OPPORTUNITIES FOR IMPROVING SUGARCANE YIELDS IN HIGH INPUT FARMING SYSTEMS

by

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ABSTRACT

Long term economic viability of high input farming systems will increasingly rely on increased efficiencies and vertical productivity improvements incorporating the efficient use of sustainable resources. Three types of resource are considered in this paper; soil, climate and plant. Research from around the world has shown that soil resources are not utilised to the full because of a condition known as yield decline. A large research program, involving researchers from a range of institutions, is in progress in Australia investigating the nature of the condition and ways to overcome the constraints. Comparisons are being made between monocultured caneland and lands under crop rotation with land that has never grown sugarcane, as well as the decline in soil properties ensuing with the cultivation of non-caneland, to determine soil properties that may be restricting yield. The concept of high density planting of sugarcane is also being investigated as a means of exploiting plant and climatic resources to the full. Responses from this management technique have been excellent, optimising the use of available light and moisture. There remains considerable scope to lift productivity in high input farming systems; this will necessitate lateral thinking and altered farm management practices.

Keywords: high density, yield decline, productivity, resources, close rows

INTRODUCTION

Many high input farming systems have reached levels of productivity where the further addition of simple production inputs viz. fertiliser, is unlikely to enhance productivity. This is the situation with sugarcane production in countries such as Australia, South Africa, USA and Colombia. Production costs are increasing and it is essential that vertical expansion in productivity is achieved to ensure sustained economic viability. Further, it is essential that productivity improvement is not achieved at the expense of resource sustainability. Thus improving sugarcane yields in high input farming systems depends upon the balanced utilisation and full exploitation of three basic resources – the soil resource, the plant resource, and the climatic resource for long term productivity and sustainability. In the Australian sugar industry one other resource has an important influence on productivity, the mechanical resource, especially in terms of the impact of the size of machines and the mechanical harvesting system.

In this paper, options for greatly improving both productivity and profitability are explored using recent Australian research into the problem of declining soil productive capacity and the utilisation of high density plantings.

The climate resource

Key climatic factors in any production system are radiation, water, and temperature. The Australian sugar industry stretches over 2,500 km of the east coast from northern New South Wales to tropical northern Queensland and has recently developed in the north of Western Australia. The recognition of climatic diversity has led to numerous studies into the best production strategies for different environments. Armed with this knowledge it has been possible to improve productivity through a better matching of production strategies and environment. Further, improved irrigation technology viz. trickle irrigation has allowed the better utilisation
of limited water and reduced the risk of climatic vagaries. Climatic conditions are important in determining the most suitable production strategies.

To improve productivity, better use of available resources – either the more efficient use of the same resources, or a greater exploitation of the available resources are needed. Important resources are incident radiation, water, and nutrients. How can the production system be changed to better manage these resources?

The soil resource

World wide, sugarcane production is largely carried out as a monoculture. It has long been recognised in Australia that there are adverse effects on a soil’s productive capacity caused by long term monoculture (Maxwell, 1900, Bell, 1935, 1938). Until the late 1970s the industry had a 75% rotation with a fallow period of four to six months between ploughing out the last ratoon and establishing the new plant crop. Subsequently the industry has moved increasingly into an almost direct ploughout and replant system. It appears that in more recent times improvements in production technology may have been sufficient to permit productivity improvements despite a degrading soil resource. Since the early 1970s, productivity improvement in the Australian industry has not matched that achieved earlier in the century. The many and varied reasons for this decreased progress in productivity gains have been discussed by Garside et al. (1997 (b)). Among the proposed causes is a phenomenon known as yield decline….the loss of productive capacity of sugarcane growing soils under long term monoculture. For the soil resource to be better utilised, constraints posed by yield decline need to be overcome.

The plant resource

Productivity can only be enhanced through the plant’s capacity to integrate the combined soil and climatic resources and cope with the soil and climatic limitations of specific environments. The most common approach to plant adaptation is through genetic manipulation, plant breeding. However, as we will discuss, alternative production strategies such as high density plantings, also offer a means by which adaptation may be enhanced.

YIELD DECLINE

The problem of declining or plateauing productivity has vexed sugar industries world wide for many years (Magarey, 1996). In Australia declining productivity due to monoculture of sugarcane was identified at the commencement of the 20th century (Maxwell, 1900) and again in the 1930s (Bell, 1935,1938). Maxwell stated …… “poor and declining yields are due to soil related factors, particularly nutrient deficiencies associated with lack of fertilisation, and pests and diseases associated with too many ratoon crops”.The monoculture of sugarcane in Australia inevitably seems to lead to poor root health and sub-optimal yield (Magarey, 1996). The effects are seen in better growth on new versus old land (Anon., 1935; Garside and Nable, 1996), following soil fumigation (Bell, 1935; Egan et al., 1984; Muchow et al., 1994; Magarey and Croft, 1995) and after crop rotation with other species (Bieske, 1965; Chinloy and Hogg, 1968; Garside et al. 1997 (a), 1998; Bell et al. 1998).

The term “yield decline” is defined as the diminishing ability of caneland to produce sugar per harvested hectare (Magarey, 1994). This term is not new to sugar industries world wide, being the subject of intensive focus during the period 1940 – 1970. Similar growth constraints are evident in a range of other cropping industries (Magarey, 1996). Within the Australian sugar industry large productivity improvements could be achieved if the causes of yield decline were identified and controls put in place.

Current Program

The perceived importance of yield decline led to the establishment within the Australian sugar industry of the Sugar Yield Decline Joint Venture in 1993. This major research and development program involves a number of research providers and is employing a multi-disciplinary team focussed on considering the whole farming system and how it may be better managed to achieve a greater and more sustainable utilisation of soil resources.
The Joint Venture has three main objectives - identifying the factors leading to soil related growth constraints, understanding how they limit productivity, and developing solutions to overcome their impact. The work program is based on three components - comparisons between old and new land, breaking the monoculture with various rotation species, and studying what happens to new land when it is planted with, and continues to grow, sugarcane. Detailed measurements of soil chemical, physical and biological properties are being undertaken with the aim of identifying differences that occur between continual sugarcane monoculture and the different breaks, and how this impacts on root growth and soil resource utilisation.

Results

The results from paired sites indicate that old land is degraded relative to new land but the degraded soil properties are not consistent across sites. Old land is likely to produce lower yields (Garside and Nable, 1996); be more acid; have lower cation exchange capacity; have more exchangeable aluminium and manganese; have less copper and zinc; (Bramley et al., 1996); have changes in organic matter composition (Skjemstad et al., 1995); have less microbial biomass (Pankhurst et al., 1996; and Holt and Mayer 1998); have greater soil strength; have lower infiltration and water holding capacity (Ford and Bristow, 1945a,b),and have more root pathogens (Magarey et al., 1997); However, all factors are not important at all sites. There appear to be many complex interactions.

Similar results are emerging from the rotation experiments. Breaks with other crops, pastures and bare fallows for different periods of time (6, 12, 18 and 30 months) are resulting in substantial improvements in cane growth and changes, particularly, in soil biological properties. Eighteen month breaks of either crop, pasture or bare fallow have resulted in plant cane yield increases of 80% in plant cane yield. In other rotation experiments, a standard break of 6 month legume fallow has resulted in sugar yield increases of 1.5 t/ha or 15% (Garside et al. 1997 (a)) which is not due to the benefits of additional nitrogen.

Research is indicating that the final expression of yield decline due to the sugarcane monoculture arises from soil biological factors, for instance nematodes, Pachymetra root rot and other deleterious organisms. However, it is not known whether these biological factors are favoured by unbalanced soil chemical and physical properties such as soil acidity, soil compaction, or a loss of soil organic matter, or whether they are independent problems. Interactions between factors are most likely involved. Long term solutions are believed to lie with changed farming systems leading to sustained improvements in a range of key soil properties, such as soil organic matter and biology.

High density planting systems

Sugarcane farming systems in Australia have evolved with increasing mechanisation of the industry. Animal traction, hand planting and husbandry of crops in the early days of the industry was accompanied by relatively narrow (by modern day) row spacing. With the advent of tractors and later mechanical harvesting equipment, row spacing has progressively increased to accommodate the passage of larger and heavier farm machinery and is currently around 1.5 metres. However, BSES research has shown that in some instances crop yields begin to decline when row spacing exceeds 1.6m. This limitation to productivity has prompted an evaluation of high density planting systems (close rows, and dual rows) as a means of increasing productivity. The high density concept is not new, and is already a common practice in many other crops. The potential for higher densities to increase production in sugarcane has been raised previously by Hebert et al (1965); Thompson, G.D., and du Toit, J.C. (1965); Matherne, R.J. (1971); Kanwar, R.S., and Sharma, K.K. (1974) and Bull (1975), subsequently addressed in detail by Irvine and Bender (1980 a and b), Irvine et al (1980) and recently reviewed by Ridge and Hurney (1994), but has yet to be adopted commercially. In other countries, the issues of moisture availability x growth responses, varieties and practical considerations hindered commercial adoption of high density planting.

The increasing pressure on the sugar industry to improve productivity (i.e. increase production per unit cost of resource), has encouraged BSES to re-examine the prospects for high density planting in more detail. Bull and Bull (1996) reported results from several trials showing the potential for high density to increase cane and
sugar yields by over 50%. Consequently BSES has embarked on a much wider program to identify and overcome the most likely reasons why commercial adoption did not occur in the past.

Current Program

The current BSES program has adopted a three-phase approach to exploiting high density planting.

Phase 1: investigating the potential and economic viability for high density to increase yields in the absence of production

Phase 2: addressing the practical application of high planting densities under grower conditions

Phase 3: developing complete farming systems and compatible equipment for widespread adoption.

The program is based on a multi-disciplinary team approach to address research issues in agronomy, breeding and pest and disease control, develop suitable farming systems and design and construction of appropriate machinery and equipment.

Trials Trials and demonstrations have been established in six key regions of the Australian sugar industry to cover a range of environmental conditions and farm management practices in irrigated and rainfed production systems. The main row spacings considered are 1.5m (standard rows), 0.5m rows and dual rows 0.5m apart with 1.5m or 1.8m between centres. Trials have been planted using a purpose built multirow (4 rows at 0.5m) wholestick planter which delivered a basal dressing of fertiliser at a fixed rate per metre of row.

Results have confirmed the potential for high planting density to increase crop and sugar yields by up to 50%, as previously reported by Bull and Bull (1996). An average of results from all of the trials conducted to date, covering 120 genotypes, rainfed and irrigated conditions, at least six major soil types, plant and ratoon cane and high and low nitrogen regimes is presented in Figure 1. This figure shows a near linear response of millable stalk numbers and cane yield to the planting densities. On average, the increase in number of millable stalks and cane yield at high density is associated with only slight decreases in stalk weight (40%) and CCS (<3%).

The benefits of high density planting arise from a more efficient use of available radiation, water and nutrient resources, during the first 100 to 200 days of crop growth. Close rows are able to access levels of these resources that are normally wasted during the growth of crops in standard (1.5m) row spacings. Bull and Bull (1996) showed that the canopy of rows at 0.5m closed about 100 days earlier than 1.5m rows and intercepted about 50% more radiation over the first six to seven months of growth. This same relation follows for irrigation water and rainfall; the 1.5m rows with close rows showing similar percentage yield increases under both irrigated and rain-fed conditions (Table 2) and giving at least a 33% increase in water use efficiency over eight months (Table 1).

Higher densities also make more efficient use of available nitrogen over a range of levels of nitrogen supply (Table 3). The yield response of both standard and close rows to nitrogen was largely unaltered between 74 to 224 kgN/ha with the 0.5m rows maintaining a yield increase of 53% to 77% across the three fold range in nitrogen supply.

Genotype (the plant) is a critical factor key factor dictating the response to high density planting. Response patterns of different genotypes range from a near linear increase in yield with increasing density down to zero or even negative response. Further, some clones which were relatively low yielding at 1.5m spacing have shown yield increases of over 100% in 0.5m rows and significantly outyielded commercial varieties grown in 1.5m rows. In general the better responses to high density were been provided by lighter tillering clones or varieties with a uniform growth pattern. The responses of current commercial varieties to high density under different trial conditions are summarized in Table 4 which includes results from Q124, used as a standard variety at several locations.
All high density trial sites have been harvested each year with a conventional mechanical harvester which is not compatible with rows at 0.5m. Despite the stool damage incurred by harvesters and haulouts, the yield increments from high density have generally been sustained into first and second-ratoon crops, but probably at lower levels than could have been achieved with a purpose built multirow harvesting/haulout system.

**Plant breeding**

Sugar industries around the world continue to rely on plant breeding activities for improved commercial yields. Berding (pers. com.) estimate an annual improvement in yielding potential of 185 kg/ha/year in northern Queensland in new varieties. It appears that at times this is not realised because of production problems such as yield decline, or in northern Queensland, an interaction of phenotype with climatic conditions resulting in the deterioration of lodged crops, subsequent production of suckers and increased extraneous matter in the cane supply. There is a need for farmers to match crop management with the requirements of the varieties being grown, in such practices as nitrogen application and cultivation techniques (for instance the hilling-up of rows to improve harvesting efficiency). There may be a need to change crop ideotype (for example, shorter and thicker stalks) in order to improve the utilisation of genotypic potential in areas such as northern Queensland. Other traits requiring specific selection may include suitability for high density cropping – canes with high sugar content, fewer tillers and uniform growth pattern.

There is considerable scope in the future for more rapid genetic gain. The principal opportunities appear to lie with improved flower induction (Berding, 1995), (enabling planned recombination of parents as opposed to a fortuitous approach of crossing parents that happen to synchronously flower), and in introgression.

Photoperiod facilities will enable shy-flowering, superior clones to be crossed leading to much more rapid genetic gain. Large improvements in flower induction have been made in Queensland, opening up a range of crossing opportunities.

The current commercial germplasm incorporates genes from around 19 *Saccharum officinarum*, and seven *S. spontaneum* clones (Berding, pers. comm.); this is a rather narrow genetic base. Genes for improved CCS (sugar content), crop vigour, and pest and disease resistance undoubtedly reside in germplasm in the centres of origin of *Saccharum* sp. These will only be utilised if adequately resourced and well planned breeding programs are conducted over an extended period. Given that major improvements in yielding potential have been made with the genetic material available, there must remain considerable scope for genetic improvement in the better manipulation of *Saccharum* germplasm. The ability to incorporate genes from closely related species, e.g. *Erianthus* spp., will further increase opportunity for improved productivity.

**Biotechnology**

The genetic transformation of sugarcane offers both some short-term opportunities for improved productivity, and some longer-term hopes for break-throughs in yielding capability.

Short term opportunities lie principally in the insertion of specific resistance genes into varieties of superior yielding ability which would otherwise be discarded due to pest or disease susceptibility or the insertion of herbicide resistance. Research by BSES has led to the development of transformed sugarcane resistant to both cane-grubs (*Dermapelma albo-lintum*) and sugarcane mosaic. Glasshouse resistance screening has confirmed the successful conferring of resistance. Field testing is still required to assess resistance under natural pest pressures and to make further observation of soma-clonal variation.

Long-term opportunities are much broader and may include modification of the cane plant physiology or resistance to organisms responsible for cane deterioration. The manipulation of enzyme systems could lead to accumulation of higher levels of sucrose within the cane plant with a subsequent break-through in yielding potential. The alteration of enzymes influencing sugar quality would free crop management practices from limitations and enable maximisation of yielding potential. Similarly resistance to cane deterioration could result in full recovery of the crop yield.
DISCUSSION

Consideration of the factors involved in yield decline and the enormous benefits available from high density planting and plant breeding opportunities clearly indicates that there is considerable potential to lift the productivity of sugarcane in high input farming systems around the world. However it is vital to consider the whole farming system in the search for improved productivity. Productivity improvements will only be achieved through the balanced utilisation of climate, soil and plant resources. The challenge is to put commercially based high production systems in place that will cope with the range of factors involved.

Soil-borne constraints are difficult to work with due to the complexity of the interactions occurring in the soil environment. In many ways, soil-based constraints involving soil biological systems remain one of the last frontiers for research which has tended to concentrate on above-ground problems and systems because they are easier to manipulate on a single factor basis. However recent research has clearly identified the potential for improved productivity through the amelioration of factors leading to root constraints. Positive advances in the field include technological developments enabling the identification and enumeration (for example GC-Fame) of a range of soil organisms, and the greater awareness in the scientific community of the need for multidisciplinary research and a farming systems approach.

High density planting enables a more efficient utilisation of available light, water and nutrients to significantly improve yield. Commercial application of high density planting will require changed farming machinery and management techniques. This will require an industry wide re-think on equipment design, management systems and farmer support. Such a process is already in train and the opportunity is being seized to bring best farming management practices and more efficient equipment designs and operations into the proposed high density farming systems.

Continued progress in plant breeding will remain a cornerstone for improved yield in high input farming systems. It is especially in these systems, where farmers and industries supply high inputs, that new technologies (such as gene manipulation) are emerging to speed productivity improvement. Improved synchronised flowering regimes offer great potential to further improve the yield of commercial germplasm. It is becoming increasingly clear that farming practices need to be considered on a holistic basis; the interaction of genotype with high density planting systems illustrates this point, and improved breeding technologies coupled with directed programs may allow the greater exploitation of improved farm practices.

Horizontal expansion (increased land area) of sugar industries is becoming less of an option globally and vertical expansion should be a major goal of all high input sugarcane farming systems. Research into factors limiting productivity and the parallel development of commercially viable farming systems to overcome them must remain a priority activity in all sugar industries, not only those which involve high inputs.

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REFERENCES


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Figure 1. Response of stalk number, weight, yield and CCS to planting density. Results averaged over 19 trials involving 120 genotypes, high and low nitrogen regimes, irrigated and rainfed sites from northern New South Wales to north Queensland.
Table 1 Water use efficiencies at high planting densities (8 month old plant crop of Q124 grown on a nitosol).

<table>
<thead>
<tr>
<th>Row Spacing</th>
<th>Trickle Tapes</th>
<th>Litres per m of row</th>
<th>Irrigation MI/ha</th>
<th>Effective rainfall MI/ha</th>
<th>Tonnes Cane per ha</th>
<th>Tones Cane per MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5m</td>
<td>1/row</td>
<td>451</td>
<td>3.0</td>
<td>4.0</td>
<td>84</td>
<td>12.0</td>
</tr>
<tr>
<td>Dual rows</td>
<td>1/2rows</td>
<td>225</td>
<td>2.5</td>
<td>4.0</td>
<td>82</td>
<td>12.7</td>
</tr>
<tr>
<td>0.5m</td>
<td>1/2rows</td>
<td>225</td>
<td>4.5</td>
<td>4.0</td>
<td>145</td>
<td>16.9</td>
</tr>
</tbody>
</table>

Table 2 Effect of water supply on response to high density (variety Q124). Plant crop on a nitosol.

<table>
<thead>
<tr>
<th>Water Supply</th>
<th>Row Spacing</th>
<th>Stalk Number per ha</th>
<th>Weight per stalk (Kg)</th>
<th>Cane Yield (te/ha)</th>
<th>CCS</th>
<th>Sugar Yield (te/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>1.5m</td>
<td>89,861</td>
<td>1.500</td>
<td>133</td>
<td>14.91</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>Dual Rows</td>
<td>108,102</td>
<td>1.545</td>
<td>164</td>
<td>15.06</td>
<td>24.7</td>
</tr>
<tr>
<td></td>
<td>0.5m</td>
<td>150,000</td>
<td>1.429</td>
<td>211</td>
<td>15.11</td>
<td>31.8</td>
</tr>
<tr>
<td>Rainfed</td>
<td>1.5m</td>
<td>81,880</td>
<td>1.406</td>
<td>115</td>
<td>13.18</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>Dual Rows</td>
<td>92,750</td>
<td>1.540</td>
<td>142</td>
<td>13.47</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>0.5m</td>
<td>126,000</td>
<td>1.319</td>
<td>166</td>
<td>14.10</td>
<td>23.4</td>
</tr>
</tbody>
</table>

Table 3 Effect of nitrogen supply on response to high density (var. Q124). Plant crop on a nitosol.

<table>
<thead>
<tr>
<th>Nitrogen Supply (KgN/ha)</th>
<th>Cane Yield (te/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5m Rows</td>
</tr>
<tr>
<td>74</td>
<td>84</td>
</tr>
<tr>
<td>124</td>
<td>86</td>
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<td>174</td>
<td>88</td>
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