Assessing the availability of crop stubble as a potential biofuel resource

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Abstract

In many crops over half the above-ground biomass is not currently harvested and could be used as a feedstock for biofuel production. There is little published information about stubble production, and the implications of harvesting it. We use a survey of field trials reporting Harvest Index (HI), ABS production statistics and APSIM simulations to assess how much biomass might be available in different regions and what factors might affect stubble production. Although HI does vary between years and regions, it does appear that robust spatial estimates of stubble production can be obtained from grain production data and HI. In many farming systems some stubble will be left to maintain soil cover, input to soil carbon or animal feed. The amount of stubble potentially available for harvesting is considerably less than the total stubble production, and the amount likely to be worth harvesting on a regional basis will be even smaller.

Keywords

Harvest index, climate variability

Introduction

Crop stubble has been suggested as source of lignocellulosic material for bioenergy production (O'Connell et al 2007). Efficient conversion of crop stubble to biofuel may have the potential to significantly help buffer the grains industry from increased fuel costs, fuel security issues and the impacts of policies to reduce carbon emissions. However, there are currently very poor data on availability of stubble in Australia and how this may vary with climate and with management. Lack of extensive data on stubble production and the factors affecting it mean that stubble production has to be estimated. The most common method of estimating stubble production is from grain yield data and knowledge about the ratio of grain to total above-ground biomass (harvest index, HI) (e.g. Higgins 2006). While yield data are widely available, HI data are less available and little is known about how HI varies spatially, between years and with management. In this paper we investigate variation in wheat HI using a database of crop yield and HI and simulations from APSIM to determine whether or not HI should be varied spatially or temporally when estimating stubble availability for bioenergy production.

Harvest Index

In Australia, climate is seen as the major determinant of HI for most crops for a given site x year x genotype (Turner *et al.* 1999). In particular, the balance between pre- and post-anthesis water stress (Passioura 1977), frost and cold temperatures at flowering (Clarke and Siddique 2004; Williams and Angus 1994), or high temperatures during flowering or seed development (Aksouh *et al.* 2001) can contribute to variation in crop HI. Delayed sowing (shortening the vegetative phase relative to grain filling) also affects HI (e.g. Batten and Khan 1987). High rates of nitrogen fertiliser have also been shown to reduce HI in wheat due to greater deposition of structural carbon and poor remobilisation of carbon to grain (van Herwaarden *et al.* 1998).

Crop Yield and Harvest Index Database (CYHIDB)

A database of crop yield and harvest index (Unkovich *et al.* 2006a) was recently compiled as part of a review of crop biomass production in Australia for the National Carbon Accounting System. The dataset is restricted to crops grown ≥1980 from more than 300 data sources, and includes >20,000 measures of crop yield, stubble production and/or HI for a range of crops. The data are not a representative sample of grain crops across Australia from a strategically formulated sampling, but a sample of (primarily) research data from experiments which are not distributed equally in space or time.

APSIM

The Agricultural Production Systems sIMulator (APSIM) model (Keating *et al.* 2003) was used to simulate wheat production for one site in each of the five main wheat growing States for the period 1940 to 2007 (Table 1). At each site simulations were conducted for two soils typical of the area with contrasting water holding capacity. Crop growth was simulated for a no-till system with four nitrogen fertiliser application rates: 0, 50, 100, and 150 kgN/ha. This range is more extreme than would typically be applied, but it is useful for investigating the impact on HI of nutrient stress and nitrogen application. In each simulation, it was assumed there was minimum carry-over of soil water and nitrogen after harvest. An amount of crop residue was retained: 15% of the calculated stubble (to account for non-harvestable biomass) plus a retained amount of standing stubble equal to 1 t/ha in southern cropping sites and 1.5 t/ha for the Qld and northern NSW sites.

Table 1. Parameters used for APSIM simulations for each site.

			Sites		
State	Queensland	NSW	Victoria	South Australia	Western Australia
Site	Goondiwindi	Forbes	Berriwillock	Roseworthy	Kellerberrin
Planting window	1may - 15 Jul	15Apr - 15 Jun	15Apr - 15 Jun	20Apr - 30 Jun	20Apr - 30 Jun
Cultivar	Janz	Dollarbird	Yitpi	Yitpi	Wyalkatchem
Population (pl/m2)	100	100	120	120	140
Soil PAWC (mm)	196 and 103	184 and 130	122 and 75	129 and 89	117 and 61
Min. residue (kg)	1500	1500	1000	1000	1000

Variation in crop harvest index

Analysis of the CYHIDB indicates that of the main grain crops, reported mean HI values varied between 27% for canola and 46% for sorghum. Average HI for wheat was 36% with a coefficient of variation of 19% across 194 sites x year combinations. Simulated wheat HI also showed considerable variation across 6,248 combinations of regions, soils, nitrogen fertiliser rates and years (Figure 1).

Table 2. Summary of HI data for wheat by State, CYHIDB (Unkovich et al 2006b).

	NSW	QLD	SA	VIC	WA
Mean	0.36	0.38	0.35	0.36	0.35
s.d.	0.07	0.06	0.08	0.08	0.07
n	80	11	27	31	54

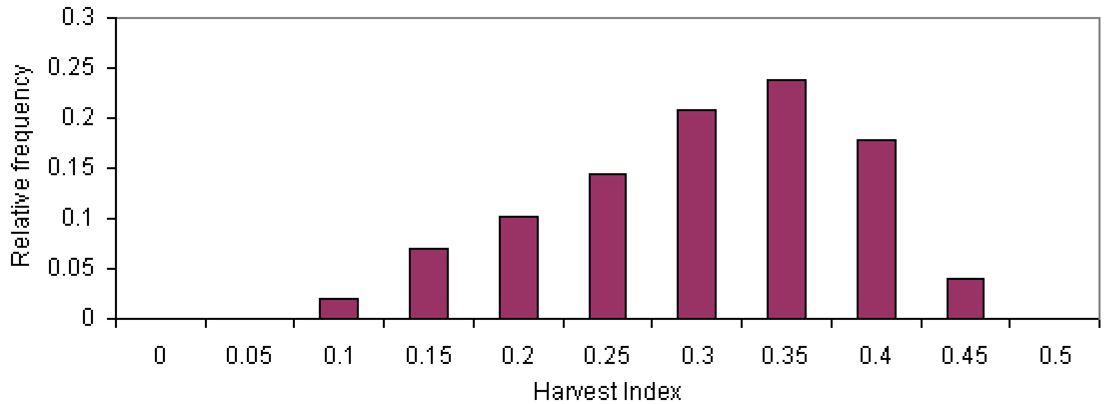

Figure 1. The frequency distribution of wheat HI from 6,248 different APSIM simulations across Australia.

Regional variation

Minimal systematic variation in HI was evident between States in the CYHIDB (Table 2) and in the APSIM simulations (Figure 2). There were also no clear differences in HI between regions with winter-dominant, equiseasonal or summer-dominant rainfall.

Management variation

Higher nitrogen application rates tended to increase simulated HI (Figure 2), and there was no evidence of an interaction between soil water holding capacity and nitrogen application rates. Variability in HI was also higher under low nitrogen application rates, especially in the sites in NSW and SA.

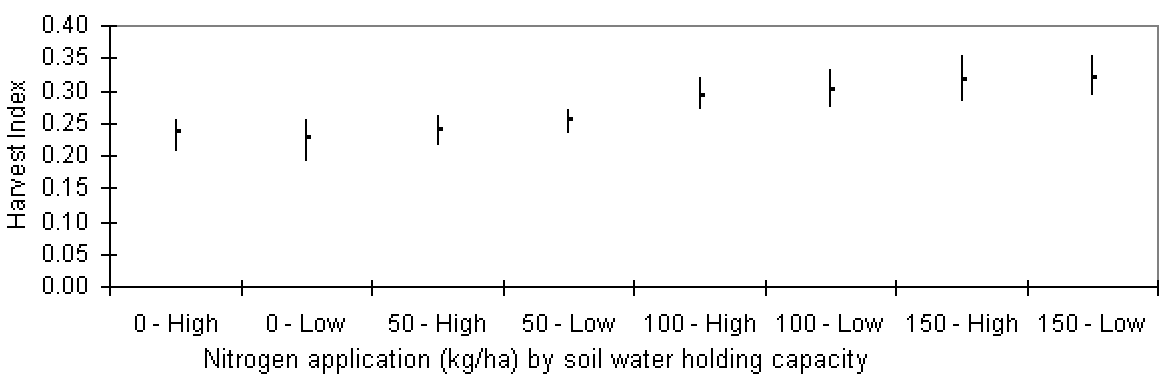

Figure 2. Simulated wheat HI comparing four N application rates (kg/ha) and soils with high and low water holding capacity, 5 sites grouped; mean and 20-80 percentile, 1940-2007.

However, simulated HI was affected by an interaction between rainfall and nitrogen at some sites. For example, in the Victorian site high rainfall years had lower simulated HI for nitrogen rates of 50 and 100 kg/ha as higher rainfall led to good biomass production but insufficient nitrogen led to relatively poor grain development (Figure 3). However, with 150 kg/ha of nitrogen there was no decrease in HI in wetter years as there was sufficient nitrogen for full grain development. This interaction between nitrogen and rainfall was less strong for NSW and SA sites, and almost absent for WA and Qld sites.

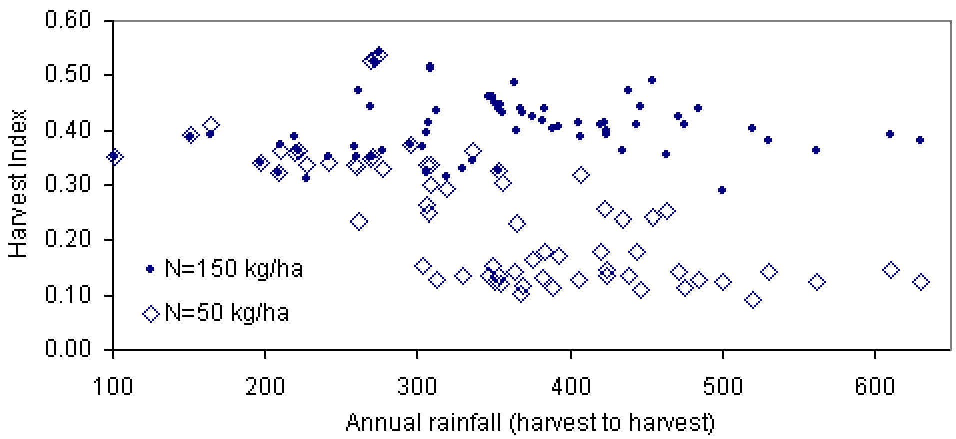

Figure 3. Simulated wheat HI compared to total annual rainfall (harvest to harvest) from a site in Victoria, with contrasting nitrogen application rates, high water holding capacity soil, 1940-2007.

Climate variability

Simulated HI varied considerably from year to year. The coefficient of variation for HI ranged from 13-23% for 150 kg-N/ha, to 20-42% for 0 kg-N/ha (for high water holding capacity soils). This was largely due to HI being reduced in high rainfall years when nitrogen was not sufficient, and to a lesser extent due to increased variability across the whole rainfall spectrum at very low nitrogen rates. In general, rainfall affected crop yield much more than HI (yield coefficient of variation was 35-47% for 150 kg-N/ha and 44-84% for 0 kg-N/ha), therefore it is highly likely variation in crop yield will have a much greater impact on calculated stubble production than variation in HI.

Stubble harvesting

Not all of the non-grain above-ground biomass of a crop will be available for collection for biomass energy production in a typical grain cropping situation. Cereal stubble consists of “chaff” (the material in the head that is separated from the grain at harvest), leaf matter and straw. Wheat stems (straw) are preferred over leaves and chaff for bioenergy production (Hess et al. 2002), and chaff, leaf and stems cut in grain harvesting are unlikely to be collected. Most farmers will also retain some straw to provide soil cover to prevent wind and water erosion and to help maintain soil carbon and recycle nutrients. The amount of straw retained will vary depending on soil type, topography and rainfall conditions. In the southern areas protection from wind erosion over the summer fallow is a priority and about 1 t/ha of stubble may be left. Where protection from high intensity rainfall is a high priority larger amounts of straw are likely to be retained. Removal of significant amounts of biomass is likely to lead to depletion of organic carbon in the soil. Loose chaff and leaf and stubble retained for soil protection will help maintain soil carbon. However, little is known about how much stubble needs to be retained to maintain soil carbon in the long-term.

Estimates of stubble availability

Estimates of grain-crop stubble availability were made for each Statistical Division (SD) using HI values for nine key grain crops (wheat, barley, canola, lupins, oats, sorghum, triticale, field peas and chick peas) from the CYHIDB and ABS crop production data for the period 1982/83 to 2004/05. Production for 2000/01 is quoted as a typical year. We provide estimates of total gross stubble production and estimates of the amount "potentially available for harvest" assuming 20% of the non-grain biomass is not harvestable and that 1 t/ha of straw will be retained in the western and southern zones for soil protection and 1.5 t/ha will be retained in the northern zone. Approximately 65 Mt of stubble in total were estimated to be produced from the major grain crops in Australia in 2001; the average production over the years 1983-2005 was 51 Mt (Figure 4). However, only about 45% of the total or 29 Mt was potentially available for harvest in 2001, with an average of 22 Mt over the years 1983-2005.

Variation in time

Estimated total stubble production during the 1983-2005 period trended upward from about 40 Mt (1986-92) to about 70 Mt (2000-2006), with a few "better than average" years and several drought years when stubble production was about 50% lower (Figure 4). Stubble potentially available for harvest was affected by drought (low yield) years proportionally more than total stubble production (or grain production), due to retaining a *fixed amount* of stubble.

The actual amount of stubble likely to be harvested for bioenergy would be considerably less than these figures. Production varies considerably regionally, and in many regions stubble will be too distributed to be worth collecting. It is also likely that the scale of any regional stubble-based bioenergy industry would be limited in order to accommodate reduced availability in frequent low production years; hence there would be limited demand for much of the available stubble in good and average years.

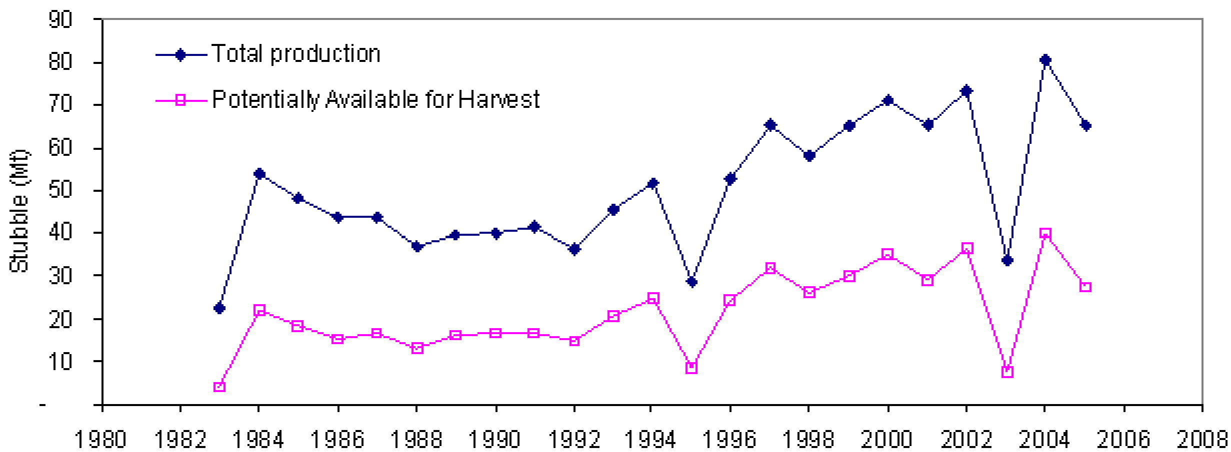

Figure 4 – Estimated national stubble: total production and potentially available for harvest from major grain crops, 1983-1997 and 2001.

Conclusion

Analysis of available grain crop HI data and simulations of wheat HI shows that little systematic variation in HI is apparent between regions, soils or rainfall, especially when nitrogen application is well matched to water availability to maximise grain yield. The greatest source of variation in estimates of stubble production is variation between years in grain yield (rainfall) and area planted (rather than HI). Therefore, for each crop, a single national HI value for all years and regions was used for estimating stubble production from grain yield data. In 2001 65 Mt of stubble was produced, but only 29 Mt were potentially available for harvest after harvestability and sustainability considerations. Stubble potentially available for harvest may be reduced by 70% or more in poor years.

Acknowledgments

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