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N_2-FIXING TREES FOR PROFITABLE FARM FORESTRY

SUMMARY

N_2-fixing casuarinas and acacias are indigenous components of the Australian flora, both families making significant contributions to the nitrogen economy of natural ecosystems. For the brigalow-belah dominated areas in northern Australia, their inputs of nitrogen allowed production of wheat using the high levels of NH_4^+-saturated clay for many years. However, despite the centres of origin for both families being in Australasia, their potential in Australian farm-forestry using rotations of less than five years has been little explored. Active applied research into the Casuarinaceae (*Allocasuarina, Casuarina, Gymnostoma, Ceuthostoma*) and its N_2-fixing microsymbiont *Frankia* is largely restricted to India, China and France. Farmers in India are pioneering profitable farming of casuarinas for paper manufacture in 3-year rotational cycles with rice. We propose major investment in a new rural scheme to promote the application of casuarinas on Australian farms and to develop local rural secondary industries with strong cash flow, responsive to market forces. Large scale carbon sequestration (up to 20 tonnes dm/ha/annum) can theoretically be achieved, reducing N-fertiliser use and expanding farmers' product and cash flow options, using vertically integrated production to maximise their value. These forest products include wood and fuel pellets, paper pulp, charcoal for hydrogen production, N-fertiliser and volatile chemicals, even including ammonia and hydrogen. One million ha of casuarinas could produce \$50 million of C-neutral N-fertiliser per annum as by-product, or adequate ammonia as stock for electricity generation or H_2 production using the N_2 fixation reaction for heat storage. This paper will examine the prospect for integrated uses of these under-utilised genetic resources, planning the required applied research in profitable fire-resistant landscape design and community economic development, also confirming feasibility in terms of underlying principles of energetics and action thermodynamics.

Keywords: *Casurinaceae, Acacias,* Frankia, nitrogen fixation, hydrogen, ammonia

INTRODUCTION

Casuarinas are fast-growing, N_2 -fixing species indigenous to Australia (Ganguli and Kennedy, 2013). This review proposes and examines the feasibility

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of a major innovative research program to make better use of this genetic resource. Firstly, short term (3-5 year) farm-forest rotations are identified as a significant gap in farming research; their increased use in these rotations offers prospects for large scale carbon sequestration (10- 20 tonnes dm/ha/annum) with reduced fertiliser-N use, while improving farmers' product options. Diversity in farm design is important; the more viable choices farmers have, the better they respond to changes in climate, commodity prices and market conditions defining profitability.

Secondly, farm-forestry is increasingly regarded as having potential for providing new options for local secondary industry, maximising value. These activities will be on a local scale and include wood products, paper pulp (Parthiban et al., 2012), charcoal for hydrogen production, N-fertiliser and volatile chemicals, potentially including ammonia and hydrogen gas. Thirdly, farm-forestry with frequent rotation minimising waste materials acting as fuel can be a timely response to national emergencies such as bushfire. Australia’s recurrent cycle of flood and excessive vegetation and fuel generation followed by devastating fires, promoted by drought conditions of extreme low humidity has now become a chronic condition. Invariably, there is a lack of preparedness for extreme conditions and huge insurance losses are suffered on an annual basis, quite apart from loss of human life and livestock. By contrast, intelligent and strategic landscape design using all the benefits of GPS mapping could provide a new kind of water and fire management, using all the technological resources available. This future would avoid high risk monoculture stands of forest trees encouraging both disease and fire.

Project outputs

Casuarinas species are chosen as highly water-efficient nitrogen-fixers and an under-exploited natural resource. A comprehensive research project would include the following objectives:

- A significant review of previous research outputs on casuarinas, with reassessment for farm-forest rotations. This should incorporate close examination of successful research elsewhere, particularly in India (Kumaravelu et al., 2012) and in China.
- Experimental field data on farm productivity of casuarinas for carbon and nitrogen fixation in cropland and rangeland landscapes.
- Data on the suitability of farm-forest rotations in areas with steeper terrain or on land potentially needing rehabilitation, such as highly acidified areas (Kennedy, 1992). Other species such as nitrogen-fixing acacias may also be suitable providing biodiversity.
- Data on the potential for farm-forest rotations with deeper roots to provide better water management, remediating acidification.

Managing water tables, often saline, can also be achieved by deep-rooted species - of casuarinas like *C. obesa* (Hollingworth, 2007). An eventual requirement will be implementation of new carbon sequestering technology on farms, but focus on the preliminary research is needed showing its feasibility. Full implementation will require a new participatory action phase where the technology will be adapted regionally and climatically. The program will also require the support of new government policy, allowing implementation of farm forestry on the large scale. Widespread extension of necessary tools to farming and rural communities will be essential, no doubt with new legislation. Major success in the technology will require social readjustments and reintegration on a large scale, involving more jobs in factories close to farm supplies to minimise transport costs. Only high value timber and other elite forest products can be transported economically to long distances. Power generation, itself a product of the new developments would be localised. A

position paper produced in stage 1 of the program will be a quantitative technical and economic assessment, analysing the potential for farm-forestry to enhance the productive capacity of farms normally growing other produce. The feasibility to establish an ethical supply of renewable energy able to completely replace coal will also be assessed (e.g. 7.5 million ha of casuarinas on favoured farmland, 25% of current Australian cropland, could produce 150 million tonnes of dry wood or pellets for electricity per annum, based on recent Indian data for ethical paper pulp and paper manufacture (Jain, 2010; Parthiban et al., 2012).

MATERIAL AND METHODS

Farm forestry

This activity will aim to establish a new farming practice and demonstrate benefits as well as expose the challenges. The outputs from the field trials and data analysis sought will include: (i) information on the nutrients most susceptible to depletion on any site; (ii) the age of greatest nutrient stress; (iii) the quantities of nutrients removed with harvesting strategies; (iv) the potential cost of nutrient replacement; (v) optimum planting density; (vi) best genetics for casuarinas (Suresh et al., 2012), needed for cloned production of highest productivity lines; (vii) optimal ages for harvesting for different purposes (viii) ability to rehabilitate acidified or salinised soil (ix) choice of species and lines to adapt to climate change.

Biological technologies – microbiology and forest genetics

At the University of Umea, a set of *Frankia* isolates have been maintained by Anita Sellstedt (Sellstedt, 1995), from a prior CSIRO collection of the 1980s. In collaborative research, these and other cultures now cultured at the University of Sydney will be characterised using molecular analysis of ribosomal DNA so that strain typing can be achieved. These techniques will then allow correlations between root-nodulating *Frankia* strains and casuarina productivity to be made, a necessary part of allowing the symbiosis to be optimised for effectiveness and to achieve maximal productivity. *Frankia* are difficult organisms to isolate from soil or nodules, partly because of their slow growth. Molecular techniques will allow identification of strains and also provide some measure or numbers, using real time PCR, collaborating with overseas experts in this area at the University of Umea (Anita Sellestedt) and in CIRAD in Montpellier, France (Claudine Franche).

Plant improvement by breeding and cloning

In India, large scale breeding of better clones of casuarinas selected for homogeneous and rapid growth has been achieved (Nicodemus et al., 2010; Kannan et al., 2012; Karthikeyan et al., 2013). This work will need to be repeated in Australia, with new selections to examine the range of diversity. In all this research, quantitative information will be sought, including the relative value of products such as timber, paper pulp, charcoal, biomass pellets, organic volatiles, N-fertilisers, ammonia, hydrogen and soil enrichment or depletion. The feasibility to establish an ethical supply of renewable energy able to complement the use of coal or even replace it eventually will be assessed. For example, 7.5 million ha of casuarinas on favoured farmlands could produce 150 million tonnes of dry wood or cogeneration pellets for electricity per annum, of the same order as the current consumption of coal in power stations.

RESULTS AND DISCUSSION

Secondary industry

Forest products are well recognised as supplying valuable feedstock for industry. In Western Australia some progress has been made in mallee farming in harvestable alleys (Sudmeyer et al. 2012), helping with ongoing landscape restoration. This followed a period of excessive land clearing for wheat cropping that seriously failed, leading to widespread salinisation in the southwest of Western Australia.

Ammonia as feedstock for H_2 generation

The root nodules of N_2–fixing casuarinas are clearly a major source of ammonia, normally used for plant growth. H_2 is often proposed as a clean fuel that would overcome many environmental problems related to pollution. But its main sources such as steam and gas are considered to be too expensive. Electrolysis of water to $2H_2$ and O_2 uses large quantities of electricity and has only been used where cheap hydroelectric sources are available. However, ammonia itself can also be used as a viable fuel to directly power motor vehicles. Less known is the fact that the Haber reaction normally used to prepare N-fertilisers can be reversed to produce hydrogen gas, consuming a considerable amount of heat (see Figure 1).

$$3H_2 + N_2 \Leftrightarrow 2NH_3 + 66.8 \text{ kJ (at 20 MPa, 293 K)}$$

This reaction, usually catalysed using Fe-based catalysts and other metals and high pressures, is unusual in that it is poised and able to be conducted in either direction, depending on the conditions of reaction. As an exothermic reaction as written, it releases heat raising the entropy of its environment. Technology to allow solar energy to be stored in a system operating in sunlight and then to be reversed at night has already been well developed at a pilot scale (Lovegrove et al., 2004) and is awaiting investment. This approach would be very appropriate for decentralised power generation, using portable factory units able to be installed from pre-fabricated units.

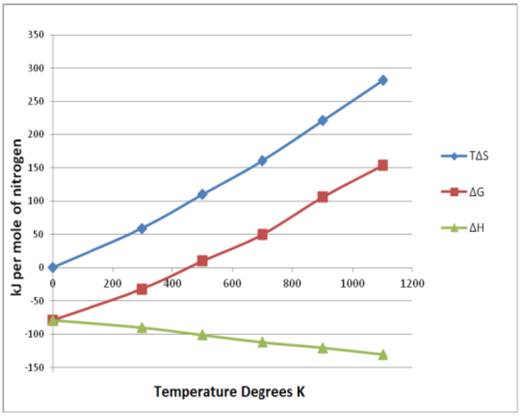

Figure 1: Thermodynamics of the nitrogen fixation reaction $3H_2 + N_2 \Leftrightarrow 2NH_3$ under standard conditions of 1 atmosphere pressure of reactants and product at temperatures shown. K_p is equal to 1.0 at 450 K (ΔG=0), where ΔH is equal to -$T\Delta S$ and ΔG is equal to zero.

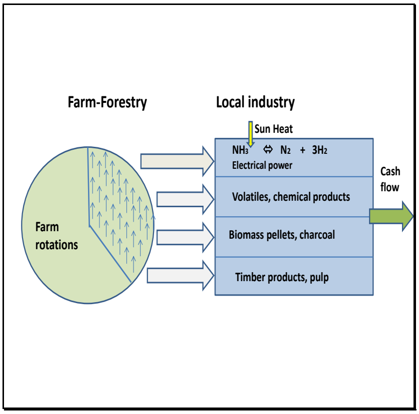

Figure 2: Integrated farm forestry-local industry would be based on an action-entropy model sustained by optimised support resources (Rose et al. 2008) allowing diversification and decentralised populations.

In principle, casuarinas could offer a relatively inexpensive source of ammonia from their foliage, harvested on a continuous basis if farms operate on a 3-4 year rotation cycle. It is not unreasonable to assume that 100 kg of ammonia could easily be harvested per ha on an annual cycle without loss of the forest resource or even more using rotations 1000 ha would yield a minimum of 100 tonnes of ammonia of value $50,000 at $US50 per ha. While there is a prospect for making H_2 which is a highly desired clean fuel, ammonia itself is an excellent fuel, releasing 317 kJ per mol of ammonia burnt (ΔH = -317 kJ/mol).

$$NH_3 + 0.75O_2 \Rightarrow 0.5N_2 + 1.5H_2O + 317\ kJ$$

By comparison, the reaction of H_2 with oxygen releases 285 kJ per mole of H_2 burnt (ΔH = -285 kJ/mol). The specific energy cost in 2004 was $US13.3 per GJ (Lovegrove et al., 2004). Thus, one tonne of ammonia would yield 19.2 GJ of energy, worth $US255, or $US25.5 yield per ha as electricity.

Hence, ammonia from farm-forests has the potential to be used in small scale electricity stations, forming H_2 by day while generating solar power and releasing heat by night allowing continuing power generation from steam (Lovegrove et al., 2004). Such flexibility can be contrasted with the very large economic inertia when chemical products are manufactured in super-large installations by the Haber process or power is generated in facilities able to supply whole states with millions of consumers..

CONCLUSIONS

Project outputs

Ultimately, the outputs of this project would be the basis for new rural industries, on the scale of millions of hectares of products, able to satisfy a significant portion of our needs for fuel (high density casuarina matches coal in calorific content, burning to a pure white ash), paper pulp, chemical products and nitrogen fertiliser. Such production, responsibly integrated for genetic diversity, site specificity and productivity, and product selection governed by current commodity markets, would be certifiable to high standards of environmental stewardship. The project would need to strongly adhere to the ethical guidelines of the Montreal Process (see www.montrealprocess/).

A new rural vision based on partnerships

This research and development project will quantify the feasibility of new technologies related to achieving carbon- effective farming using indigenous nitrogen-fixing casuarina species for short-term agroforestry on a 3-5-year production cycle. It will generate detailed information on the potential for soil carbon sequestration from foliage-fall and nitrogen-addition to fertility of the soil in farming-forestry in a range of habitats, using versatile species of casuarina that are collectively capable of growing in a range of habitats and adverse climatic conditions, often too harsh for most other plants. The potential agro-industrial impact of using these trees as an intercrop forestry system in farming landscapes, for land rehabilitation but with particular emphasis on generating cash products such as charcoal, volatile chemical by-products and nitrogen fertilisers will be investigated.

An integrated program (see Figure 2) must be linked to completed research in industrial chemistry such as for the N2 fixation reaction as a source of electrical power using its heat-storing properties. The data thus obtained could be utilized to generate more sustainable plantations of casuarinas, for increasing soil carbon and fertility in a given habitat in the context of local industries as by-products, similar to those being sought in mallee farming. It will target the greening of vast marginal lands of Australia by significantly increasing the population of N2-fixing native casuarina trees. It will aim to reverse the trend of depopulation of the countryside and even to substantially reverse it, making rural communities much more attractive places to live. The overall result would be a more resilient agriculture, united in a diversity of production and rewarding activities

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