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**SRDC PROJECT BSS208
LITERATURE REVIEW OF
METHODS OF IMPROVING
THE GERMINATION OF SUGARCANE**

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SUMMARY

Sugarcane is propagated from vegetative cuttings of the stalk (setts or billets). The cuttings can be planted by hand or through mechanical whole-stalk or billet planters. Billet planters have given variable results because of damage to the billets and uneven delivery of the billets into the furrows. Germination of the buds on the sugarcane cuttings is affected by temperature, moisture in the sett and the soil, plant hormones and the availability and rate of release of reducing sugars (eg glucose) within setts. Pineapple disease caused by the fungus, *Ceratocystis paradoxa*, rots setts of cane and can cause total germination failures. Wireworms (*Agrypnus variabilis* and *Heteroderes spp*) attack the buds and can cause poor germination.

The speed of germination and the percentage of buds that germinate can be improved by soaking setts in water, short hot water treatment, pre-treatment of planting material with nutrients including nitrogen and application of mercurial fungicides. Except for the fungicide, these treatments have practical problems for application in commercial planting. Coating setts with materials to protect them from fungal and insect attack and to provide ideal conditions for germination is an attractive concept but no practical methods for achieving this concept have been reported.

1.0 INTRODUCTION

Planting sugarcane is the most expensive operation on a farm. New planting systems have been developed to reduce the cost of planting, primarily by reducing the amount of labour. This has led to the development of whole-stalk planting machines and more recently billet planting. Whole-stalk planting machines perform well in most situations but the initial results with billet planting have been variable.

The success of the establishment of a sugarcane crop affects the yield of that field for the whole crop cycle. Large gaps reduce yield and allow weed infestations. A failure to obtain a successful establishment can result in the expense of replanting.

There are many methods of planting sugarcane throughout the world and many treatments have been used to attempt to improve the reliability of germination. This literature review will outline the current techniques of planting sugarcane, the environmental, biotic and abiotic factors that affect germination and the treatments that have been applied to improve the germination of sugarcane. It will also briefly review methods of improving germination in other crop species, which may be applicable to sugarcane. It will not discuss in detail the machinery used for planting sugarcane or the physical aspects of planting such as planting depth, soil tilth and soil- sett contact.

2.0 MORPHOGENESIS

Sugarcane is propagated for commercial production by vegetative cuttings. The stalk of the sugarcane plant has buds and root primordia at each node of the stalk (Fig. 1). The stalk is cut into pieces with one or more nodes, which are called setts or billets (a sett is the common term for cuttings produced by whole-stalk planters and a billet for cuttings produced by chopper harvesters, the terms are interchangeable). When a sett is placed in moist soil at the right temperature, the bud will shoot and roots (sett roots) sprout from the root band. The developing shoot and roots draw nutrients from the sett for a number of weeks. The sett roots supply the young shoot with water and nutrients for eight to twelve weeks until roots are produced from the base of the developing shoot (Julien *et al.*, 1989). When the shoot roots are well established, the sett roots begin to die. Until the shoot roots develop, the young shoot is dependent on the sett initially for much of its nutrients but later as a conduit from the sett roots to the shoot. Rotting of the sett during this period can lead to death of the young shoots even after they have emerged.

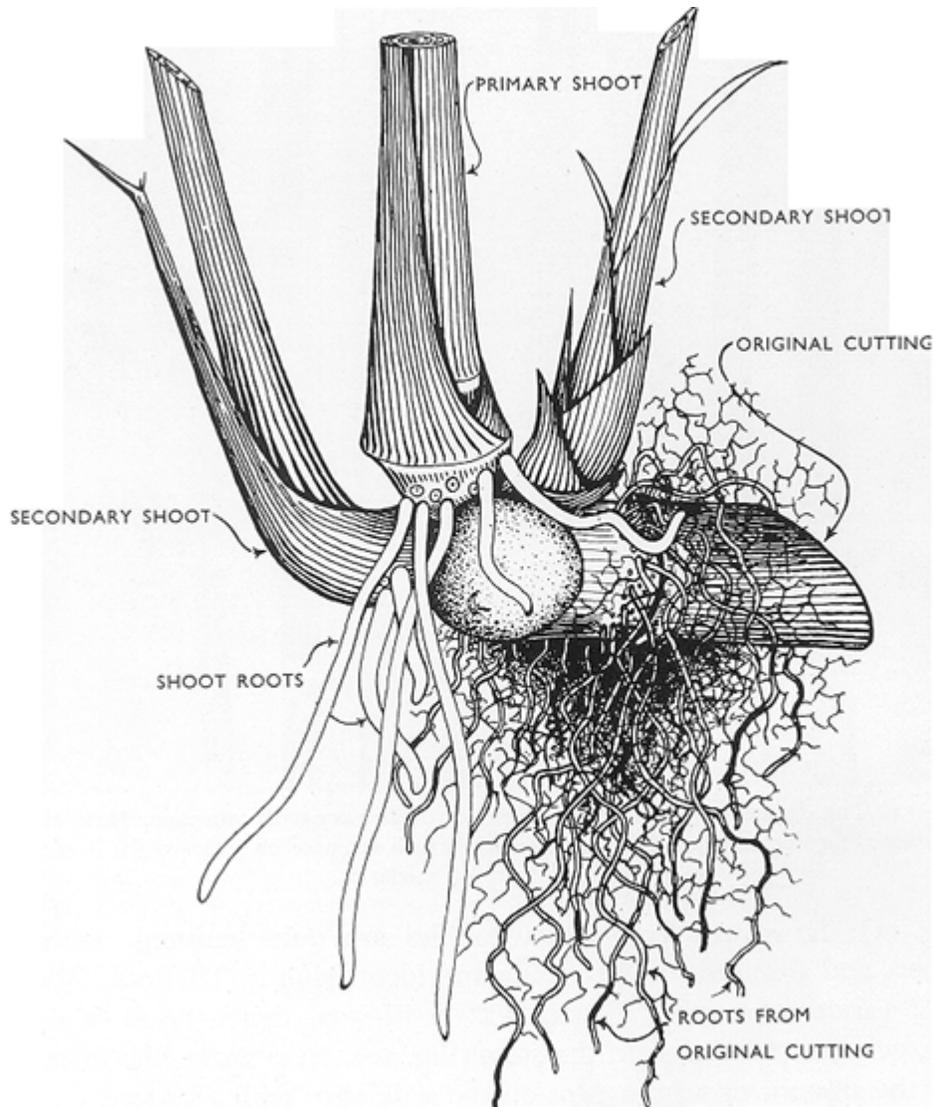


Figure 1: Young sugarcane plant propagated from a stalk cutting

All buds on a stalk have the potential to produce shoots but the speed of germination is greater in the younger buds in the top half of the stalk. Buds at the base of the stalk germinate erratically and are often damaged by insects or cultivation. The immature buds at the very top of the stalk will germinate rapidly but the bud often matures before the root primordia which results in a shoot forming with no root development.

3.0 PLANTING METHODS

In Australia, there are two main planting methods known as whole-stalk planting and billet planting. Whole-stalk planting involves one or two people feeding whole-stalks into a

planting machine, which cuts the stalks into 300-400 mm setts. The setts are sprayed or dipped in fungicide and then dropped into a furrow opened by the machine, fertiliser is applied beside the sett, and the furrow is partially closed to cover the setts with soil. Billet planting uses a chopper harvester to cut the stalks into billets. The billets are loaded in a tipper or elevator haul-out vehicle, which carries the billets to the billet-planting machine. The billet-planting machine uses conveyors to feed the billets into the open furrow. Fungicide is applied through sprays or dips, fertiliser is added and the furrow partially closed, as in the whole-stalk planting machine.

The advantages of whole-stalk planting is that the planting machine, if well maintained, produces undamaged setts of a standard length which usually have two or more eyes and the setts are evenly spaced in the planting furrow (Robotham and Chappell, 1998). The two people who feed the planter usually overlap the top of one stalk with the base of the next stalk to allow for poorer germination of the buds at the base of stalks. The disadvantages of the system are that it is labour intensive and relatively slow compared with billet planting. The whole-stalk plant cutters used to supply the stalks can only cut erect cane. If the cane is lodged, it must be cut by hand which greatly increases labour costs. Sometimes farmers will avoid lodged cane and will plant a less productive variety that is erect or take cane from an older ratoon crop, which is at a higher risk of having diseases such as ratoon stunting disease. Labour to cut cane and feed the planter is difficult to obtain, particularly in areas where planting coincides with harvest.

Billet planting has the advantages of being able to plant more area in a given time and it requires less labour. Billet planters can plant up to 5 ha per day compared to 2 ha per day with a whole-stalk planter. Another advantage is that a chopper harvester can cut billets from lodged cane. The disadvantages are that the harvester used to cut the billets can cause damage which makes the billets more susceptible to pineapple disease (Robotham, 1999). Lodged cane that is cut for billet planting is more susceptible to damage than erect cane because of the twisting of the cane as it is gathered by the harvester and fed through the machine. The harvester can also physically damage the eyes. The rate of feed of billets in the billet-planting machine can be erratic leaving gaps or clumps of setts with poor soil-billet contact (Robotham and Poulsen, 1996). To compensate for these inadequacies billet planters usually plant twice as much cane as whole-stalk planters (8-10 t/ha compared with 4-5 t/ha, respectively) adding to the cost of the operation. Billet planters can give good results under ideal conditions but germination can be poor under less than ideal conditions.

In some overseas countries, including the USA, sugarcane is planted by hand in pre-formed furrows (Lonsdale, 1977). The cane is often laid in the furrows as whole-stalks and then cut into sections in the furrow. In Louisiana, where harsh environmental conditions make sugarcane establishment difficult, two to three stalks are laid in the furrow side-by-side and the stalks are not cut up. If plants die during the winter, buds on the stalks can germinate in the spring to replace those that have died. This method is labour intensive and uses high planting rates.

In some countries where labour is inexpensive, the tops of the cane are collected during harvesting and these are used as planting material (Singh and Kumar, 1977). The tops can be planted horizontally and covered with soil or planted vertically. This method is very labour intensive.

Small sugarcane plants grown from one-eye cuttings can be transplanted into the field to establish the crop. The plants are grown in containers for two to three months and then transplanted into the field. This technique is widely used in South Africa for the distribution and establishment of disease-free nucleus plots (Goodall *et al.*, 1998) and has been used in South Africa (Bailey, personal communication), Philippines (Tianco, 1992), Columbia (Anon, 1995) and Taiwan (Tang and Chen, 1974) for limited establishment of commercial plantings. In Hawaii, large scale planting of pre-germinated plants was practised on some plantations (Jakeway, 1985) and there has been extensive research into cutting, heat treating and planting pre-germinated plants (Jakeway, 1986; Ferreira and Jakeway, 1986). A similar approach is to use tissue culture derived plantlets to establish sugarcane crops. This is currently restricted to establishment of nucleus disease-free seed plots (Anderlini and Kostka, 1986). Somaclonal variation is a problem if the tissue culture process has a callus phase (Heinz, 1973).

Planting pre-germinated plants has a number of advantages in that it requires much less planting material, plants can be germinated in environment-controlled chambers and planting rate in the field can be controlled precisely. Automated planting machines used in the vegetable industry can be adapted to plant these plants. The disadvantage of this system for commercial planting is the labour and material costs involved in producing the plants. In Australia, mass produced cuttings of tea-tree are sold at 12-15 cents per plant (Mullins, personal communication). The cost of billet cane on a per plant basis (10 tonnes of cane to achieve 20,000 plants per hectare, cane costed at \$30/tonne and \$10/tonne to cut) is two cents per plant. Another major limitation is that this system can only be used reliably on farms with irrigation. The young plants need to be irrigated soon after planting to ensure good establishment. Pre-germinated plants yield no better than conventionally planted cane and in fact often yield slightly less than conventionally planted cane in the plant crop (Anon, 1986).

4.0 TEMPERATURE

Sugarcane requires temperatures above 8.5°C (Julien *et al.*, 1989) for germination with an optimum of 32-38°C (Humbert, 1963). There is genetic variability in the germination response of different varieties to soil temperature. Yang and Chen (1980) found that F178 and 67-9 still obtained 80-90% germination at 18°C whereas 69-463 and 70-5122 only reached 20-30% germination at this temperature. The speed of emergence is greatly affected by temperature. At 30°C, Yang and Chen (1980) found that it took approximately eight days for 50% germination in four varieties, 8-25 days at 26°C, 14-30 days at 22°C and 36 days for two varieties at 18°C. Two varieties failed to reach 50% germination at 18°C. Temperature is one factor that largely determines the time of year suitable for planting in different districts. The increase in contract planting in Australia, especially billet contract planting, has increased

the pressure to plant later in the autumn and earlier in the spring. Contractors want to maximise the return on their investment by extending the period their machinery is in use. This has led to an increase in germination failures when cool wet conditions occur soon after planting.

5.0 SOIL WATER

Soil moisture is another critical factor in germination. Waterlogging or soil saturation will cause complete germination failure (Yang and Chen, 1980; Van Dillewijn, 1952). Germinating setts have a high oxygen demand and waterlogging prevents oxygen movement through the soil. Yang and Chen (1980) found the optimum soil moisture for germination was -0.3 bar. At -3 bar, the germination of F178 and 67-9 was only slightly reduced but the germination of varieties 69-463 and 70-5122 fell by 50-60% . The variety F178 still obtained 90% germination at -15 bar (wilting point). Obviously the moisture in the sett can provide some moisture for germination even in extremely dry soils.

6.0 PHYSIOLOGY

The physiology of germinating stalks has not been studied extensively. The relationship between reducing sugars in stalks and germination has been investigated. Reducing sugars are the source of energy for cell division and new cell formation. Mukerji (1979) found a strong correlation between glucose content of setts ($r = 0.82$) and germination. Chen *et al.* (1986) also found a strong relationship between reducing sugars and germination. Yang and Hsieh (1977) found that the rate of sucrose inversion is closely related to the rate of germination in different varieties. The slow germination of the lower buds on a stalk may be partially explained by the lower concentration of reducing sugars in these sections of stalks. Reducing sugars make up 2% of the dry weight in mature stalks compared to 8% in immature stalks (Julien *et al.*, 1989). The rate at which sucrose can be converted to reducing sugars decreases with stalk maturity (Lauritzen and Balch, 1940). The field observation that older, more mature cane (older than 12 months) does not germinate as well younger cane would support the theory that the ability to convert sucrose to reducing sugars is important for germination.

Water content in stalks has also been related to germination. Setts which are soaked in water for 24 hours or more germinate much faster than untreated setts (King *et al.*, 1953; Chen *et al.*, 1986). This could be due to the increase in water within the stalk, leaching of chemicals that inhibit germination or a physical softening of the bud scales. Conversely, cutting stalks and letting them dry for 1-3 days before planting can also improve germination. This is believed to be related to the increase in reducing sugars within stalks, which can more than double after three days drying (Chen *et al.*, 1986). A combination of drying for one to three days followed by soaking for 24 hours doubled the speed of emergence compared to no drying and no soaking (Chen *et al.*, 1986). Some farmers in Australia routinely cut stalks a few days

before planting. This method of improving germination is not possible with billet planting because of logistic problems of handling the billets and because of the rapid deterioration of billet cane (Egan, 1971).

In irrigated crops, discontinuing irrigation about one month before cutting setts can significantly improve germination. Ingram (1986) obtained a 30% improvement in germination by applying a 325 mm evaporation deficit before cutting setts.

Osmotic and matric priming are used to improve germination in some seeds (Jett *et al.*, 1996). These practices involve controlled hydration followed by redrying. Seed soaking is also widely practised to improve germination.

7.0 GENETICS

Varieties differ greatly in their speed and reliability of germination (Van Dillewijn, 1952, Yang and Chen, 1980). However, the final yield of a variety is not correlated with speed of germination except where there is a significant germination failure. Breeding for speed and reliability of germination is likely to be successful and is probably already a component of the Plant Improvement Program. Clones that have good establishment are likely to perform well in trials. Observations are made on germination speed and reliability in the later stages of the Plant Improvement Program and this information is distributed with variety descriptions when a variety is released. Speed and reliability of germination are not characters specifically included in breeding objectives in the BSES Plant Improvement Program.

Varieties are likely to differ in their potential to germinate in different planting systems. Varieties with characteristics that make them more prone to damage in a harvester, for example, soft or brittle rind or protruding buds, may perform poorly if billet planted but may be acceptable for whole-stalk planting.

8.0 NUTRITION

Germination of cane that is suffering from nutrient deficiencies can be retarded. Deficiencies of calcium (Ridge *et al.*, 1980), zinc (Reghenzani, personal communication) and phosphorus (Van Dillewijn, 1952) have been reported to affect germination.

Apart from gross nutrient deficiencies there have been many reports that manipulating the nutrition of cane for planting can lead to improvements in germination. Nitrogen is the nutrient most often used to promote germination. This can be applied to the cane before it is cut for planting (Yates, 1964; Ingram, 1986; Croft, 1998) or in water used to soak cane (King *et al.*, 1953). Phosphorus application has also been reported to improve germination (Yates, 1964; Croft, 1998). Excess potassium has been reported to be detrimental to germination (Yates, 1964).

In Australia, nitrogen fertiliser is often reduced on cane that is intended for planting, to reduce the risk of lodging. This practice may have a deleterious effect on germination of the cane because there is ample evidence that high levels of nitrogen favour germination. However, preventing lodging is important in providing good planting material. If cane lodges, it cannot be cut by mechanical whole-stalk plant cutters, and billets cut by mechanical chopper harvesters suffer more damage when cane is lodged.

Applying nitrogen one to two months before cutting cane for planting has been practised sporadically by a few farmers. The reason why farmers do not adopt this practice more widely is not clear. In some areas, preventing lodging is critical for maintaining the quality of cane for planting and adding extra nitrogen may promote growth and increase the risk of lodging. In the wetter districts, predicting exactly when planting will occur is difficult and this may affect planning for treatments which have to be applied one or two months in advance of planting.

9.0 PLANT HORMONES

Plant hormones are involved in preventing germination of the buds on a stalk while the stalk is growing normally. Cytokinin and auxin have both been found in the apex of sugarcane stems (Vlitos, 1974) and these plant hormones are known to be involved in apical dominance (Wickson and Thimann, 1958). If the growing point is damaged, the hormonal balance is disturbed and the buds will germinate, usually beginning from the top of the stalk. Once the top few buds have germinated, the growing points of these side-shoots produce hormones that suppress the further development of the lower buds. In planted setts, this phenomenon is also observed when one bud on a sett germinates rapidly and suppresses the growth of the other buds on the sett (Lonsdale, 1977). The growth regulatory chemical, ethephon, which is used to ripen sugarcane, has the side-effect of upsetting the hormonal balance and results in side-shooting of stalks (Vlitos, 1974). There have been a number of reports of this chemical being applied to setts, or as a foliar spray to cane to be used as plants, to improve germination (Diaz *et al.*, 1996; Eastwood, 1979).

Vegetative cuttings of many woody plants are treated with hormone formulations to stimulate root formation (Hartmann and Kester, 1983). The natural auxin, indole acetic acid (IAA), and the artificial auxins, indole butyric acid (IBA) and naphthalene acetic acid (NAA), are widely used to stimulate root growth in vegetative cuttings. These auxins will stimulate root growth of sugarcane but they also inhibit bud germination (Van Dillewijn, 1952). Some commercial hormone preparations have been sold in Australia for treatment of setts but their benefits have not been supported by experimental evidence.

10.0 SIZE OF CUTTINGS

The size of the sugarcane cutting has a significant effect on both the percentage of buds that will germinate and the vigour of the resulting plants. Ingram (1986) found that one-eye setts gave 17% better emergence than three-eye setts but the plants from one-eye setts had 15% fewer tillers and were 28% shorter than plants from three-eye setts at three months. Croft (1998) found that plants from 30-50 mm setts were 41% shorter than plants from 120-140 mm setts and that the plants from 120-140 mm setts were 10% shorter than plants from 260-280 mm setts at 10 weeks. Croft (1998) found that one-eye setts germinated faster and had a greater percent germination than two-eye setts. Lonsdale (1977) found that three-eye setts gave far fewer gaps (sections of row >30 cm with no shoots) than five and seven-eye setts and whole-stalks.

Shorter setts, particularly setts with only one node are more susceptible to desiccation and rotting organisms.

Whole-stalk planters in Australia cut the majority of setts in the range 350-400 mm (Robotham, 1999). A chopper harvester set up to deliver cane to a mill cuts the majority of billets in the range 200-300 mm. Billets cut by a harvester set up to deliver to the mill may have as few as 30% sound undamaged billets. The length and percentage of sound billets can be improved in chopper harvesters by modifications to the feed rollers.

11.0 DISEASES AND PESTS OF SUGARCANE PLANTING MATERIAL

11.1 Pineapple disease

The fungus *Ceratocystis paradoxa* (Dade) Moreau causes a rotting of the planted setts which can result in total germination failures (Wismer and Bailey, 1989). The disease is known as pineapple disease because of the strong fruity smell, similar to rotting pineapples, produced by the fungus. The fungus occurs in all sugarcane producing areas of Australia. The fungus multiplies on decaying plant material and particularly high populations occur soon after the stubble of a crop is ploughed into the soil. A range of fungicides is available for control of the disease. The fungicides are usually effective but they can fail if the setts are damaged with splits or punctures of the rind or shattering of the end of the sett. The nodes of the setts slow the progress of the fungus and setts with two or more nodes have a better chance of resisting an attack by the fungus (King *et al.*, 1953). Large cavities or pipes in the centre of stalks are common in some varieties, particular when the cane has suffered from waterlogging during its growth. These act as passageways for entry of *C.paradoxa*. The disease is also favoured by environmental conditions, which slow the germination of the cane including low temperatures, excess or deficiency of soil moisture, excessively soil cover and poor soil sett contact.

11.2 Other diseases

Red rot, caused by the fungus *Glomerella tucumanensis* (Speg.) Arx and Mueller, can attack setts (Singh and Singh, 1989). The disease is more common in subtropical regions with cool, wet weather after planting. Red rot is not a common cause of planting failures in Australia.

Many other diseases including the common diseases, ratoon stunting disease and chlorotic streak will slow germination of sugarcane. Systemic diseases such as Fiji disease, mosaic, leaf scald, bacterial mottle and *Sclerophthora* will severely affect germination, but because of the low incidence of these diseases they are not a common cause of germination failures.

11.3 Pests

The most serious insect pest of germinating cane is the wireworm, which is the larval stage of the click beetle (*Agrypnus variabilis* and *Heteroderes spp*) (Agnew, 1997). These insects burrow into the young germinating buds and can cause total germination failure in some fields. The insects are currently controlled by application of chlorpyrifos as a spray over the setts at planting.

Other pests which can attack germinating shoots are black beetles, grubs of the Rhyparida beetle, bud moth borer, crickets, termites and unidentified mites. These pests cause sporadic damage in some localities.

12.0 CHEMICAL TREATMENTS

Sugarcane setts germinate more rapidly after treatment with the fungicide, methoxyethylmercury chloride, even in the absence of pineapple disease or other rotting organisms (Steindl, 1970). The reason for the stimulation is not known.

Ethephon has been used to stimulate germination in some countries (see plant hormone section).

A range of non-hormonal chemicals have been reported to break dormancy and stimulate germination of seeds (Cohn, 1996). These include acids, aldehydes, alcohols and esters.

13.0 PHYSICAL TREATMENTS

13.1 Soaking

Soaking setts in water for as long as 36 hours before planting gives a significant stimulation of germination and was practised by some growers in Australia in the past (King *et al.*, 1953). In Taiwan, a high yielding high sucrose variety, ROC1, was slow to emerge when planted.

Soaking setts in 2% lime solution for 24 hours reduced the time to emergence of the first bud by 40% and increased the relative speed of shoot emergence by 55% (Chen *et al.*, 1986). This practice is impractical for large scale commercial planting in Australia.

In some cases, nutrients such as Ca NO₃ (King *et al.*, 1953), CaCO₃, MgSO₄ and KOH (Chen *et al.*, 1981) have been added to the water used to soak the setts. This was reported to improve germination in comparison to soaking in water alone.

A few farmers in Australia have developed a system of soaking billet cane for a few minutes in fungicide in the haul-out vehicle (Benson, personal communication). The haul-out vehicle has been converted into a tank. The fungicide solution is pumped into the haul-out vehicle from a storage tank when it is full of billets and pumped out again into the storage tank.

13.2 Heat treatment

Hot water treatment is the most effective treatment for stimulating germination (Wismer, 1961). Treatment of planting material with hot water containing mercurial fungicide was practised on a large scale in Hawaii (Wismer, 1961; Anon, 1985). Various temperature by time combinations have been used including 50°C for 20 minutes (Wismer, 1961), 52°C for 10 minutes (Goodall, 1998) and 54°C for five minutes (Anon, 1985). Croft (1998) found that hot water treatment at 52°C for 10 minutes combined with fungicide improved the speed of germination and the control of pineapple disease. Hot water treatment by full immersion for periods even as short as five minutes does not appear to be a realistic option for commercial planting in Australia.

Hot water treatment of cane at 50°C for two to three hours for control of ratoon stunting disease is widely used (Gillaspie and Teakle, 1989). This treatment is usually deleterious to germination.

Hot air and aerated-steam (steam-moistened hot air) have been used for treatment of cane stalks for control of ratoon stunting disease (Gillaspie and Teakle, 1989). Longer times at higher temperatures are required for these treatments to achieve the same curative affect as hot water (58°C for eight hours for hot air, 53°C for four hours for aerated steam compared to 50°C for three hours with hot water). The effect on germination of hot air and aerated steam treatments of shorter duration has not been reported. Further research is required to see if temperature-time combinations with aerated steam or hot air could be used to stimulate germination.

Heat treatment of seeds is widely used to break dormancy. Australian plants are adapted to bush fires and seeds of many Australian plant species will not germinated until they have been heat treated (Hartmann and Kester, 1983). The common way to propagate these species in nurseries is to treat the seeds with hot water. Grape-vine cuttings can be hot water treated to control bacterial diseases, improve storage and promote root growth (Wample, 1997).

13.3 Protective coatings

Coatings have been added to many seeds to protect the seed from damage, to add nutrients and pesticide, to add beneficial microorganisms and to improving the flow characteristics in planting machines (Scott, 1989). This concept has not been explored extensively in sugarcane. Sett coatings including neoprene, latex rubber, synthetic and natural waxes, emulsified asphalt, methyl cellulose, synthetic and natural resins and polyethylene film were investigated by Osgood and Hilton (1971). Wax coated one-eye setts performed as well as three-eye setts in an irrigated experiment, but poor germination was experienced with the one-eye setts in unirrigated fields (Osgood and Hilton, 1973). Croft (1998) found that polyethylene coating alone did not control pineapple disease and that polyethylene coating combined with fungicide was no better than fungicide treatment alone.

A few farmers in South Africa and Australia (Sluggett, personal communication) have practised filling the furrow with mill mud to provide an ideal environment for germination. This practice is expensive and has not been widely adopted.

Clayton (1987) has promoted the concept of a seed package, which provides a young germinating plant with all the requirements for initial establishment. This concept is attractive because it removes most of the risks of plant establishment. Seed coating is widely used in many small seeded crops and in legumes where addition of the correct strain of *Rhizobium* bacterium for a crop is important for nitrogen fixation. The coating materials also reduce the amount of pesticide that has to be applied to seed and reduces the risk of pesticide dust affecting operators (Clayton, 1987).

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