of photoperiodic period were sensitive to the perception of photoperiodic stimulus that also supposed to be more stronger in these varieties compared to late flowering type. This was evident when cutting leaf spindle in late flowering varieties on any single day between July 9 and August 23 reduced the flowering significantly. But it was not effective in early and mid-late flowering varieties where floral initiation take place in majority of the stalks of these varieties. Flowering in these groups could be checked successfully only when the leaf spindle was removed continuously during inductive photo period between July 8 and August 15. Physiological mechanism leading to floral initiation following the perception of photoperiodic stimulus and time taken between perception of stimulus and initiation of flowering were more stronger in early flowering varieties than late flowering types.

Study on natural photo inductive range for flowering of sugarcane at Coimbatore (Singh 1977a) reported the most effective day length to range from 12 h 42 min to 12 h 32 min between July 22 and August 12. Further the maximum and minimum natural inductive temperature during inductive day length range (July–August) for initiation and development of floral primordia in early and late flowering varieties of sugarcane varied from 81 to 86 and 70 to 75 °F, respectively (Singh 1985). The range in maximum as well as minimum temperature for floral initiation was higher in early flowering varieties than late types. More inductive cycles for flowering of sugarcane were required in late than early flowering varieties.

Studies on flowering of sugarcane varieties both in plant and ratoon crops (Singh 1977c) reported the Inductive photoperiodic range, floral initiation period, the process of flowering following the perception of photoperiodic stimulus, intensity and nature of stimulus in early-mid-and late flowering groups planted in different months from November to June and ratooned from April to June, relation between time of floral initiation and their emergence, the minimum stage of 'ripeness-to-flower' and sensitive leaf spindle cutting with regard to inhibition of flowering in different flowering groups and also significance of spindle leaves removal preceding floral initiation or with that when development of floral buds reached to the milking stage during terminal phase of inductive photoperiod. The above aspect of flowering with regard to floral initiation and development and inhibition of flowering has been discussed. Studies on the above basic aspects of flowering made it possible to prevent flowering in commercial crop of sugarcane by defoliation, chemical spray and withholding irrigation. Investigations on the effect of inhibition of flowering on improvement of cane yield and juice quality (Singh and Sanjiva Reddy 1976) revealed that in late flowering variety Co419, spray of Paraquat during the first and second week of August suppressed the flowering almost completely, while in early flowering variety Co853, flowering could be checked only when spindle leaves were cut continuously from July 15 to August 12 at 4–5 days intervals. The cane and sugar yield increased significantly in sprayed non-flowered crop of Co419 both in February and April, being higher in latter than former. Suppression of flowering by defoliation in Co853 also increased the cane and sugar yield in and after February. Similarly, in subsequent studies under field conditions flowering were reduced significantly by with holding irrigation from August 5 to August 30 and August 17 to August 30, the reduction being more in late flowering varieties compared to early flowering types (Singh et al. 1988). In all the varieties, growth of the plant was initially retarded in irrigation stoppage treatment following the application of treatment in August. But in December the treated and untreated crops did not differ significantly. In February, growth of crops improved in treated compared to untreated control. In December, in treated crops, the sucrose percent juice decreased significantly with an increase in reducing sugars in all the varieties. The difference in juice quality between moisture stress (treated crops) and control disappeared by middle of February and in April, juice quality improved significantly in treated crops. The stoppage of 2–3 irrigation during floral initiation period in area like Tamil Nadu where active monsoon does not coincide with floral initiation period can suppress the flowering substantially in late flowering varieties, resulting in an increase in both cane and sugar yield, especially in late harvest.

In tropical India, especially in Tamil Nadu where because of high irrigational requirements, crops suffer from moisture stress at one or other stages of growth that unlike sub-tropic affects the juice quality and thereby sugar recovery significantly. It was, therefore, considered necessary to study at Coimbatore the crop performance under different soil moisture level and also on drought resistance capacity of sugarcane varieties of different maturing groups as well as thin and thick stalk types. Results on growth, yield and juice quality of sugarcane varieties under different soil moisture regimes maintained during formative stage of the crop revealed that the above characters were affected more adversely when soil moisture decreased from 60 to 20 % followed by 40–20 % than that of 60–40 % available soil moisture (Singh and Sanjiva Reddy 1980). The rate of leaf emergence was least affected, while growth in height followed by leaf area were most sensitive to moisture stress. The magnitude of effect differed with the varieties. Thin stalk varieties in general appeared to resist drought better than thick stalk. The adverse effect of moisture stress on juice quality was higher at 10 months age than that of 12 months age of maturity. Under lower soil moisture, there was a trend of progressively greater reduction in purity of juice and increased reducing sugar with increasing maturity lateness and stalk thickness of a variety. Thin stalk varieties with more green leaves, tillers and rate of leaf emergence were more resistant compared to thick stalks and tall mother shoots. In similar study (Singh and Ram Krishnan 1977), it was observed that drought resistant varieties with thin stalks produce more green leaves and tillers and shorter mother shoot as well as deeper and more extensive root system than drought susceptible varieties with thick stalks. The significance of these above characters in evading drought during early stages of growth that coincides with summer months in sub-tropical India has been discussed.

Further, it was found from the report on the effects of soil moisture stress on juice quality of early and late maturing varieties of sugarcane that under moisture stress both at 10 and 12 months age of the crop, sucrose percent juice, purity of juice and commercial cane sugar percent decreased and reducing sugar in juice increased, especially at 10 months age (Singh and Naidu 1985). The deleterious effect of moisture stress on juice quality was higher in late than in early maturing varieties. Moisture stress delayed the maturity more in late than early maturing varieties. This was more evident in tropic, where conditions for growth in terms of greater production of immature internodes and thereby more juice weight during maturity phase following the release of moisture stress, remain favourable. Studies on germination of sugarcane varieties in relation to sett moisture and soil salinity (Singh and Sanjiva Reddy 1983) reported that germination was depressed significantly with increasing moisture caused by either sett moisture or soil salinity. The depressing effect of lower sett moisture on germination was greater than that of soil salinity. Varietal differences were also significant. It also suggested that inhibitory levels of soil salinity for germination may differ with initial moisture content of the setts which influence the sprouting of buds and initial shoot growth.

While reviewing the work on physiology of drought resistance in sugarcane (Singh 1977b), it was observed that degree of drought resistance depends on the contribution of two components of drought resistance namely drought avoidance and drought tolerance. While phenotypic characters under environmental influence are related to avoidance, genotypic characters primarily contribute to tolerance. Growth characters associated with yield which are largely influenced by environment, play in evaluating varieties for resistance to stresses. Thus, considering the cane yield improvement under prevailing Indian conditions where there are periodic stresses and where farmers realize at least marginal economic yield, importance should be given more to the characters related to avoidance rather than to tolerance unless breeders feel genetic yield stability under any specific conditions and then only identification of traits related to tolerance is needed. Hybrid varieties with more genomes of *S. spontaneum* and *S. barberi* perform better under drought conditions than that of *S. officinarum* genes and thus relatively thin stalk varieties with fast germination, short mother shoots, extensive and deeper rooting system, greater green leaf number and larger number of tillers per plant at early stages of growth were found to have close association with drought resistance. The most sensitive stage to moisture stress, especially in relation to tonnage and sugar yield and the nature of drought injury have been indicated.

For screening varieties for high yield potential, information on growth characteristics contributing to cane and sugar yield and also breeding to incorporate these growth characters into commercial varieties would be an ideal physiological oriented breeding approaches for crop improvement. Studies were, therefore, undertaken on above aspects. Studies on leaf area with yield in sugarcane (Singh and Gururaja Rao 1988) revealed that varieties with high yield also had more leaf area index (LAI). The association of this character with cane yield was positive but significant only during early stage of growth when LAI showed negative correlation with sucrose content. The use of this character for selection of genotypes for yield potential has been suggested. At various growth stages of crop, the leaf area ratio (LAR) showed negative and significant correlation with cane yield and the relationship was highly consistent over the years. But this association was positive with sucrose content at most of the stages. Varieties Co419 Co740 and Co.7219 which perform well under high yielding environment of tropics had lower LAR than that of Co J-64 and Co1148 which are known to grow well under low yielding environment of sub-tropic, possibly a larger leaf area helps the crops to withstand adverse conditions prevailing in sub-tropic (Singh and Gururaja Rao 1987a). It was also observed from the studies on varietal differences in growth characteristics in sugarcane that growth indices NAR, LAI, CGR, RGR and SLA were high in high yielding varieties Co419, Go740 and Co7219, whereas LAR and SLW were high in low yielding varieties Co1148, Co.j.64 and Co.975 (Singh and Gururaja Rao 1987b). Studies on growth characteristics in relation to earliness and lateness in maturity reported that NAR, RGR, LAR, LAI and SLA were collectively responsible for earlier and higher accumulation of sucrose than late maturing group. Since use of these growth characteristics by breeders in selecting early maturing types at an early stage of growth in limited, the simultaneous tiller production, the compact crop canopy, relatively short erect and scattered leaves and early as well as rapid internode formation can serve as useful indices for identifying early rich sugar varieties (Singh and Venkataraman 1987). Thus, the above growth characteristics may help the breeders in selecting high yielding and early rich sugar varieties.

Singh and Naidu (1981) found that among the various cultural schedules for raising a good ratoon crop, the optimum time to harvest plant crops, that is primarily determined by favourable temperature and suitable method of harvesting in relation to the stubble size left after harvesting plant crops is more important. Use of trash mulch after harvesting plant crop that conserves soil moisture and keep high humidity results in better ratooning. A need to identity the morpho-physiological characters responsible for good ratoon crop and for its earliness in maturity has been stressed. Singh (1983) indicated the possible reasons for superior quality performance of early maturing and high sugar varieties in those areas of tropic where climatic and edaphic conditions are less favourable for maturity. In most parts of tropics, especially in Tamil-Nadu where climatic conditions for maturity are not so favourable and soil moisture stress during formative stage of crop occurs prolongs the growth period during maturity phase following the stress and thereby affects the juice quality at harvest. Also, in peninsular India, sugarcane flowers heavily during October–December which adversely affects the juice quality if harvested late in the season. The deleterious effect of flowering is, however, not observed in early maturing varieties because of their harvest early in the season. Thus, for realizing high sugar recovery, a need to grow high sugar and early maturing varieties in most parts of tropics, especially in Tamil Nadu has been suggested.

Wider adaptability to various environmental conditions is considered to be very important in this crop because of its long duration spread over extensive variation of ecological conditions to survive a number of season in a year (Singh et al. 1983). High yielding ability and stability and plasticity and stability are the two components of wider adaptability. Association of these two attributes with yield components is important for wider adaptability of a variety. High yield of a crop is due to its sensitive response to cultural conditions, but insensitive to uncontrollable natural environment namely locations and years to stabilize yield. Gene controlling yield stability by and large differs from those controlling high yield and it may be possible to obtain a variety with high stabilized yield by combining the two gene groups in plant breeding program. Venkataraman et al. (1991) revealed that acid invertase was correlated with elongation of cane but negatively with sucrose percent juice in high sugar varieties. A less variable neutral invertase showed peak activity at 10 months age when sucrose percent juice reached full potential and ceased to function thereafter. High relative growth and crop growth rates during formative and grand growth phases with optimum leaf area Index and greater dry matter partitioning at maturity were associated with high sugar content of cane varieties.

In varietal development programmes sugarcane seeds (fluff) obtained from various crosses are sent to different states for selecting new varieties. In this context, it is necessary to know the optimum time and temperature for seed viability and seedling growth so that viability of seeds may not be lost before they reach to different states. Laboratory experiments were therefore, undertaken on germination of stored seeds of sugarcane varieties in relation to temperature and storage period (Singh 1988). Results showed that germination declined at a faster rate with increasing period of storage from 60 to 80 days both at 30 and 35 C temperature. Germination was higher at 35 C followed by 30 C than 40 C and 25 C temperature. The optimum temperature for germination and seedling growth lay between 30 and 35 C. Varieties differed in respect of their temperature requirement. The inhibition was more on seedling growth than germination. Seed stored at low temperature (3 ± 2 C) gave significantly higher germination than ambient temperature that caused the loss of viability. Further, seeds obtained from varieties with more genomes of *S. officinarum* lose viability earlier compared to that obtained from varieties with more genomes of *S. spontaneum*.

While spreading awareness of production technologies among cane growers and cane development staff, I realized that cane production technologies developed at research organization have not yet reached to the cane growers because of poor extension networks. Also in sugar industry, adoption of varieties which is less expensive and less tedious get top priority compared to that of crop management. During the period of my interaction with cane farmers, I found that a sizable number of progressive farmers of the state of Uttar Pradesh get cane yield comparable to that of tropic. But a large number of marginal and sub-marginal farmers harvest poor yield causing low average yield of the state. This is the reason for a big difference between actual and potential yield in sub-tropics than tropics, indicating a great scope for improving yield in sub-tropic.

Future Line of Research

On the basis of my long experience associated with sugarcane crops, I suggest following priorities in sugarcane physiology research for sustainable better sugarcane yields:

- Physiological basis of high yield and superior juice quality under soil moisture deficit associated with intense radiation imposed during elongation phase in sub-tropical India.
- Studies on physiological factors related to variation in stalk tissue hydration and temperature that affect the juice quality in over standing matured cane crops during prolonged crushing.
- Studies on sett germination in relation to natural sett hormone and inhibitor as well as amino acid and amide nitrogen under the influence of synthetic hormone.
- Physiological basis of high cane and sugar yield under increased seed rate in sub-tropic, especially in late planting after wheat harvest.
- Studies on physiological characters of yield determinants associated with resistance to cold and water logging.
- Physiological basis of early drop in sugar recovery in eastern compared to western followed by central Uttar Pradesh.
- Studies on gibberellic acid relationship of growth hormone and inhibitor with the bud and root sprouting of stubbles in ratoon under low temperature condition.

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