Nitrogen fixation in Sugarcane

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Saccharum is a genus from the grass family (Poaceae) that contains several species of tall perennial grasses, native to warm temperate to tropical regions in Asia, Oceania and South America and now cultivated extensively in tropical and warm-temperate regions between 35˚N and 35˚S. It contains the species (and associated hybrids – most plants grown commercially are complex hybrids) of great renown – *Saccharum officinale* – sugarcane. Sugarcane cultivation is responsible for 79% of global sugar production, and has also emerged as a leading source of bio-ethanol feedstocks. By production quantity [biomass], sugarcane is the largest single crop worldwide.

Saccharum also contains such species as *S. ravennae* – elephant grass, an invasive grass once planted ornamentally, and other hardier, wilder sugarcanes such as *S. robustum*, *S. barberi, S. sinense* and *S. spontaneum.* There is a close relationship with other grasses that grow similarly and are also used for biomass production such as *Miscanthus.*

Nitrogen fixation in sugarcane has likely been suspected for a long time, at least since the 1950s as observations have been made of sugarcane plantations in Brazil that have been continuously harvested for well over 100 years without the addition of nitrogen. Trials in the late 1950s found that nitrogen addition to sugarcane plantations in Brazil statistically had little or no improvement on growth rates in most cases (perhaps approximately up to 10% faster) – a strong indication of obligate nitrogen fixation. This would make sense, as sugarcane has been bred in Brazil for hundreds of years without nitrogen supplementation.

Early soil tests trying to identify the nitrogen-fixing source isolated a bacteria present in the rhizosphere, and a considerable amount of testing was performed to identify this bacterium. The results normally indicated these bacteria were fixing nitrogen, but not at the levels required to explain the rapid growth of Brazilian sugarcane.

A later joint Canadian-Cuban study was able to prove that a bacterium (*Acetobacter* – now named *Gluconacetobacter diazotrophicus)* was living inside intercellular spaces (an endophyte) – as likely being mostly responsible. This bacteria had previously been isolated from sugarcane and is able to fix large amounts of nitrogen when growing in a solution of sucrose. To confirm this bacteria was not present on the outside of the plant, the researchers carefully peeled and used ethanol on the tissue, and then lit it on fire (only way to be sure.). The intercellular spaces (apoplasm) of sugarcane and a number of other related grasses are filled with a ~10% sucrose solution, which is near to the optimal conditions for *Glucoacetobacter* growth. [1][2][4]

Later work has expanded the knowledge of known nitrogen fixation endophytic bacteria associated with sugarcane to become a more complicated grouping of multiple species:

Current knowledge of endophytic nitrogen fixing associated bacteria in sugarcane. Adapted from [6]
ASIDE – The C4 pathway

Why might it be more beneficial to grow sugarcane as a biomass plant, than say willow? All photosynthesizing plants utilize one of the three pathways of carbon fixation – C3, C4 and CAM. Broadly speaking C3 is the simplest and oldest evolved – but one of the crucial enzymes is not very specific at capturing carbon dioxide, and often wastes significant amounts of energy capturing oxygen molecules. C4 plants by contrast use a more complicated pathway that has a much better selection ratio for carbon dioxide. The price for this extra efficiency is that C4 plants are less effective than C3 plants at low temperatures and lower light levels. There is a crossover temperature, at which higher temperatures increase the efficiency of C4 fixation relative to C3 fixation, and this is approximately 23°C. The C4 pathway is also much more water-efficient and tolerant of higher light levels. As the global climate is warming, C4 carbon fixation will increasingly be a more suitable option for carbon sequestration in subtropical climates as they heat up and have more dry spells. In New Zealand, sugarcane has been grown by home gardeners (mostly in the North Island) for a number of years, although with climate change this suitable range is likely to creep down the country. There are varying reports of success, with some describing it as slow-growing (usually south of Auckland) and others as “growing like a weed”. It does not grow much higher than four metres in New Zealand, and so it’s likely the current genetics are not a particularly vigorous hybrid. [3]

Currently in Brazil, the nitrogen-fixing ability of commercial sugarcane varies from being not present up to 200 kg N/ha/y, but is mostly estimated at approximately at least 130 kg N/ha/y. This represents 60% – 80% of the annual need of the crops, and as mentioned previously – there are some sugarcane fields that have never had supplemental nitrogen fertilizer. Conversely, in the USA, 200-400 kg N/ha/y is applied, along with a heavy reliance on mechanization (this reduces the energy balance to almost 1 – i.e. almost no net energy gain). The productivity of sugarcane in tons per hectare varies globally from 31 to 89 – with Brazil having 69 – so it’s clear that sugarcane varieties that are able to fix nitrogen effectively are able to perform close to the maximum growth rate. Australian sugarcane plantations currently use about 160 kg N/ha/y.

A recent review summarized some results including a study that pointed to the possible parent of the hybrid Brazilian sugarcane responsible for the high rates of fixation: The analysis showed very large BNF-inputs to several sugarcane varieties, especially the wild non-commercial species Krakatau (S. spontaneum) used in plant breeding in Brazil, as well as the commercial varieties SP 70-1143 and CB 45-3 in low-fertility soils. This same study found that up to 60% of nitrogen (as measured by a 15N dilution technique) was fixed by sugarcane. Japanese sugarcane varieties were estimated to fix only 20% of their requirements.

It’s difficult to apply the rate of nitrogen fixation from Brazil to more temperate regions, because the length of the growing season, angle of the sun and ambient temperatures are all much higher closer to the equator than in temperate regions. The rate in temperate regions using improved nitrogen-fixing cultivars has never been measured or inferred. However, as will be discussed in later articles, we may not need anywhere near as much nitrogen addition as previously thought.

How does this knowledge change the usage of sugarcane in agroforestry systems?

Sugarcane is extremely useful as a biomass crop/carbon fixer – the large, extremely rapidly growing stems are great as a large supply of mulch or to build soil volume. If your climate is good enough, you may even be able to extract sugar from the canes first. Sugarcane is one of the most efficient carbon fixers known. Gardeners are usually wary of planting large areas of ‘hungry’ crops for the fear that they will scavenge nitrogen from the soil and reduce the growth of other nearby plants. By knowing that sugarcane is adding a significant amount of nitrogen to the soil we can use it as one of our nitrogen fixers, as well as being a potent carbon fixer.

It is worth noting that the commercial range of sugarcane is not the same as the useful growth range – sugarcane is likely to be able to be grown significantly further pole wards, but without a usable crop of sugar (but you were growing it for the biomass, right?). Unfortunately, the nitrogen fixing ability of 80-100% seems to be confirmed only in Brazilian hybrids for now. *Miscanthus* may prove to be a worthy alternative in the more poleward regions (first year growth was measured as fixing 15% of its nitrogen needs), especially if the local *Saccharum* available is not a strong nitrogen-fixer, as it can handle tougher conditions and doesn’t expend as much energy on creating sucrose.

The warming climate also increases the area where C4 photosynthetic plants are more efficient at carbon capture than C3 plants, thus sugarcane (and other C4 plants) will have an increasingly important role to play in carbon sequestration. Further research and trials to determine whether the relative benefits of a nitrogen-fixing C4 carbon-fixer outweigh those of a nitrogen-fixing C3 carbon-fixer in a forest gardening context, is needed.

Are you growing sugar cane at your place? Jon would love to know what varieties are being propagated in New Zealand. You can email him at west.coast.agroforestry@gmail.com. *Jon is a West Coast NZTCA member. www.agroforestry.co.nz*

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