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Multidimensional Approach to Make Sugarcane Cultivation Sustainable

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NEED FOR A PARADIGM SHIFT IN SUGARCANE DISEASES AND PESTS MANAGEMENT

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In the past 90 years, hundreds of improved varieties were identified and popularized for commercial cultivation in India. However, only a few varieties have stood in the field and benefited the farmers in a sustainable way. During the period several varieties have succumbed to red rot, smut and wilt. When the disease incidence increases at an alarming rate due to development of disease epidemics, cane yield declines drastically and the subcontinent witnessed several epidemics of red rot during the past and during each epidemic a popular variety was removed from cultivation (Viswanathan, 2010). Impact of these fungal diseases to sugarcane cultivation has been thoroughly established. Ratoon stunting (RSD) and grassy shoot (GSD) have been found to cause considerable yield losses in some regions. Among the viral diseases, mosaic is prevalent in almost all the states in the country. However, in the recent years emergence of yellow leaf (YLD) has emerged as a major concern in different states (Viswanathan, 2012). Minor diseases such as *pokkah boeng*, rust and brown spot have assumed severity in certain regions in the country. Sudden emergence of these diseases to epidemic levels poses challenge to varietal planning and successful cropping in different regions in the country. The first part of the review focuses on the prevailing disease situation, emerging new diseases, varietal degeneration in sugarcane and disease management along with healthy seed nursery programmes.

Current sugarcane disease scenario in the Southern States

Red rot was a threatening disease in east coastal regions in the country in the past and the disease incidence had come down with introduction of new varieties with disease resistance or field tolerance. Currently the disease is confined to few old varieties in limited areas in Tamil Nadu and Andhra Pradesh (Table 1). However, incidences of smut have increased in several parts of the region mostly due to cultivation of susceptible variety CoA 92081 (87A298) in AP and Tamil Nadu. In Karnataka also the disease prevails in different districts at trace to moderate levels. Wilt incidence is confined to certain pockets in the coastal regions mostly due to adverse climatic conditions. Moderate to severe occurrences of foliar diseases and rust are common during monsoon/post-monsoon seasons in Karnataka and coastal AP. In recent years we found major concern of YLD in almost all the regions in the tropical India and this disease has affected productivity in major sugarcane varieties.

Still, grassy shoot (GSD) is a major concern in old varieties and areas where healthy seed nursery programmes are lacking.

Table 1. Occurrences of major diseases in Southern India

Diseases	Spread
Red rot	Moderate to severe (10-25%) in Co 92012, CoSi 6, Co 87012, Co 97009, CoV 09356 (2003V46) in Tamil Nadu; 10-40% in Co 62175, 81 A 99, 93 V 297, 81 V 48 in AP
Smut	Moderate to severe (10-15%) incidences of smut in Co 97009, CoC 22, CoA 92081 in TN; Severe (10-60%) in CoA 92081, CoV 05356, 91 V 83, 97 R 83 in AP & Telengana; Trace to moderate in Co 8011, Co 740, Co 86032, Co 62175 in Karnataka.
Wilt	Moderate (10-15%) incidences of wilt in Co 86032 in TN; Severe (10-40%) in Co 8368, 87 A 380, Co 7219, 91 V 83, CoA 92081, Co 62175, 81 A 99 in AP.
Foliar diseases	Top rot, ring spot and rust observed in AP; severe rust in CoM 0265, CoC 671, Co 8011, Co 86032, Co 2001-15, Co 94012, Co 740 in Karnataka.
Non-fungal diseases	Severe YLD in Co 86032, CoV 92102 in TN; Severe YLD and GSD in AP & Telengana; Severe YLD in 86032 and low in CoC 671, Co 92005; GSD in Co 94012 in Karnataka

During 1999 when yellow leaf (YLD) was first noticed in the country it was thought to be a minor disease. However, in the past 15 years increased disease outbreaks were recorded in different states, which indicate that the disease has assumed a serious threat to sugarcane cultivation in the country. Although mild infections of the disease do not cause much crop loss, continuous use of seed from such fields leads to severe disease out breaks. In India, YLD symptoms occurred in most of the sugarcane growing regions of the country and the disease intensity was recorded up to 100 per cent in certain susceptible varieties (Viswanathan 2002; 2012). Similarly, *pokkah boeng* has become a serious constraint in different parts of the country during the last season (Viswanathan and Rao, 2011). Due to introduction of new varieties or change in cultivation pattern, minor diseases become severe.

Approaches in sugarcane disease management

Healthy seed nursery programme

As vegetative propagation in sugarcane favours harbouring of the pathogens causing red rot, smut, wilt, GSD, YLD and RSD in the setts, adequate care should be taken while selecting seed canes. Healthy seed nursery is being recommended in sugarcane for many decades as part of integrated management of sugarcane diseases. Before 1970s, hot water treatment was recommended to clean the seed from systemic pathogens. During 1970s, aerated steam therapy (AST) was invented at SBI and it was popularized throughout the country to eliminate systemic pathogens like GSD and RSD from sugarcane. Similarly, moist hot air therapy (MHAT) was advocated from IISR, Lucknow for healthy seed nursery programmes and is giving similar benefit like AST. Three-tier seed programme was successfully implemented during 1980s and the benefit was realized in many factory areas. Implementation of SARP project in the country two decades ago also benefitted the sugar industry in establishing the healthy seed nurseries in sugar mills. However, in the recent past it has been noticed that disease problems are alarmingly high in several mill areas in the country. This situation affected the life of ruling varieties in the region and many diseases attained to the epidemic status during the last 10 years. We have witnessed varietal degeneration in many ruling varieties and lack of proper seed nursery programmes has also contributed to this situation. Also it is observed that many mill areas do not maintain primary nurseries in their farm and nursery programme is not implemented in true spirit. The senior author has witnessed large scale farmer to farmer exchange of seed material and repeated use of the same seed for several generations at farmers' holdings in different regions. Hence there is need to create disease free nursery chains across sugarcane growing regions to augment seed cane requirement in the country.

Recently initiatives like sustainable sugarcane initiative (SSI) have been initiated to supply disease planting materials through bud-chip or single-bud nurseries. However, at many places it has been observed that seed health is ignored and such ignorance may lead to catastrophic effect on crop hygiene and we may fail to achieve higher cane productivity. This will also lead to distribution of disease throughout the area. Poor implementation of such schemes will also cause loss of farmers' faith in new initiatives. Further, another new initiative like micro irrigation combined with multi-ratooning will receive drubbing if seed quality is ignored.

Tissue culture to raise healthy planting materials

Since many of the viruses and phytoplasmas infecting sugarcane are systemically infecting sugarcane, their elimination through meristem-tip culture is being followed in many countries. *In vitro* culture techniques employed for virus elimination involve indirect morphogenesis. However, clonal fidelity is not assured when plants regenerate via a callus stage. Some viruses can be effectively eliminated from infected plants owing to their mode of replication and their mechanism of movement within the plant. Meristem tip culture is the most widely used method to eliminate the virus/phytoplasma. This technique takes advantage of the fact that many viruses are unable to replicate in this region. Transfer of the meristem dome, together with one or two leaf primordial, to a culture medium and development into a plantlet may lead to the elimination of a virus. Successful elimination of sugarcane mosaic virus and Fiji disease virus in sugarcane through apex or bud culture has been reported earlier.

Even since YLD became a serious disease studies were conducted to eliminate the associated pathogens SCYLV and SCYP by tissue culture from infected sugarcane plants worldwide. In Mauritius, the tissue culture derived regenerated plants were remained free from the respective pathogens over a period of one year in the glasshouse, confirming that the pathogens had been eliminated by tissue culture. Attempts made from CIRAD, France achieved virus elimination of 92% however, only 64 % disease free plantlets were achieved. Hence stringent seed indexing methods have to follow while screening of the regenerated plantlets. The potential for eradicating pathogens via rapid regeneration of plants directly from leaf roll discs was explored in South Africa. The technique, NovaCane®, has been used successfully to remove SCYLV from sugarcane. Plantlets were transferred to seedling trays after ten weeks and acclimatized in the glasshouse. Two months later, tests for the presence of the disease causal agents in selected plants were performed by RT-PCR for SCYLV and it was found that the process eliminated SCYLV. In addition, this process enabled elimination of bacterial pathogens from diseased sugarcane plants while simultaneously enabling large-scale micro-propagation. As disease eradication was not 100% effective, they have suggested that donor plants require conventional screening for the presence of known causal agents prior to micro-propagation.

Detailed studies were conducted at SBI, Coimbatore to eliminate *Sugarcane yellow leaf virus* (SCYLV) from infected sugarcane. Meristem culture combined with viricide Ribavirin has effectively eliminated the virus and reverse transcription polymerase chain reaction (RT-PCR) is being used routinely to index the tissue culture materials (mother plants or seedlings) for the virus. Production of SCYLV-free seedlings has ensured supply of YLD-free planting materials to the growers fields and such fields showed renewed vigour in the crop. Overall, virus elimination through meristem culture combined with molecular diagnosis has been demonstrated as a viable strategy to manage YLD, which occurred in epidemic form in sugarcane in the recent years.

All the tissue culture seedlings supplied form the institute are indexed for the viruses. In addition, SBI offers virus-indexing service to tissue culture production units in the country and many laboratories are utilizing the service. Multiplication of virus-free planting materials in the nurseries ensures crop vigour in the field. Detailed studies conducted in the factory areas in Tamil Nadu revealed that adopting tissue culture derived YLD-free nurseries resulted in better crop stand with good vigour. Such fields recorded higher yields compared to the YLD infected crops in the same region. There is also apprehension from the factories that the virus-free crop would acquire virus through aphid vectors subsequently. Yes, it would happen in the field. However build-up of virus titre in the disease-free plants would take about 5-6 years. By the time it is due for new seed through the seed cycle and the fields are to be replaced with fresh seed. SBI offers indexing of seedlings for viruses causing mosaic (SCMV & SCSMV) and YLD (SCYLV) and phytoplasma causing grassy shoot. During the last five years many tissue culture production units in the country utilized the services from us to produce disease-free planting materials (Table 2). Hence this approach is sustainable to manage sugarcane from non-fungal diseases and to prevent varietal degeneration in popular varieties.

Table 2. Indexing of mother clones/*in vitro* stock cultures for virus indexing in sugarcane at SBI

Year	Tissue culture laboratory	No of batch samples	SCYLV		SCMV		SCSMV		GSD-phytoplasma	
			+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve
2009-10	EID Parry, TN; Rajshree Sugars, TN	185	179	6	-	-	-	-	33	143
2010-11	VasantadaSugar Institute, Pune;EID Parry, TN; Rajshree Sugars, TN; TC Lab, SBI	378	270	108	13	7	19	1	17	166
2011-12	VasantadaSugar Institute, Pune, EID Parry, TN; Rajshree Sugars, TN.	181	107	74	3	36	3	33	5	111
2012-13	VasantadaSugar Institute, Pune; EID Parry, TN; Rajshree Sugars,TN; KEMROCK Agritech Private Ltd, Gujarat; KCP Sugars Ltd, AP; C.G. Bhakta Inst., Bardoli, Gujarat	280	257	123	52	208	40	220	34	251

Year	Tissue culture laboratory	No of batch samples	SCYLV		SCMV		SCSMV		GSD-phytoplasma	
			+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve
2013-14	Rajshree Sugars, TN; C.G. Bhakta Inst., Bardoli, Gujarat; Lokmangal Organic R&D, Wadala, Solapur, MS, Navabharath Ventures Ltd, Samalkot, AP, Sarvaraya sugars, Chelluru, AP, EID Parry Ltd, Pugalur, TN	427	150	277	49	336	47	338	68	287
2014-15	Rajshree Sugars, TN; Navabharath Ventures Limited, Samalkot, AP; Sarvaraya sugars, Chelluru, AP; Harinagar Sugar Mills, Harinagar, Bihar	288	87	201	26	256	14	268	24	258
	Grand Total	1739	1050	789	143	843	123	860	181	1216

*Note : (-) Not tested; Additionally SCMV and SCSMV were tested for few batches.

Disease surveillance

Taking preventive measures immediately on noticing the disease occurrence is the best way of avoiding any major outbreaks of the diseases. When due attention is not paid during the first infection stage it would lead to its eventual spread and thereafter attaining epidemic proportion. In general, either the field staff could not identify the disease correctly or ignored the likely build-up of disease in later stages of the crop or in the ensuing ratoon. After planting the setts and proper regulations of irrigation water, the field will have to be kept under periodical disease surveillance. Regular monitoring and detection of all major diseases in the nursery and commercial plots, will keep them free from all major diseases. Also identifying and characterizing the pathogen populations regularly is also important to assess the pathogen variability in the region. Currently many ICT tools are available to get expert's opinion to identify the disease and to take up disease preventive measures.

In USA remote sensing using a fibre optic spectrometer was utilized to determine leaf infection by sugarcane mosaic. Analysis of mild and severe SCMV leaf reflectance measurements were correctly classified in 75 and 68% of the cases, respectively. Similarly leaves infected by SCYLV were correctly identified in 77% of the time (Grisham et al., 2010). Recently at SBI efforts were made to standardize use of remote sensing techniques to identify YL infection in the field. The results revealed a clear cut spectral differences between YL-infected and healthy fields (Palaniswami *et al.*, 2014). Further studies are required to optimize the same technique to identify other diseases, other biotic and abiotic constraints affecting sugarcane in the field. A comprehensive strategy to detect various stress factors will bring down the application cost and overall crop health status will be known to the researchers/industry. Sugar industry associations should come forward to map sugarcane areas for different diseases, pests or other constraints using remote sensing approaches in association with SBI and other institutions. This will lead to precisely estimating threats faced by the sugar industry and to take up timely management strategies.

Scientific introduction of varieties for cultivation

In the past, sugar industry has encountered many red rot epiphytotics in the country (Viswanathan, 2010). Through introduction of disease resistant varieties and simultaneous removal of disease susceptible varieties, the disease was contained in different regions. However, the senior author has witnessed continuous occurrence of red rot in the tropical region especially in the States of Gujarat, Tamil Nadu, Andhra Pradesh and Orissa. After the severe red rot epiphyototics, the cvs CoC 671 and CoC 92061 were removed in Tamil Nadu and Puducherry from cultivation. The present popular variety Co 86032 was introduced to replace those varieties along with other varieties like Co 86249, CoV 92102 etc. Due to these efforts, red rot was contained in most of the sugar factory areas in the State till 2005-2006 seasons. However, there were craze for new varieties again in different regions. Either they re-introduced CoC 671, or equally susceptible varieties and this has resulted in the resurgence of red rot in almost entire Tamil Nadu probably except few western districts. Similar is the situation in Gujarat, where Co 94012 was introduced in some places again facilitated revival of red rot there. Unless the factories follow scientific varietal introduction, it is difficult to minimize red rot occurrence in the country.

Similarly, introduction of CoA 92081 (87A298) and 99V30 (CoV 05356) in different parts of Andhra Pradesh States, has enhanced smut severity in the state. Among the two, the former has been spread to all the factory regions in AP and Telengana States and suddenly the region had become epidemic to smut. The senior author has witnessed nearly 100% smut whips in ratoon crops of CoV 05356 in many fields in Chittoor Dt during 2010. Here, the farmers are deprived of ratoons, which severely affecting their return from sugarcane agriculture. Due to severe smut, smut has over taken the loss caused by red rot in the recent years in the state. Before expanding such varieties to large areas they need to be thoroughly tested for their suitability in the region especially for disease tolerance. Similarly, very severe smut was recorded on a variety brought from other country in different factory areas in AP. This case of introducing varieties from unknown sources by-passing established channels affects successful disease management. This invites unreported diseases in India and introduction of new races of existing viruses. The new diseases may not be serious in the parent country and it may become very serious in the new environment. Similarly the new races of the viruses which were not expressed elsewhere may cause severe symptoms and pose new challenge to cane cultivation. Hence, it is suggested that the factories/farmers should desist from such misadventure of introducing unknown varieties.

Maintaining varietal purity in the field

Sugarcane varieties vary in their resistance potential against different diseases and any elite commercial variety may not possess tolerance against all the major diseases. Hence, while recommending a variety care should be taken on the possible vulnerabilities of it to the new location/region. In the past, the varieties were multiplied and introduced to larger areas ignoring the threats they may cause to other varieties e.g. CoSi 95071, a red rot resistant variety was introduced in the parts of Gujarat and Tamil Nadu to mitigate from red rot during late 1990s. Although the variety withstood red rot for some years, its high susceptibility to smut created a havoc to sugar industry in the regions. Before, its introduction, smut was not a serious constraint to sugarcane in Gujarat and later it has also become a serious problem along with red rot and wilt. Apart from unscientific introduction and management of sugarcane varieties, another important practice i.e. not practicing varietal purity in the field leads to disease persistence and slow build-up of red rot in the region. It is a common phenomenon noticed in many disease endemic locations where predominant variety will have mixture of few other varieties. In places where seed nursery programmes are not followed this kind of varietal mixtures are rampant. Such practices benefit the pathogen in many ways. When a resistant variety has consistent mixture of a susceptible variety, the pathogen surviving on the susceptible host gradually adapts to the resistant host and may make it susceptible one. The senior author has witnessed mixture of CoC 85061, CoC 90063, Co 6304, Co 95020 etc different fields of Co 86032. This would cause severe strain to the tolerant variety from the virulent pathogen surviving in the environment. In contrast, wherever 89V44 was found as mixture in main crops of Co 86032 or CoV 92102 in Cauvery delta in Tamil Nadu showed red rot. Such situations can be cited in different States for red rot or smut. This situation would lead to continuous emergence of pathogen variants in the region. Such a varietal admixture is a hindrance to the successful management of red rot and other diseases. Similarly, rampant varietal mixture in red rot free areas like

Karnataka and Maharashtra also found. As suggested earlier, sugar industry should take adequate care in maintaining variety purity to sustain longevity of elite commercial varieties in that region.

Chemical control

Chemical controls are possible for few of the diseases, particularly those caused by fungal pathogens. Sett rot pathogen survives in the soil. As a prophylactic measure, the setts are to be dipped in Carbendazim solution to protect the cut-ends from the pathogen. This practice is in vogue for several years and beyond that only limited studies have been conducted to establish efficacy of fungicides against major fungal diseases. Recent studies at SBI, Coimbatore revealed that sett treatment of Thiophanate Methyl fungicide alone or in combination with biocontrol bacterium *Pseudomonas* reduces debris borne infection of red rot pathogen (Malathi et al., 2002). If rust is severe five to six sprayings of Mancozeb (0.2%) between November and March is recommended to control. Similarly to control eye spot spraying of copper oxy chloride or Mancozeb (0.2%) once in 30 days during early period of disease is recommended. Whenever the disease is high, fungicidal application should be sprayed at fortnightly intervals.

Although there are limitations to extend disease management in standing crop through chemicals, the current disease scenario in case of red rot, smut and *pokkah boeng* warrant fungicide application to reduce the disease severity. To save future ratoon crops in case plant crop is infected with red rot or smut and to reduce disease intensity in plant crop, we have to explore fungicide delivery mechanisms for effective disease management in sugarcane. We have taken up detailed studies to enhance fungicide (Thiophanate methyl and Propiconazole) uptake in the planting setts. A mechanized sett treatment device was developed at SBI to increase fungicide uptake and this resulted in extended protection of sugarcane crop against red rot and smut in respective susceptible varieties. To take care of disease build-up during grand growth phase, delivery of Thiophanate methyl and liquid formulation of *Pseudomonas* through sub surface irrigation system effectively reduced red rot under endemic location. Similarly spraying of Propiconazole at 15 days intervals during young crop has effectively managed smut in ratoon crop These new opportunities have created alternate strategies to manage red rot and smut diseases in sugarcane. This will also reduce the chaos during sudden outbreak of these diseases in a new location or a variety by effectively protecting the crop.

Disease management vis a vis stress situations

Sugarcane diseases perpetuate in the sugarcane ecosystem and cause damage to the crop depending on the prevailing environmental conditions. The disease severity is aggravated when the crop suffers from other stress conditions. Many of the diseases like wilt, smut, YLD, sett rot, RSD and mosaic in sugarcane are aggravated by various biotic and abiotic factors. Also neglected crop suffer more from different biotic and abiotic factors like different borers, sucking pests, drought or water logging etc. Biotic factors such as infestation of borer pests or *Striga* favour early expression of YLD. Similarly root borer infestation favours wilt outbreaks in different regions. Also it is well known that early drought before south west monsoon and water logging after the monsoon favour wilt in different regions in the country. To some extent RSD is also aggravated similarly. Water logging during germination phase or during maturity phase favours pineapple disease either in planted setts or standing canes, respectively. Viswanathan (unpublished) has found "drought islands" in the drip irrigated fields due to improper laying or clogging of laterals in many places. This situation favoured early expression of YLD and severe symptoms of mosaic and ultimately poor yield inspite of additional expenditure. Severity of *pokkah boeng* is aggravated by top borer infestation in the subtropical region. Here again careful management of top borer has reduced incidences of *pokkah boeng*. These instances reflect the influence of different stresses; hence adequate care should be taken to minimize such predisposing stress factors in the crop to reduce the impact caused by severe disease infection. The drought situation prevailed in the past was unexpected and continuous drought for the last three seasons in the region indicates the possible climate change effects. This needs detailed investigation. As discussed earlier diseased sugarcane suffers more during drought situations hence the industry needs to follow an integrated disease management in sugarcane to avert losses caused by the diseases.

Recently, Grisham et al. (2008) reported the usefulness of tools applied in precision agriculture to sugarcane pathology in USA. They found influence of environmental conditions and cultural practices on the incidence of brown rust and the infection was positively correlated with soil properties, particularly the levels of phosphorus and sulphur. It was deduced that excess fertilizer applications could bring about a higher rust incidence and thereby negatively affecting sucrose and cane yields. Similar studies are required under Indian conditions to assess the impact of various environmental factors on various stalk, foliar and soil borne pathogens in sugarcane. During the last few years, impact of climate change is being felt on crop growth and yield. How, climate change impacts on disease occurrence and epidemics in sugarcane have not been studied yet. Since sugarcane is being grown continuously throughout the year, it is getting exposed to all the vagaries of climate in all the growth stages. Such alterations may also favour the pathogens in gaining virulence and development of disease epidemics.

Insect pest management in sugarcane

Like other agricultural crops, the insect pests of sugarcane can be categorized as borers, sucking pests, subterranean pests and defoliators. Among the four different categories of insect pests, the sucking pests outnumbers (79 spp.) the remaining three categories viz., borers (25 spp.), subterranean pests (46 spp.) and defoliators (62 spp.). Of the 212 insects, which were recorded as pests of sugarcane, only 18 of them have been considered as major pests (David and Nandagopal, 1986). Unlike other crops, in sugarcane, there is no significant change in the status of many pests over the past three decades. In fact, some of the sucking pests like *Aleurolobus barodensis* and *Melanaspis glomerata*, which were reported as major pests of sugarcane, have become minor ones both in the tropical and subtropical cane belts. On the other hand, the Lepidopteran borers are still the major ones and cause significant damage to the crop consistently over the years. Emerging insect pest problems in sugarcane in the tropical region and their management strategies are briefly discussed hereunder.

Emerging problems

Introduced or invasive pests: The introduction of top borer in the 60's and root borer in the 90's from subtropical to tropical India and their subsequent stabilization, owing to natural enemy establishment or unfavourable climatic conditions, contrasts with the devastation caused by the invasive woolly aphid in tropical India in the early part of this decade. Thus, sugarcane in both tropical and subtropical belts is vulnerable to invasion and establishment of pests from the other region if they are introduced through movement of seed or by some other mode. The same holds good for exotic pests from neighbouring sugarcane growing countries.

Proliferation of established pests: In the recent past, several established pests began proliferating in a region specific manner. Pests such as shoot borer with a nationwide distribution have largely remained under control, except for occasional spurts under extremely favourable weather conditions. In fact, the pest was reported to have dropped below the damaging levels over the last couple of decades in some parts of the country. On the other hand, the tropical internode borer has gained prominence partly due to its transformation from a truly internode borer to a meristem feeder leading to loss of canes instead of internodes. Different species of white grubs are fast becoming a serious threat to sugarcane cultivation in both tropics and subtropics. Rats are becoming a serious problem in the vast tracts of sugarcane monocultures devoid of diversity or alternative food sources. Drip irrigation system seems to encourage the menace, possibly due to the undisturbed nature of the soil surface.

Occasional pests: Local disturbances in the crop habitat often lead to spurts in the populations of pests. Such localized outbreaks in a severe form have been noticed for sucking pests such as whitefly, pyrilla, yellow mite and scale insect. Most often, it is difficult to determine the specific causative factors retrospectively. Nevertheless, judicious use of insecticides for short-term relief followed by adoption of long-term strategies lead to restoration of balance in one or two growing seasons.

Strategies to be followed in the changing environment

While research focuses on the development of new pest control technologies, maintenance of healthy sugarcane requires tactical field use of available or emerging technologies. The following strategies would be useful in such approach:

Survey and surveillance

- Regular surveys through establishment of a network to detect invasive pests
- Adoption of quarantine to prevent entry of invasive pests through transport of cane for crushing and seed purpose, including new varieties
- Constant monitoring of the field status of established major pests
- Monitoring of minor pests to establish their transformation into major pests
- Early identification of problem and assessment of the intensity

Varietal management

- Varieties found susceptible to any particular pest obviously need to be taken out of cultivation at least temporarily in the endemic area
- If less susceptible varieties are available, they may be grown in such areas
- Indiscriminate introduction of varieties from different regions without ensuring their reaction to important pests should not be done
- Transgenics showing resistance to pests need more standardization and environmental clearance

Biological control

- Deployment of potential natural enemies for short- and long-term control
- Monitoring pest populations for the status of potential natural enemies
- Area-wide application of candidate biological agents instead of individual plot releases

- Establishment of mass multiplication facilities for the production of proven candidate biological control agents to cater to the area-wide requirement
- Mass multiplication of newer biological control agents to target various stages of pests

Chemical control

- Minimal use of insecticides is advocated
- Against invasive pests, insecticides may be resorted to as an emergency measure
- Only those insecticides registered by the Central Insecticide Board and Registration Committee may be used (Table 3)

Table 3. Registered insecticides for sugarcane as per Central Insecticide Board and Registration Committee

Pest	Insecticide/s recommended (Technical Name)	Commercial formulations available in the market	Recommended dose		Spray fluid (water) required(lit./ ha)
			Active ingredient (a.i.) (g/ha)	Commercial formulation (mL/ha)	
Early shoot borer	Chlorantraniliprole	18.5% SC	75	375	1000
		0.4% GR	75	18.75 kg	Dry application
	Chlorpyrifos	20% EC	250-300	1250-1500	500-1000
	Quinalphos	25% EC	500	2000	500-1000
	Monocrotophos	36% SL	600-800	1500-2250	500-1000
	Cypermethrin	10% EC	60-70	650-760	500-700
	Fipronil	5% SC	75-100	1500-2000	500
		0.3% GR	75-100	25-33.3 kg	Dry application
Top borer	Chlorantraniliprole	18.5% SC	75	375	1000
		0.4% GR	75	18.75 kg	Dry application
	Phorate	10% CG	3 kg	30 kg	Dry application
	Carbofuran	3% CG	2 kg	66.6 kg	Dry application
Root borer	Fipronil	5% SC	75-100	1500-2000	500
		0.3% GR	75-100	25-33.3 kg	Dry application
White grub	Phorate	10% CG	2.5 kg	25 kg	Dry application

Pest	Insecticide/s recommended (Technical Name)	Commercial formulations available in the market	Recommended dose		Spray fluid (water) required(lit./ha)
			Active ingredient (a.i.) (g/ha)	Commercial formulation (mL/ha)	
Termite	Clothianidin	50% WDG	125	250	Soil drench (1000 L)
	Imidacloprid	17.8% SL	70	350	1875
	Chlorpyrifos	20% EC	1.25 kg	6.25 Lit.	Soil treatment
	Chlorantraniliprole	18.5% SC	100-125	500-625	1000
Scales	Monocrotophos	36% SL	600	1500	500-1000
Mealybugs	Monocrotophos	36% SL	600	1500	500-1000
Pyrilla	Chlorpyrifos	20% EC	300	1500	500-1000
	Quinalphos	25% EC	300	1200	500-1000
	Dichlorvos	76% EC	300	375	500-1000
	Monocrotophos	36% SL	200	500	500-1000

Behavioral control

In the behavioral method of control, the use of sex pheromone lures for mass trapping of borers has gained some degree of acceptance. However, the currently available pheromone combinations often under-perform highlighting the need to improve the efficacy of the components. Although the role of behavioral chemicals in enhancing parasitoid or predator efficiency in the tri-trophic context has been realized and researched upon, the approach needs more time to reach the field.

Key management practices for different pests are summarised below

Early shoot borer

- Early planting (December-January) in endemic areas
- Two rounds of light earthing-up and trash mulching during early crop stages
- Frequent light irrigations instead of heavy irrigations at long intervals
- Coriander, onion and garlic, potato and green gram intercrops in the subtropics, green gram, black gram and soybean or coriander in the tropics
- Sex pheromone traps @ 25/ha to be setup 15 days after planting with one lure change

- Multiplication and field colonization of the parasitoid *Sturmiopsis inferens*

Internode borer

- Removal of water shoots at eighth or ninth month age of the crop
- De-trashing at fifth and seventh months
- Sex pheromone traps @ 25/ha from fourth or fifth month with lure changes after 30 days
- Weekly releases of 5 cc/ha *Trichogramma chilonis* during 5-11 months age of the crop
- The larval parasitoid *Cotesia flavipes* can be mass multiplied and released inoculatively
- Early application of systemic insecticides on top internodes after de-trashing

Top borer

- Planting during July-August to be avoided in hot spot areas in the tropics
- Pulse crops such as green gram, black gram, cowpea, soybean and groundnut in the tropics reduce incidence of second brood
- Sex pheromone traps @ 50/ha for 30 days in each of the first two broods in the subtropics
- Hand collection and destruction of egg masses every four days in each brood
- Redistribution of *Isotima javensis* from parasitoid-rich areas to parasitoid-free areas

Root borer

- Deep harvesting of canes that are to be ratooned to expose larvae or pupae
- Avoidance of ratoons in endemic areas; digging and destroying stubbles after harvest
- In severe attack, fields should be ploughed up and stubbles with larvae destroyed
- Incorporation of green gram intercrop in spring/summer planted sugarcane
- Collection and destruction of moths using light traps
- Release of *Trichogramma chilonis* @ 2.5 cc/ha at 15 days intervals from July to October

Pyrilla

- Removal of cane trash after harvest until March to destroy unhatched egg masses and overwintering nymphs

- Detrashing from August to reduce populations and enable plant protection operations
- Removal and destruction of egg masses or egg-bearing leaves at regular intervals
- Release and distribution of field-collected or laboratory multiplied egg masses or cocoons of the ecto-parasitiod *Epiricania melanoleuca*

Woolly aphid

- Avoidance of transport of seed material or green tops from affected areas
- Destruction of affected leaves in the early stages and priority for harvest of affected cane
- Cultivation of resistant varieties CoSnk 0344, CoSnk 0361 and CoSnk 03754 or CoVc 2003-165 if needed
- A few patches in the field to be maintained as refugia to conserve natural enemies
- Redistribution of larvae and cocoons of the predator *Dipha* from established to new areas
- Mass multiplication and field release of *Dipha* at 1,000 cocoons per ha
- Mass multiplication and release of the predator *Micromus igorotus* in predominant areas
- Conservation and distribution of the parasitoid *Encarsia flavoscutellum*

Whitefly

- Water management to avoid extremes of dry conditions or water-logging
- Detrashing and destruction of leaves bearing whitefly puparia before adult emergence
- Redistribution of the parasitoid *Amitus minervae* to fields where it is not active

Scale insect

- Selection of healthy seed from pest free areas and uninfested fields
- Prevention of waterlogging to reduce humidity and minimize buildup
- Detrashing of crop two or three times beginning with internode formation; adoption of wide-row spacing, and wrapping and propping operations
- Avoiding ratoons in high intensity area for two to three years

Mealybug

- Use of uninfested setts with leaf sheaths removed reduces perpetuation to new plantings

- Detrashing disturbs and dislodges fully developed females, and exposes colonies
- Avoidance of ratoons which can act as reservoir for the next season crop since the mealybugs can multiply in the underground clumps
- Management of water stress and general health of the crop

Termite

- Destruction of conspicuous termite mounds and removing the queen termite
- Ploughing or disturbing high field bunds to expose and destroy subterranean termites
- Clearing and burning crop residues and debris to deprive food and reduce foraging
- Avoidance of trash mulching in areas endemic to termites
- Frequent irrigation in termite-prone or endemic areas for temporary relief

White grub

- Large scale mechanical collection of beetles congregating on neem trees during mass emergence, starting from the night of first showers and continued for a week
- Mechanical collection of easily detectable third instar grubs in fields showing yellowing or drying of clumps late in the season
- Repeated deep ploughing at land preparation in February, i.e. before summer showers; flooding such ploughed fields for 24 – 48 h wherever possible. Also rotation with puddled paddy reduces grub population.
- The fungus *Beauveria brongniartii* formulated with press mud, lignite or talc to be mixed with FYM or pressmud and applied at 2.5×10^{12} spores/ha during June–July followed by irrigation. Repeated application for 4-5 years may be needed.

Management of root grub with entomopathogenic nematodes (EPN)

- EPN of the genera *Steinernema* and *Heterorhabditis* are potential biopesticides that infect a wide range of insects. Biological control with entomopathogenic nematodes has been particularly successful against white grub species that spend a large portion of their life cycle in the soil. Based on previous success in suppressing white grubs and the time that white grubs spends in soil, the EPN may be a good candidate for control of white grubs. Research efforts have been made at the Institute, on utilization of EPN against white grubs *Holotrichia serrata*. Extensive survey was conducted in white grub endemic areas of sugarcane for isolation of EPN; bioefficacy of EPN was evaluated against different instars of white grubs and potential EPN was identified under laboratory, pot culture, microplot and field conditions. Three different field trials were conducted to evaluate the efficacy of EPN *Heterorhabditis indica* against white grub *H. serrata* at Bannariamman Sugar Mill, Thalavady, Tamil Nadu, Dharmapuri Sugar Mill, Palacode, Tamil Nadu and Coromandel Sugars, Karnataka. In all the trials, reduction in number of grubs was observed in the EPN treated plots as compared to the control plot. The reduction of grub population due to EPN treatment was 43 to 77 per cent at Bannariamman Sugar Mill, Thalavady, 30 to 78 per cent at Dharmapuri Sugar Mill, Palacode and 28.5 to 100 per cent at Coromandel sugars. The results from the above studies indicated that EPN can be utilized effectively for managing white grubs in sugarcane ecosystem.

Rodent

- Manual or mechanical removal of wild vegetation or weeds on crop field boundaries; reduction in bund thickness and height
- Deep tillage and ploughing of vacant land around fields to destroy burrows
- Wrapping and propping of standing crop and judicious irrigation to minimize damage
- Ploughing fields between crops, flood irrigation or smoking the burrows by burning cow dung cake or paddy straw drives out bandicoot rats
- Closing or smoking the burrows a day before treatment helps to locate the active burrows in the field.
- The single dose anticoagulant bromadiolone 0.005% bait cakes to be placed near or inside the active burrows
- Barn owls to be encouraged by placing suitable perches at the canopy height in the field.

Conclusion

The fungal diseases like red rot, smut and smut were responsible for the elimination of many elite commercial varieties in the past in different epidemics. Additionally many of the non-fungal diseases contribute to decline in their performance due to 'varietal degeneration'. Lack of awareness on seed cane health and ignoring quarantine regulations resulted in introduction of diseases, their epidemics and varietal degeneration in the country. Sugarcane varieties vary in their potential against different diseases and any elite commercial variety may not possess tolerance against all the major diseases. Hence to sustain the productivity in such varieties alternate management strategies need to be developed. Recent outbreak of *pokkah boeng* and rust in different parts of the country could be due to climate change. Hence factory personnel need to be aware of emerging diseases and develop preparedness to tackle emergencies arising out of disease epidemics.

Although YLD has created a havoc to sugarcane cultivation in the country and we have evolved strategies to manage the disease through meristem culture combined with molecular diagnosis of the virus. Hence, need of the hour is to establish YLD-free nurseries in different sugar mills to reduce disease severity. Disease surveillance programmes in the country need further strengthening including use of remote sensing approach. This novel approach is implemented through a collaborative institute-industry mode, crop status, varietal purity, disease infection or pest emergence and yield estimation can be assessed in a region or entire country. This would also lead to creation of disease maps for various diseases in sugarcane and this would facilitate developing possible forewarning systems and varietal deployment in a region in the future.

Establishing disease-free nursery chains of sugarcane varieties across the country would facilitate healthy sugarcane in the field and varietal vigour will also be maintained in the long run. In this regard, multiplication of disease-free seedlings through tissue culture needs special emphasis. Hence, industry associations may come forward to create common tissue culture laboratories to produce healthy seedlings. We offer virus-indexing service to tissue culture production units in the country. This combined effort would lay foundation to create seed nursery chains in different regions to produce quality planting materials. Ultimately these efforts would increase sugarcane productivity and sustain sugarcane cultivation in the country.

Early shoot borer, internode borer and occasionally top borer cause significant damage to the crop in the tropical cane ecosystem. Sporadic incidences of scale insects, whiteflies, pyrilla, mealybugs and aphids have been reported here and there in the tropical cane belt. Although the upsurge of sucking pests occurs occasionally in the cane ecosystem, outbreak of invasive pests like woolly aphid disturbed the cane ecosystem to a greater extent in the past decade. Apart from being pests of sugarcane, some sucking pests like aphids are proven vectors of emerging viral diseases of sugarcane. Termites and white grubs are the important subterranean pests. Although the cultivation of insect resistant varieties with outstanding yield potential appears to be the attractive option for managing the pests of sugarcane, lack of availability of resistant varieties drives the cane farmers to go for insecticides during the early stages of crop growth and biocontrol agents during the later stages when the insecticidal application becomes impractical due to dense crop canopy.

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