II. REVIEW OF LITERATURE

Sugarcane is an important commercial crop of India and an efficient converter of incidental solar energy into cane sugar. Exploiting the full production potential of sugarcane is much essential for maximizing its production as well as productivity, which is an outcome of adequate and appropriate agronomic management practices. Sugarcane is a one of the exhaustive crop, hence requires huge supply of external inputs and optimum management practices. Suitable nursery production techniques coupled with optimum plant population under sustainable sugarcane initiative (SSI) method are the key factors for productivity enhancement of sugarcane. Field experiments were conducted at the Experimental Farm, Faculty of Agriculture, Annamalai University, and Farmer's field during 2011-2013 to optimizing plant population with suitable nursery production practice for productivity enhancement of sugarcane. The literature falling within the scope of the investigation is reviewed under the following captions.

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2.1. Nursery studies

2.1.1. Effect of coco pith on sugarcane nursery

Coco pith is a spongy material found inside the coconut husk and its' a by product of the coir industry can be converted into organic manure using biotechnology, making it amenable for organic growing medium. Coco pith is an ideal soil reconditioner, soil structure improver and substrate with excellent water holding capacity (Veerabadran, 1991).

Savithri and Hameed Khan (1994) observed that many nursery problems can be nullified when the soil is fertile and contain components like micro and macro nutrients. Much attention must be paid to keeping it in good condition for providing quality seedlings. The ideal rooting medium or pro tray medium having the characters like deep, friable, well drained and has high organic matter content.

Proper rooting medium provides the basis for good seed germination and subsequent growth of young seedlings. Careful use of various soil amendments can improve the physical and biological condition of soil and provide the best possible starting ground for the crops.

Special features of coco pith compost

- Contains macro nutrients – nitrogen, phosphorus and potassium.
- Contains micro nutrients – calcium, magnesium, copper, etc.
- Contains natural enzymes
- Excellent water holding capacity
- Improves soil aeration
- Enhances strong heap root system
- Stimulates production of phytohormones
- Ideal pH level of 5.6 to 6.4
- Eco friendly.

Coco pith not only revitalizes the plants, it induces uniformity in growth by enhancing water retension and microbial activity. Coco pith contains high quality of nutrients that keep the soil healthy in a natural way. It acts as top dressings that help in maintain soil moisture and reconditions. Coco pith enhances the nutrient carrying capacity of plants (Arunachalam and Rajasekaran, 2009).

2.1.2. Effect of coco pith on crop plants

Jayaraj (1989) observed that coco pith could hold water about 5 times of its' weight, its' incorporation increased the water holding capacity of the soil. Devaraj and Chockalingam (1991) reported that coco pith mulching along with ridges and furrows in sugarcane produced higher cane yield of 82.5 t ha^{-1} compared to 71.3 t ha^{-1} under no mulch treatment. Mixing of coco pith + soil in 75 : 25 ratio as potting mixture significantly increased yield of tomato and vegetable cowpea over the yield of these crops raised on the soil alone (Baskar, 1996). Thangamani *et al*. (1996) indicated that incorporation of coco pith along with FYM, sand and soil at 1:1:3 ratio was found to be a good rooting media for vegetatively propagated clove plant, which increased the root length, root weight, number of branches and height of the seedlings. Anand *et al*. (2006) observed that higher root and shoot weights were recorded in corn plant, which received higher quantities of enriched and pretreated coco pith compost also resulted in increase soil organic carbon, available phosphorus, zinc and other micro nutrients.

Loganandhan *et al*. (2013) revealed that coco pith + vermicompost combination resulted in the higher germination of more than 88 per cent in sugarcane settlings, when compared to other mediums.

2.1.3. Effect of vermicompost on sugarcane nursery

Vermicompost is an established organic soil amendment that is produced by non-thermophilic process in which the organic matter is broken down through interactions between earth worms and micro organisms under aerobic conditions. Vermicompost have been demonstrated to be valuable soil amendment that offer a balanced nutritional release pattern to plants, providing nutrients such as available nitrogen, soluble potassium, exchangeable calcium, magnesium and phosphorus that can be taken up readily by plant (Edwards, 1998 and Edwards and Fletcher, 1988). Jambhekar and Bhiday (1992) reported that vermicompost application in furrows decreased the EC of soil and improved the growth of sugarcane planted in saline soil. The fertility and jaggery content of sugarcane juice was also improved under the treatment of vermicomposting compared to FYM and chemical fertilizer treatment. Solaiyappan *et al.* (1995) obtained enhanced cane yield of 112.5 t ha^{-1} through the combined application of 500 kg ha^{-1} of vermicompost and 100 per cent recommended NPK fertilizers. Zende *et al.* (1999) concluded that application of vermicompost enhanced the cane yield and sugar recovery and helped in reducing the dose of chemical fertilizer to the extent of 25-50 per cent depending upon soil type and climatic condition prevalent during the crop growth period. They further opined that vermicompost application increased the recovery percentage of sugar besides improving the fertility of the soil.

As the break down of organic wastes by earth worms is a non-thermophillic process, vermicompost had much greater microbial biodiversity and activity than conventional thermophillic composts (Edwards, 1998 and Edwards, 2004).

Norman *et al.* (2005) reported that the potential of vermicompost to improve plant growth was due to the changes in physio-chemical properties of soils, overall increase in microbial activity are due to the effects of plant growth regulators produced by micro organisms. Ushakumari *et al.* (2006) stated that vermicompost is a potential source of readily avaible plant nutrients, plant growth hormones, vitamins, enzymes, antibiotics and number of beneficial micro organisms. Roy and Singh (2006) found that increase in growth and yield components of crops due to application of vermicompost was mainly because of microbial stimulation effect and N supplied through gradual mineralization in a steady manner throughout the crop growth period.

Experiments conducted with vermicompost showed that application of vermicompost @ 5 t ha^{-1} along with recommended levels of N, P and K significantly improved the soil properties like bulk density, organic carbon content, CEC and soil fertility status as reflected in the available status of N,P and K and the metallic micronutrients *viz*., Fe, Mn, Zn and Cu (Angayarkanni, 2006). Singh *et al. (*2007) reported that application of vermicompost with recommended dose of NPK fertilizer significantly increased sugarcane yield. Sekar *et al*. (2007) concluded that application of vermicompost @ 5 t ha^{-1} along with recommended NPK registered highest cane yield (157.51 t ha^{-1}) and commercial cane sugar (12.60%). Rajeev *et al.* (2010) stated that application of vermicompost significantly influenced the soil chemical properties and nutrients status over control.

2.1.4. Effect of chip bud planting on sugarcane nursery

Sugarcane chip bud planting is the latest technique of sugarcane planting, where in the bud along with a portion of the nodal region is chipped off and planted in pro tray with coco pith and vermicompost. Dillewijn (1952) who first suggested, that a small volume of tissue and a single root primordium adhering to the bud are enough to ensure germination in sugarcane. He also stated that where growing conditions are favourable, cutting with only one bud did well as seed materials. Jayabal and Chockalingam (1990) reported that only 40 to 50 per cent germination was recorded under field conditions due to various reasons including soil factors such as soil temperature, crusting, compactness, soil born pest and diseases, moisture stress or dampness *etc*., resulting in high wastage of costly seed materials in conventionally planted canes. It was further observed that improved crop geometry through proper spacing of plants was therefore crucial for upgrading the productivity of cane crop. In order to boost the cane yield, the spaced transplanting technique (STP) was developed. Tillering with earliness and intensity is an important contributing factor for final yield of crop in terms of stalk weight and sugar (Yadav, 1991).

Nagendran and Sekar (1988) reported bud chip seedlings transplanting technique as most suitable for adoption in the wet lands of Cauvery delta. Narendranath (1992) emphasized that the bud chip raised seedlings were three times more cost effective than the way sugarcane was normally planted. Prasad and Sreenivasan (1996) used the bud chip method as a technology for easy transport of cane seed material. Panneerselvam *et al.* (2012) elucidated that sustainable sugarcane initiative (SSI) is an efficient and innovative method of sugarcane production system, where in only very less sugarcane seed material ($1/10^{th}$ of conventional method) is used for raising pro tray seedlings, besides saving of water, efficient use of fertilizer and other resources. (Biksham Gujja and Natarajan (2013) reported that sustainable sugarcane initiative (SSI) also known as “chip bud technology”, involves removal of buds from cane and raising nurseries results in drastically reduce the seed cane requirement, about 4 – 6 t ha^{-1} compared to conventional method of planting.

2.1.5. Effect of chip bud planting on growth character of sugarcane

Gokhale (1977) conducted field experiment and reported that the bud of sugarcane removed with cortical portion, excluding the pith, could be successfully used as seed material for planting sugarcane. Baddi Reddy *et al.* (1986) opined that higher productivity to single bud or chip bud seedlings was due to enhanced tillering capacity compared to conventional methods of planting.

Sakunthala and Devaraj (1992) recorded higher bud germination percentage in poly bag due to careful planting of bud chips in poly bag and 100 per cent establishment of seedlings in the main field with no need for gap filling operations. They also stated that poly bag method of transplanting cane crop produced more and uniform tilters as compared to conventional method.

According to Tamilselvan (2000), transplanting of 40 days old chip bud seedlings grown in poly bags produced uniformly early tillers and recorded of more cane lengths. Establishing the sugarcane crop using bud chips in place of setts could save about 80 per cent by weight of stalk material, however the technology has not been scaled up at commercial levels due to poor survival of bud chips under field conditions. Study aimed at improving sprouting and establishment of bud chip seed stocks of sugarcane by pre planting soaking in growth promoting chemicals, treated bud chips recorded higher bud sprouting, root number, fresh weight of shoot and roots and plant vigour index (Rhadha jain *et al.* 2010). Loganandhan *et al.* (2013) reported that average number of tillers per clump in chip bud method of planting were more (7.71) compared to conventional practice (4.98) with an increase of about 55 per cent.

2.1.6. Effect of chip bud planting on yield characters of sugarcane

Patil *et al.* (1991) reported that higher cane and sugar yield recorded by planting single budded settlings than conventional planting. Hunsigi (1993) opined that transplanting techniques in sugarcane cultivation increased the yield to the tune of 20–25 per cent over conventional method of planting. Kasthuri (1996) reported that in chip bud planting technique in poly bags, germination failure can be overcomes with additional advantage of higher individual cane weight and total cane yield more than conventional method.

Williams (1993) suggested that chip bud planting with poly bag seedling transplanting was superior to normal method in the following ways.

a) Highest seed multiplication ratio of 1: 70 against 1: 40 in conventional method.
b) One month age advantage through seedling planting saves time between two crops in the main field.
c) Immediately after seedling transplanting, quick establishment of cane crop takes place with high yield potential.

Transplanting of 30 to 40 days old chip bud seedlings recorded highest tiller production, millable can population and cane yield (Marimuthu *et al.,* 2002). Ramdos *et al.* (2003) reported that raising of poly bag seedlings reduced the seed cane by 6 tones per hectare and in the main field there was good interception of sunlight, more uniformly distributed crop canopy and markedly reduced formation of late tillers.

According to Tamilselvan (2006), Chip bud planting methods revealed that planting seedlings grown on raised bed or poly bags for 40 days at 80 x 20 cm spacing could enhanced the productivity; these seedlings produced 63 per cent more early tillers, well developed stalks with high juice content and cane yield of 108 tonnes ha^{-1} compared to 55 tonnes ha^{-1} with direct planting of chip buds. The seedlings method was comparable with the conventional system of planting two budded setts; early synchronous tiller production, higher conversions of tiller into cane population, and uniform final stalk population resulted in higher juice quality. This methods of planting also resulted in a higher benefit cost ratio by saving 90 per cent of seed cane. Bhullar *et al.* (2008) reported that trench transplanting with 4.0 t ha^{-1} of seed rate could help in increasing higher productivity and profitability of sugar cane. The average weight of individual canes was more in chip bud planting method (1.97 kg) compared to the conventional canes (1.53 kg). Hence, the yields were found higher (about 20 per cent) in chip bud method (138.30 t ha^{-1}) than that of conventional method (115.00 t ha^{-1}) reported by Loganandhan *et al.* (2013).

2.1.7. Effect of single bud/ring bud planting on sugarcane

Sugarcane crop raised through single budded seedling registered higher germination and established uniformly with good stands (Bull, 1975, Perumal and Raghavan, 1975; Kathirvel and Devaraj, 1977).

Spaced transplanting (STP) method was developed by Srivastava *et al.* (1981), in which single bud nursery was raised and seedlings were transplanted in the main field with wider spacing with in row to facilitate availability of abundant solar radiation and soil aeration to enhanced high levels of tiller production. Tianco (1995) in Philippines, used 40 days old seedlings raised by using single bud setts in poly bags and found that yield were 11 per cent higher, millable canes were 17 per cent lower but individual canes were 34 per cent heavier as compared to normal method of cultivation. Recently developed single bud setts planted poly bag method of planting provided a solution for faster multiplication by higher tillering and more yield with higher quality (Williams, 1993). Gupta (1999) reported that the single bud setts used in poly bag planting required 1.5 tonnes of seed material per hectare, as compared to

10 tonnes per hectare in normal planting. Karthikeyan and Kumar (1996) observed that the single bud setts planting in poly bag method significantly increased the cane yield and reduced the main field duration. Thirunavukkarasu *et al.* (1997) revealed that the rise in sugar recovery was mainly attributed because of more physiological age of single bud settling planted crop as compared to two budded sett planted crop and due to simultaneous and healthy growth of tillers.

The single bud setts planted in poly bag method of planting in sugarcane culture is a new attempt and highly ideal for economizing the seed cost. (Sundara, 2002). Pawar *et al.* (2005) reported that significantly higher germination per cent (96–98 percentage) was recorded in single budded ploy bag settling as compared to two budded sett planting. Raskar and Bhoi (2003) revealed that planting of single bud settling recorded significantly higher in cane height, cane girth, number of inter nodes per cane, individual cane weight and dry matter production per plant than micro propagated plant and ratoon canes. Radha jain *et al.* (2010) observed that various limitations in chip bud technology mainly due to their poor survival under field conditions. The chip bud seed material has relatively low food reserves (1.2 to 1.8 g of sugar per bud) compared to conventional 3 bud seed material (6.0 to 8.0 g sugar per bud). The food reserves and moisture in the chip bud depletes at a faster rate compared to 2 or 3 bud sett which is reflected in their poor sprouting and early growth without treatment. Satpal Saini *et al.* (2012) inferred that single bud setts planted cane achieved highest germination percentage (94–97 percentage) as opposed to least germination percentage (76–84 percentage) in conventional method of planting.

2.1.8. Effect of humic acid on chip buds /ring buds in nursery

The dynamic physical and chemical properties of soils are controlled largely by clay and humus. They act as centers of activity around which chemical reactions and nutrient exchange occur. Further more by attracting ions to their surface, they temporarily protect essential nutrients from leaching and then release them slowly for plant use. Because of their surface charges they are also thought to act as 'contact bridges' between larger particles, thus helping to maintain stable granular structure so desirable in a soil that is easily filled. Dhara and Gupta (1984) reported that humic acid played an important role in the formation of water soluble aggregates.

Balasubramanian *et al.* (1989) noticed that the organic carbon content of the post harvest soils applied with humic acid was higher. The rate of increase in soil organic carbon content was proportional to the amount of humic acid application and the increase was significant up to two weeks and declined gradually indicating the degradation of humic acid (Gurunathan and Kaliyaperumal, 1989). Dhanasekaran (1999) revealed that supply of micronutrients through humate forms maintained higher level of available micronutrients in soil as compared to their salts. Sivakuamr (2003) found that the humic acid at various levels had brought out substantial increase in soil available NPK. The DTPA extractable micronutrients *viz*., Fe, Mn and Zn showed a linear increase upto 40 kg ha^{-1} level.

2.1.9. Effect of humic acid on sugarcane crop

In a field experiment on sugarcane, Saravanan (1989) observed that the beneficial effect of humic acid by enhancing the yield attributes like tiller number, number and length of millable canes, single cane weight, number of internodes, internodal length and girth of cane. Humic acid application increased the content and uptake of nutrients such as N, P, K, Ca, Mg, Fe, Mn and Zn but decreased that of Cu in sugarcane. It was also reported to be effective in improving the juice quality which inturn resulted in higher commercial cane sugar per cent and yield of sugar. Govindasamy (1992) reported that the humic acid added in field experiment either as soil application or as sett treatment influenced the growth and yield of sugarcane.

The application of humic acid @ 60 kg ha^{-1} increased the content and uptake of N,P,K, Ca, Mg, Fe, Mn and Zn, (Ravikumar and Govindasamy, 1992). Govindasamy and Chandrasekaran (1992) opined that humic acid applied @ 6 gm m^{-2} significantly increased the sugarcane yield. Dhanasekaran (1999) revealed that application of Zn and Fe humate either alone or in combination, significantly increased the growth and yield of cane as well as improved the juice quality. Among the treatments, application of Zn and Fe as humates at 5 and 10 kg ha^{-1} respectively recorded the highest yield of cane (157.2 tha^{-1}) and sugar (21.94 t ha^{-1}) and uptake of cationic micronutrients. Khungar and Manoharan (2000) revealed that sugarcane treated with humic acid @ 10 kg ha^{-1} increased the yield significantly and reduction in the application of urea, SSP and MOP by 25 per cent.

Sellamuthu (2002) recorded highest values of relative agronomic efficiency (RAE), relative economic efficiency (REE) and benefit cost ratio (BCR) in the treatment, humic acid plus recommended NPK in sugarcane. Muralidharan *et al.* (2002) reported that the combined application of humic acid up to 20 kg ha^{-1} as soil application and 0.1 per cent humic acid as foliar spray along with 100 per cent recommended NPK resulted in the highest cane and sugar yields and quality characteristics of sugarcane juice when compared to soil application of 40 kg humic acid ha^{-1} and 0.1 per cent foliar spray along with 75 per cent recommended NPK. Sellamuthu and Govindasamy (2003) revealed that humic acid application @ 30 kg ha^{-1} significantly influenced the microbial activity of sugarcane. The increased microbial population might be due to the presence of humic acid in the root zone, which favours the microbial growth in the rhizosphere. Sellamuthu *et al.* (2004) revealed that 100 per cent NPK and humic acid @ 30 kg ha^{-1} recorded the highest cane yield of 135.68 t ha^{-1} and sugar yield of 18.26 t ha^{-1}. Manoharan (2006) stated that application of 20 kg humic acid ha^{-1} increased the yield by 34 per cent over control. Jader Galba Busato *et al.* (2010) elucidated that the ability of humic acid to promote main and lateral root development was directly related to the stimulation of plasma membrane ATP ase activity.

2.1.10. Effect of Acetobacter on sugarcane nursery

Biological nitrogen fixation (BNF) is a fascinating biological phenomenon which has been extensively studied during the last hundred years with the sole objective of harnessing its potential to provide low cost nitrogen to increase crop productivity (Shantharam and Mattoo, 1997).

Acetobacter diazotrophicus (now renamed as *Gluconacetobacter diazotrophicus*) is an endophytic, gram negative, rod shaped, acid-tolerant bacterium associated with sugarcane. It is highly capable of growing aerobically on high sucrose concentration (up to 30 per cent) and very low pH (3.0), also they could tolerate higher nitrate concentrations i.e. up to 60 to 80mm. The bacterium tends to colonize the root cortex and may even penetrate the epidermis to colonize the stele, from which they may subsequently be translocated to aerial parts. Among the microbes, *Acetobacter* is one of the best biological N source for sugarcane.

The Biological nitrogen fixation is a potential biological process that maintains soil nitrogen and prevents the environment pollution. Lima *et al.* (1987) and Urquiaga *et al.* (1989 and 1992) suggested that more than 60 per cent of the input N of Brazilian sugarcane cultivars were obtained from BNF. Use of N_2 fixing associations can be solution to increase the use of atmospheric N as well as to minimize the environmental hazards (Quispel, 1991).

2.1.11. Effect of Acetobacter on growth and yield of sugarcane

Cavalcante and Doberenier (1988) and Boddey *et al.* (1991) observed that *Acetobacter diazotrophicus* could promote root development and improve sugarcane growth. The possible reason for the enhanced growth and yield could be due to the quantity of nitrogen fixation by this entophyte that contributed nitrogen to sugarcane whenever required and the quantity of nitrogen supplied may be important during critical phases of sugarcane development as suggested by Bashan *et al.* (1989).

Fuentez – Ramirez *et al.* (1993) reported that the *Acetobacter diazotrophicus* produced IAA and suggested that this bacterium could promote rooting and improves sugarcane growth by direct effect on metabolic process in addition to their role in nitrogen fixation. Rajendran (1995) stated that the sugarcane inoculated with *Acetobacter diazotrphicus* along with different levels of nitrogen were superior and recorded higher growth parameters like leaf length, tiller number, node number, cane girth and cane height.

Quispel (1991) have calculated that as much as 41 per cent of total N is being contributed from roots through N fixation. While for whole plants this contribution reaches a maximum of 5 per cent and 9 per cent derived from nodes and seed pieces in sugarcane respectively. But the occurrence of diazotroph like *G.diazotrophicus* in leaves and stem in large numbers where more than 100 tonnes of plant material ha^{-1} containing 10 per cent sugar contrasted with the concept of rhizosphere associations where in only a small portion of the root exudates are available for them.

Panneerselvam (1997) concluded that the sugarcane plants treated with 75% N + Azotobacter + Gluconacetobacter + VAM showed maximum cane height, cane girth, cane yield, sugar yield and commercial cane sugar content than that of any other treatment. Thopate and Jadhav (1997) registered significantly highest (78.78 per cent) germination per cent when sugarcane setts was treated with acetobacter culture applied with 75 per cent fertilizer nitrogen compared to control (73 per cent). Pawar *et al*. (2000) observed that the actobacter treated cane recorded a plant population of 96,666 ha^{-1} while control produced 71,666 plants ha^{-1}.

Muralikrishnan and Muthukaruppan (1998) observed that by treating the setts with *Acetobactor diazotrophicus* @ 5 kg ha^{-1} with 50% recommended N had increased yield (128.10 t ha^{-1}) than uninoculated cane (99.63 t ha^{-1}).

Suvarana and Jayasheela (2002) reported that the germination per cent was maximum with *Acetobacter diazotrophicus* inoculation (82.5) and minimum with *Bacilllus megathirum* (70.75) in sugarcane. Jayachitra (2004) observed that inoculation of Acetobacter increased the growth attributes *viz*., cane height, number of tillers m^{-2} and dry matter production over control in sugarcane. Singh *et al.* (2007)

found that application of acetobacter @ 15 kg ha^{-1} along with vermicompost increased the cane yield about 34 – 48 per cent compared to control (53 t ha^{-1}). In wider row spacing (120 cm) of cane cultivation, application of acetobacter @ 10 kg ha^{-1} along with recommended dose of fertilizers recorded higher single cane weight (1.41 kg), cane yield (141.97 t ha^{-1}) and sugar yield (16.62 t ha^{-1}) (Manimaran *et a.,* 2009).

It is considered that the endophyte *G. diazotrophicus* might be responsible for the high rates of N_2 fixation (150 kg N ha^{-1} yr^{-1}) observed in certain sugarcane varieties (Speir *et al.,* 2004; Yadav *et al.,* 2009). The nature of entophytes and their role in growth promotion were clearly explained by Compant et *al.* (2010). Prabhudos and Stella (2010) observed that *G. diazotrophicus* and AM Fungi with 50 per cent of NPK fertilizers significantly influenced the growth, development and yield of sugarcane through N fixation, P mobilization and P and Zn solubilization by producing some growth promoting substances like IAA, gibberellins etc.

2.2. Main field studies

2.2.1. Effect of wider row spacing in sugarcane

2.2.1.1. Effect of wider row spacing on germination in sugarcane

Wider spacing of 112.5 cm resulted in better germination than closer spacing of 75 cm in Tarai tract of Uttar Pradesh (Umrao Lal and Banwari Lal, 1978). In contrast Singh *et al.* (1991) did not observe any significant difference in germination due to different row spacings in sandy loam soils at Ghagharaghat, Uttar Pradesh.

The crop planted at 120:60 cm row spacing recorded higher germination percentage followed by 90, 120:30, 60:30, 75 and 150:30 cm row spacings. The significantly lowest germination was recorded under the 150:30 cm row spacings (Avtar Singh and Rajbahadur Singh, 2001). Vasantha *et al.* (2011) revealed that under wider row spacing it resulted in more germinents and higher establishment percentage.

2.2.1.2. Effect of wider row spacing on tiller population in sugarcane

Tillering is a critical phase in the physiology of sugarcane. It is mainly contributing to the cane population at harvest, final cane yield and quality. Closer row spacing generally results in higher tiller population per unit area than wide row spacing. But the number of tillers per clump in wide row spacing is generally more compared to closer row spacing.

Bull (1975) indicated that closer row spacing promoted rapid tillers development in cane varieties *viz.*, H 51.8029, 1639–4 and 1695–1 in Australia. Despite of sufficient quantities of seed, fertilizer and irrigation water, the cane number was drastically reduced in closely spaced rows at Anakapalli, Andrapradesh. Here, the sunlight seemed to be the deciding factor for tillering in sugarcane (Venkateswara Rao, 1979). Inter row spacing in the northern cane growing region can be increased to 120 cm without any adverse effect of stalk population (Kanwar, 1986).

Sugarcane productivity can be enhanced one way by increasing plant population to some extent. In general, closer spacing is adopted in soils of low fertility and wider spacing in fertile soils. In wider spacing, tiller per clump is more and canes are thick, while in closer spacing tiller per clump is less and canes are thin (Ramendra Singh *et al*., 1981 and Gururaj Hunsigi and Satpute, 2000).

Onkar Singh and Kanwar (1987) reported, higher tiller mortality in 60cm row spacing than 90 and 120 cm row spacings. Singh *et al.* (1991) observed a marked reduction in tillers with increase in row spacing from 60 to 90 cm. The plant population (90, 120, 150 and 30:120 cm row spacings) was found to be significantly affected by row spacing (Sajid Hussain *et al*., 2005). Wide row spacing are facilitate more space for higher tillering and better tiller survival (Vasantha *et al.,* 2011). Natarajan (2011) reported that planting of nursery raised seedling in wide row spacing (SSI method) results in high level as well as synchronous tillering.

2.2.1.3. Effect of wider row spacing on cane height in sugarcane

The millable cane length can effectively be increased by increasing the row spacing of sugarcane (Yadav, 1981). Nagendran and Palanisamy (1997) observed taller canes (430 cm) under wider row spacing of 150cm and shorter canes (322 cm) in narrow row spacing of 75 cm. Sundara (1998) observed individual cane growth is better under wider row spacing than narrow row spacing. A wide row spacing of 140cm recorded significantly higher stalk height in the first ratoon crop than 100, 120 cm row spacings (EL-Geddawy *et al*., 2002).

2.2.1.4. Effect of wider row spacing on dry matter production in sugarcane

Irvine and Benda (1980) indicated that there was on considerable difference in biomass production among the different spacings adopted (19, 38, 76 and 152 cm). Sreenivasulu (1999) recorded the higher DMP at all stages in normal row spacing (90 cm) than wider row spacing (150 cm). Vijayakumar and Suresh (2011) observed that under wider row (150 cm) spacing chip bud raised settling planted 45 cm apart gave higher DMP of 300 gm per plant on 180 days after planting.

2.2.1.5. Effect of wider row spacing on leaf area index in sugarcane

The leaf area index under 19 cm row spacing is higher (8.20) when compared to 152 cm spacing (3.30) (Irvine and Benda, 1980). Sundara (2003) observed that the increase in row spacing (90, 120 and 150 cm) significantly reduced the leaf area index (3.19, 2.94 and 2.60, respectively).

2.2.1.6. Effect of wider row spacing on number of millable canes in sugarcane

Prabhakar (1999) observed higher tiller population per unit area is recorded in closer row spacing compared to wide row spacing, their survival is lower under closer row spacing than wide row spacing. Because of this, the difference in millable cane population between the closer and wide row spacings narrowed down at harvest.

Venkateswara Rao (1979) recorded a millable cane population of 0.61 lakhs per hectare under wide row spacing of 120 cm compared to 0.80 lakhs per hectare under closer row spacing of 60 cm. The reduction in millable cane population under wide row spacing as compared to closer spacing was 23.8 per cent.

While on millable cane population of 1.05 lakhs per hectare under wide spacing of 150 cm as compared to 1.20 lakhs per hectare under closer row spacing of 75 cm was observed by Nagendran and Palanisamy (1997). Here the reduction in millable cane population under wide row spacing as compared to closer row spacing was 12.5 per cent. Sundara (2003) reported the number of millable cane was highest under 90 cm row spacing which was significantly higher than 150 cm single row planting but at par with 120 cm and 150 cm dual row planting. Patel *et al.* (2005) revealed that planting geometry (90 cm and 60:120 cm) did not exerted any significant effect on cane yield, NMC and CCS per cent. Farmers opined that tiller mortality was significantly reduced as the inter row spacing increased. Wider spacing also produced thicker canes compared to narrow spacing. The high single cane weight compensates the less number of millable canes with better cane yield (Patel *et al.,* 2006 and Gopalsundaram, 2009).

2.2.1.7. Effect of wider row spacing on length and girth of internodes and individual cane weight in sugarcane

The length of internodes and girth of cane tends to be higher under wide row spacing as compared to closer row spacing. This contributes to higher single cane weight under wide row spacing than closer row spacing. A higher individual cane weight was observed in dual row planting of 40-80-40 cm spacing as compared to 125 cm row spacing at Taiwan (Yang *et al*., 1981). The individual cane weight was higher under wider spacings of 90 and 120 cm than 60 cm (Mali and Singh, 1986). On the contrary, Ramesh (1997) observed that the single cane weight was not significantly influenced by different planting geometrics.

2.2.1.8. Effect of wider row spacing on cane yield in sugarcane

A study at Sugarcane Breeding Institute, Coimbatore on the feasibility of obtaining normal cane yield under wide row spacing indicated that the cane yield in wider row spacing (150 cm) can be maintained at par with conventional row spacing (90 cm), provided the seed rate and fertilizer dose per unit area are kept constant (Sundara, 1997).

Under wide row spacing, generally heavier canes are obtained but they are lesser in number, compared to closer row spacing. If the number of canes does not go below a reasonable level under wide row spacing, the heavier canes can compensate the yield loss due to reduction in number of millable canes. The number of millable canes can be kept at a reasonable level by agronomic manipulations like use of more buds and optimum fertilizers per unit row length (Prabhakar, 1999).

Ali *et al.* (1999) observed that the cane yield and sugar yields were similar at row spacings of 100 or 125 cm. There was a positive increase in cane and sugar yields up to 120 cm row spacing of sugarcane (Abd-El-Latif *et al*., l999). Shah Nawaz Vains *et al.* (2000) observed a higher cane yield (141.64 t ha^{-1}) with 90 cm spaced double row planting and the lowest (86.21 t ha^{-1}) with a row spacing of 120 cm in single row system. Avtar Singh and Rajbahadur Singh (2001) observed that the paired row spacings of 120:30, 60:30 and 120:60 cm proved effective against the 90 cm row spacing in enhancing the cane yield under late planting situations.

In contrast, the mean cane yield was unaffected by increasing the row spacing to 120 cm from 90 cm but further increase to 150 cm reduced the cane yield significantly (Sundara, 2002b). Further he reported the mean cane yield (117 t ha^{-1}) at wide row spacing of 150 cm with uniform seed and fertilizer rates was on par with 90 cm spacing (118.6 t ha^{-1}) while at reduced seed and fertilizer rates, it declined (100.6 t ha^{-1}). Under Vapi in South Gujarat conditions, it has been reported that yields at 341 t ha^{-1} were achieved by adopting wider row spacing (Mangal Rai, 2002).

Baig *et al.* (2005) observed that among the row spacing, paired row planting at 75 and 150 cm gave significantly higher cane yield (136.59 t ha^{-1}) than 100 and 150 cm row planting. A non significant influence of planting geometry i.e. row spacing on cane yield was observed by several researchers (Mishra *et al*., 2004 and Patel *et al*., 2005). Increase in planting density through narrow spacing in plant crop significantly increased the NMC and cane yield in ratoon crop (Singh *et al*., 2006). Garside and Bell (2009) experimentally demonstrated that high density (wider row space) planting did not produce more cane or sugar yield at harvest than low density (normal row space) planting regardless of location, crop duration, water supply and soil health. Rajula Shanthy (2010) reviewed that wider row spacing of 150 cm to give better crop stand than normal spacing, produces thick canes, good crop growth and increased cane yield. Kapur *et al.* (2011) reported that cane weight and cane yield were higher in wide row planting resulting to comparatively more number of millable canes as well as longer duration and high yielding nature of the cane.

2.2.1.9. Effect of wider row spacing on cane quality in sugarcane

Quality is primarily controlled by the weather parameters that prevail during the maturity phase of the crop. It could be altered to some extent by the composition of canes of different physiological age of cane formed shoot. The researchers argued that the spacings had no effect on juice quality of cane juice (Singh *et al*., 1991 and Roodagi *et al*., 2001).

Onkar Singh and Kanwar (1991) observed that the purity and commercial cane sugar (CCS) were found to be significantly higher under wider row spacing (120 cm) than narrow row spacing (60 cm). Sundara (1993) observed that significant increase in cane yield, sucrose content and juice extraction to the tune of 29, 9 and 15 per cent respectively, due to increase in CCS per cent in spaced planting technique with higher sugar yield. The quality parameters of sugarcane were improved with higher dose of nutrients in widely spaced (150 cm) sugarcane, while marginal reduction was observed in normal row spacing (90 cm) (Sreenivasulu, 1999). Commercial cane sugar per cent (CCS%) of sugarcane was not influenced significantly by the row spacings of either 90 or 150 cm (Sundara, 2002b).

In general, altering the row spacing of sugarcane did not have any significant influence on pol values. However, Sajid Hussain *et al.* (2005) observed comparatively higher pol value under wider (150 cm) row spacing than narrow row spacing.

2.2.1.10. Effect wider row spacing on mechanized cultivation in sugarcane

In the present and future contexts of sugarcane agriculture in the country with emphasis on cost reduction, mechanization, adoption of drip irrigation, conservation farming etc., Mechanization of sugarcane farming is an important requirement in the country in view of the labour shortages increasingly felt throughout the country. Mechanization would help reduce dependence of manual labour, facilitate timely operations like tillage, planting, weeding and earthing up, plant protection, harvesting, loading, transport and other post harvest operations including ratooning. (Sundara, 2011). It is therefore logical to assume that wider spacing was necessitated by mechanized cultivation (Hunsigi, 1993).

In countries where sugarcane cultivation is highly mechanized, sugarcane is grown at row spacing ranging from 140 to 180 cm to facilitate the movement of machineries (Blackburn, 1984). Wider row spacing (150 cm) of sugarcane is a pre-requisite for mechanical harvest. Hunsigi (1993) reviewed the row spacing adopted under commercial cane cultivation in various parts of the world and reported that the row spacing ranged from 0.6 to 2.4 m. In areas where mechanized cultivation is predominant, the row spacing adopted is wider (>1.2 m) while narrow row spacing (0.6 m-1.2 m) was adopted in conventional sugarcane farming.

In Tamil Nadu, Mahalingam and Manickam (1999) advocated a row spacing of 1.5 m (5 ft) in order to facilitate complete mechanization of cane farming. Growing sugarcane in wider rows, facilitates mechanized harvesting without any loss in cane or sugar yield (Sundara, 2002a). Adoption of such wide row spacing would be useful not only for mechanization of cane farming but also to facilitate intercropping. Adoption of wide row spacing in sugarcane is fast spreading among the farming communities particularly in tropics (Sundara, 2002b).

Sundara (2002) reported that wide row planting facilitates easy labour movement within the field, permits mechanized inter culture, saves cost, seeds and fertilizers, gives better rations, and allows insitu trash management. Wider row planting in tropical areas facilitate mechanization of field operations and reduce production costs (Sundara, 2003). Khandagave (2010) revealed that wider row planting in sugarcane facilitates mechanical harvesting that reduces the harvesting charges and avoided the trash burning operation. Stubble shaving is not needed in the case of machine harvested plots due to cutting of cane close to ground level.

The cumulative effects of wider row planting, mechanized cane operation including harvesting and multi-ratooning facility will boost up profit margin to the cane growers (Nagendran, 2009 and Gopalasundaram, 2009). Wider row spaced planting helped to provide abundant sunlight for increasing cane yield provides proper space for intercultural operations and also proper adoption of mechanization there by incrasing the per unit profitability (Panghal, 2010 and Chaudhari *et al.,* 2010).

Rajula Shanthy and Muthusamy (2012) concluded that wider row spacing in sugarcane planting was a pre-requisite for mechanized farming. Panneerselvam *et al*. (2012) were conducted field experiment on efficiency and effect on manual and motorized bud chipper on the germination performance of bud chips, they observed that the manual bud chipper removed 300 chip buds per hour were as the motorized bud chipper removed 4000 chip buds per hour from the seed cane. There was no significant difference in the germination performance of bud chips were observed in the pro tray due to manual and motorized bud chipper. Ravindra Naik *et al.* (2013) reported that wide row space planting of sugarcane chip bud settling raised in pro trays facilitates mechanical planting, showed 40 and 85 per cent saving in cost and labour, respectively over manual chip bud settling planting.

2.2.1.11. Effect wider row spacing on nutrient content and post harvest soil nutrient status of sugarcane

Arumugam *et al.* (2002) observed that the different planting systems with varied spacings of which the system with 120 cm surface drip with a single row planting was found to be the best. While Sundara (2003) reported that at 150 cm spacing, the dual row planting pattern was found better than single row planting. Patel and Patel (2005) observed that the planting geometries had non significant influence on nutrient content in sugarcane plant and nutrient status of soil after harvest. While, uptake of nutrient *viz*., N, P_2O_5 and K_2O by sugarcane were higher under 60-120-60 cm paired row planting compared to normal (90 cm) and 120 cm twin row planting geometries.

2.2.1.12. Effect wider row spacing on Economics of sugarcane

Paired method of planting was found better and profitable (Kumar *et al*., 1992 and Singh *et al*., 1996). Net returns were higher in paired planting compared to normal method of planting with higher B:C ratio of 2.76 (Roodagi *et al*., 2000). Sugarcane raised under 195 cm spacing between drip lines and 75 cm between two paired rows recorded the highest benefit cost ratio of 1.46. However, 120 cm row spacing with surface drip irrigation recorded the benefit cost ratio of 1.39, whereas under conventional surface irrigation, the ridges and furrows (90 cm) recorded the benefit cost ratio of 1.32 (Arumugam *et al*., 2002).

Roy and Singh (2004) reported that paired row method of planting was economically sound since the net return (Rs./ha) was significantly higher than that of furrow and ring method of planting. Mishra *et al.* (2004) observed a B:C ratio of 1.51 which remained at par with 90 cm row spacing but superior to 45, 60 cm row spacings and paired row planting system of 60:30 and 150:60 cm. Wider planting gave significantly higher net return (Rana *et al*., 2006). Rajula Shanthy *et al.*(2007) observed that there are quite a few technologies in sugarcane that can minimize the cost of cultivation with increased returns, this includes wide row spacing.

2.2.2. Effect of intra row spacing in sugarcane

2.2.2.1. Effect of intra row spacing on tiller population in sugarcane

The inter plant and intra plant competition determines the cane spacing leading to ultimate stalk population (Srinivasan, 1995). End to end placement of setts in a row, there is a little variation ‘within’ row spacing though the exact distance from bud to bud changes from sett depending upon the length of the stalk between two buds (Venkateswara Rao, 1979). Lakshmikanthan (1983) stated within the row, there may be a slight over lap of the setts.

Sundara (1998) concluded that under normal conditions, ridges and furrows method is easy and most beneficial. Here the setts are placed in end placement in end to end or in an over lapping fashion. End to end placement of setts is followed when the seed rate adopted is lower and inter nodal length of variety chosen is shorter. The 'over lapping' type of sett placement is followed if the setts have longer internodes and seed rate is higher.

A tiller population of 2.70 lakhs per hectare under wider row spacing (setts placed across the furrow) of 150 cm as compared to 4.13 lakhs ha^{-1} under closer row spacing of 75 cm was observed by Nagendran and Palanisamy (1997). The effect of setts placement systems (end to end, right angles to the direction of the row and 'dual row') under wide row (150 cm) spacing resulted in lowest shoot population (89,396 ha^{-1}) and stalk number (72,941 ha^{-1}) in end to end placement of setts at reduced seed rate. Not much difference existed between 'end to end' or right angles to the direction of the row (Sundara, 2001).

The highest number of tillers (152.0×10^3 ha^{-1}) were recorded under closest spacing of 165 (105+60) cm x 30 cm followed by 180 (120 + 60) cm $\times$ 30 cm (BSRI, 2004). Raghu *et al.* (2006) reported that sugarcane raised through micro propagation with 90×60 cm spacing recorded the highest tiller number of 1.88 lakh ha^{-1}.

2.2.2.2. Effect of intra row spacing on number of millable cane in sugarcane

Scandaliaris *et a.* (1989) observed that growing sugarcane up to a 160 cm intra row spacing increased shoot and stalk population and raised the efficiency of solar energy utilization. Jayabal *et al.* (1989) reported that the conventional method of planting produced more number of millable canes than 30 cm and 45 cm intra row spacing. The reduction of millable cane was more in the 45 cm intra spacing. While on millable cane population of 42,000 per acre under wider spacing (cross planting) of 150 cm as compared to 48,000 per acre under closer row spacing of 75 cm was observed by Nagendran (1999). The planting density could not exhibit significant effect on millable canes (Singh *et al*., 2005)

2.2.2.3. Effect of intra row spacing on cane weight in sugarcane

The setts planted at 30 cm intra-row spacing either as single budded or as two budded setts both in normal row as well as paired row system of planting were on par and superior to other methods in individual cane weight (1.351 to 1.391 kg) (Devaraj, 1986).

Devaraj and Shanmugasundaram (1988) observed that cane weight enhanced due to lesser seed rate either as single budded setts or wider spacing within the row by across planting of two budded setts with lesser seed rate. Nagendran and Palanisamy (1997) observed 30 per cent heavier canes in wide row spacing (150 cm) with cross planting method than conventional planting method. The cane height, millable canes and number of inter nodes did not differ significantly by intra-row spacing but cane girth and per cane weight increased significantly at wider intra-row spacing of 90 cm (Raskar and Bhoi, 2003).

2.2.2.4. Effect of intra row spacing on cane yield in sugarcane

Irvine *et al.* (1980) considered that wider rows or wider distances between plants produced higher stalk numbers and higher cane yield in sub – tropical areas. A higher yield in 80 cm row spacing planted with two budded setts across the furrow at 15 cm (104.9 t ha^{-1}) as compared to continuous (end to end) planting (98.3 t ha^{-1}) was observed by Devaraj and Shanmugasundaram (1987). Jayabal *et al.*(1989) reported that conventional method of planting produced more tillers and millable canes which resulted in higher cane yield than 30 and 45 cm intra row spacing of setts. Nagendran and Palanisamy (1997) reported by changing the sett placement from along the row to across the row at 150 cm row spacing, higher cane yield was obtained in comparison to conventional row spacing. Prabhakar (1999) recorded the cane yield of almost same in both spacings, 119.1 t ha^{-1} under wide row (150 cm with cross planting) and 119.8 t ha^{-1} under normal row (90 cm) spacing.

The wide row spacing facilitates of abundant sunlight to cane crop which may help to increase the biomass production and yield of cane (Nagendran, 1999). Sundara (2000) studied the effect of sett placement pattern with dual row planting (20 cm apart), end to end (single row) and setts placed at right angles to the direction of the row found that the dual row planting gave significantly higher cane yield(123.3 t ha^{-1}) than single row planting (114.7 t ha^{-1}).

Amit Bhatnagar and Saini (2005) noted that 30 cm intra row spacing exhibited significantly higher cane yield, i.e. 13.5 per cent higher than that of 60 cm spacing. Patel and Patel (2005) reported that the 90 cm normal, 60-120-60 cm paired row and 120 cm twin row planting geometry were equally good for cane yield.

Pawar *et al.* (2005) enumerated that the cane yield was significantly increased by 17.48 t ha^{-1} in 60 cm inter settling spacing as compared to control (106.65 t ha^{-1}) in five feet wider row spacing. Conventional row spacing of 75 cm with setts placed along the rows and wide row spacing of 150 cm with setts placed across the rows gave cane yield on par (Arvind Misra and Tripathi, 2006). Raghu *et al.* (2006) reported that sugarcane raised through micro propagation with 90 × 60 cm spacing recorded the highest cane yield of 105.90 t ha^{-1}.

2.2.2.5. Effect of intra row spacing on cane quality in sugarcane

Jayabal *et al.* (1989) observed an increased in juice quality (CCS per cent) by 0.6 unit in 30 cm intra row spacing over conventional method of planting. Conventional method of planting recorded the higher sugar yield (8.8 t ha^{-1}) than 30 cm (8.2 t ha^{-1}) and 45 cm (7.3 t ha^{-1}) intra row spacings. Sundara (2002b) observed that the quality parameters were not influenced by the setts placement patterns.

Pawar *et al.* (2005) suggested that settling transplanted at 30, 60 and 90 cm inter settling spacing, settlings transplanted at 60 cm spacing was resulted in highest rise in cane yield (17.48 t ha^{-1}) than all other spacings. The similar trend also observed in sucrose content in cane juice and CCS per cent.

2.2.2.6. Effect of intra row spacing on Economics of sugarcane

Devaraj and Shanmugasundaram (1987) observed a maximum gross income as well as net income by planting 1,11,200 buds ha^{-1} as single budded setts at 15 cm intra-row spacing in paired rows with a net profit of Rs.14,505 ha^{-1} and the higher net return of Rs.1.04 per rupee invested. Besides, there was a saving of 25.9 per cent seed setts as compared to conventional planting of 15,000 buds ha^{-1}. Raskar and Bhoi (2003) reported that the higher value of B : C ratio (2.95) was recorded at 90 cm intra – row spacing with single bud settling planting method. Mahendran *et al.* (2005) observed, drip fertigation at with paired row planting system with spacing of 120 cm was highly profitable and the B:C ratio of 2.29.

From the foregoing review it could be seen that evaluation and introduction of suitable nursery production technique in order to increase quality and vigour of settling raised through pro tray medium was meager.

Chip bud technology has proved to be an alternate to reduce the mass and improve the quality of seed cane over conventional method. Since this method, though have multifaceted advantages also bear certain drawbacks e.g., poor survival in the main field and relatively low food reserves etc. This can be managed with suitable source of planting material combined with pre planting settling treatment practices.

The overall perusal of the literature documented with regard to optimization of plant population in sugarcane. Row to row and inter plant distance influence the productive tillers/millable cane population and individual cane weight in sugarcane production. Many investigations had reported the spacing effect on growth and yield attributes. In this juncture development of SSI method is an innovative agronomic method to enhance the cane productivity by adoption of wider row spacing practice. Limited work was carried out in India especially in Tamil Nadu with respect to wider row spacing wider row spacing method of planting have great potential to product higher cane yield and facilitate mechanized cane cultivation.

Considering the above aspects, the present investigation was taken up to study the effect on optimizing plant population with suitable nursery production technology to enhance the productivity of sugarcane and its’ ratoon under SSI method.