Multiple and cover cropping in Brazil

Status and opportunities for biofuel production

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Summary

Since the 1970s, two distinctive practices have increasingly become characteristic of Brazilian agriculture. First, the 'sistema de plantio direto' (SPD), a form of conservation agriculture that involves no-till planting and the maintenance of year-round soil cover has achieved an increasingly wide penetration as a way to reduce soil erosion and more generally manage soil quality. Second, the practice of double cropping involving has become increasingly widespread, allowing two food harvests to be delivered on the same piece of land in a single year. The dominant form of double cropping, operated on about 13 million hectares of land, is a soy crop followed by a 'safrinha' corn crop. This safrinha corn model has been so successful that the safrinha harvest is now larger than Brazil's first-crop corn harvest. Smaller areas in Brazil also practice soy-cotton double cropping and second crop beans. About 40% of Brazil's soy area is now followed by a safrinha corn crop, and about 30% of Brazil's cropland is subject to some form of double cropping.

The development of the safrinha corn model has been achieved in parallel with significant increases in the yields of both the soy and corn crops. It is not easily possible to determine the net impact of safrinha corn production on soy yields – the need to manage two crops in a year places limitations on farmers and may result in some soy yield reductions and increased post-harvest losses when farmers compromise to balance the two crops, but on the other hand planting corn after soy offers some agronomic advantages. While firmly establishing the overall impact would be analytically challenging, we can say that soy yields in states where there is a high penetration of safrinha corn have not fallen behind soy yields in other states, which suggests that at worst the yield drag is modest. The yields of the safrinha corn itself have improved considerably over the decades, with typical yields now around 5 t/ha, comparable to first crop corn yields around 6.5 t/ha.

Whether or not a safrinha corn crop is grown, the SPD requires that a cover crop should be planted after harvest of the main crop(s) for the year. The SPD has reportedly been applied to about three quarters of Brazilian crop area, which implies that at least three quarters of Brazilian farms use cover crops. Cover crops protect the soil, cycle nutrients and support the development of organic matter content. Cover crops are established after main crop harvest and are then left to grow until just before the next crop is ready to be planted – this generally means after the dry season/winter (although the agricultural cycle varies across Brazil). A range of cover crops is in use by Brazilian farmers, with crop choice determined by local conditions. In warm parts of tropical Brazil biomass production may be prioritised to ensure that after crop desiccation the residues will not disintegrate too quickly and leave the soil unprotected. In other circumstances, cover crops may be chosen for nitrogen fixing potential, for their role in pest control or for their potential forage production to support the livestock industry.

While some cover crops could in principle produce a food harvest, it is generally not economically beneficial for farmers to harvest grains/seeds/etc. from winter cover crops, and therefore cover crops are not currently a potential source of feedstock for first generation biofuel production. It may however be possible to develop 'productive cover crops', which could equally be considered as alternative safrinha crops. There may be cases in which an oilseed crop such as sunflower or brassica carinata could deliver a return for farmers when a safrinha corn crop would not be viable, thereby providing oil that could be used for biodiesel feedstock along with co-products meals for livestock feed use.

In Europe, the recast Renewable Energy Directive (RED II) has created a potential market for ‘intermediate crops’ on the basis that their use for biofuel feedstock may have less impact on land use and food markets than the use of main crops. There is a lack of clarity about precisely what will be counted as an intermediate crop, but based on the language of the Directive safrinha corn would seem to be excluded from the category. However the Member States decide to interpret these requirements, we can say with confidence that as safrinha corn is an established part of the world grain market, its use as biofuel feedstock would be expected to have much the same type of market impacts as using first crop Brazilian corn would. If instead the EU is able to support the development of novel second cropping/ productive cover cropping models, this could make a genuine contribution to minimising land use impacts from the biofuel industry.

Contents

1. Introduction

Agricultural productivity is dependent on soil, but soils can be damaged by agricultural use. The development of agriculture in Brazil has been associated with severe soil erosion, and as agricultural land use expanded so the problem of erosion increased – Hernani et al. (2002) estimated an annual loss from Brazilian cropland of 750 million tonnes a year. Large agricultural areas in Brazil are particularly vulnerable to soil erosion due to high rainfall – especially at the start of the planting season (de Freitas & Landers, 2014). Erosion reduces soil fertility and increases costs to farmers as additional fertilizer application is required to replace lost nutrients, and in extremis can lead to land abandonment or even desertification. Traditional approaches to reduce soil erosion such as reducing land slope by terracing have proved inadequate to manage the problem at scale (de Freitas & Landers, 2014).

Recognizing the limits of erosion control through trying to manage the flow of water, Brazilian farmers have increasingly focused on the maintenance of year-round soil cover protect soil. Erosion is much less of a problem once a crop is established than while it is being planted, because the roots of the plants help hold soil together, and the leaves protect the soil from the impact of rainfall. By maintaining soil cover during periods of the year when a main productive crop is not being grown, erosion can be dramatically reduced. Continuous soil cover is one of a package of measures associated with conservation agriculture (Denardin et al., 2012). There are two basic ways to provide soil cover. Firstly, by leaving crop residues in place after harvesting a crop. Secondly, by establishing additional crops during other periods of the year.

There are costs associated with planting these additional crops. The best outcome for farmers is that additional crops can be grown that not only provide cover but that can be harvested to generate additional revenue. Multiple cropping, in which several cash crops can be harvested from a single land area during a single year, can boost farmer incomes and help reduce demand for additional agricultural land. When a second crop can be grown for harvest in a single year this is referred to as 'double cropping' or sequential cropping[1]. The ability to adopt multiple cropping systems is generally dependent on local weather conditions. Brazil spans a vast area and there are significant climatic differences between the north and south, coast and interior; still, there are large areas of Brazil where mild winters make such double cropping or even triple cropping agro-economically viable.

Even if an additional crop cannot be profitably harvested, it can still provide value to farmers. A crop that is grown primarily for its role in protecting and enhancing soil quality rather than for harvest is referred to as a "cover crop". As well as protecting the soil from water and wind erosion, cover crops can play a role in pest management, reducing soil compaction and improving nutrient cycling. Cover crops fitting this description may be harvested for animal forage but are not used to produce food commodities such as grains or oilseeds, even in cases where the cover crop is capable of producing a food harvest in the correct conditions. In the EU's current Renewable Energy Directive (RED II), cover crops are defined as "temporary, short-term sown pastures comprising grass-legume mixture with a low starch content to obtain fodder for livestock and improve soil fertility for obtaining higher yields of arable main crops".

1 A variation of double cropping referred to as relay intercropping involves planting a second crop before a first crop has been harvested.

The variety of possible agricultural systems can make it difficult to adopt a definitive terminology for referring to the various crops that can be grown during a year. In this report, the following terms are used:

- Cash crop: a crop grown with a view to harvesting and selling the produce (e.g. the grains, oilseeds, fruits, vegetables);
- Cover crop: a crop grown primarily for the purpose of maintaining or enhancing the productivity of the land, often present in the field over the less productive part of the year (this is generally the winter, but in tropical locations may be associated with a dry season in a different part of the year). The biomass in cover crops is not harvested for sale unless for use as animal forage in the local area;
- First crop: the first cash crop harvested in the agricultural year[2] (i.e. harvested after the winter), generally in the summer or autumn;
- Second crop: a cash crop planted and harvested later in the agricultural year than the first crop. In some cases a second crop could have greater value to the farmer than the first crop;
- Third crop: a cash crop planted and harvested later in the agricultural year than the second crop;
- Safrinha crop: a Brazilian term meaning "off-season crop" referring specifically to a second crop planted in the summer directly after harvest of the first crop and harvested in the late autumn or early winter, and which has a lower associated value to the farmer than the first crop. Safrinha corn is harvested for food and feed (and potentially biofuel) markets and therefore does not meet the definition of a cover crop given above;
- Single cropping: an agricultural rotation that includes only a first cash crop, but may also include one or more cover crops;
- Double cropping: an agricultural rotation that includes a first and second crop, and may also include one or more cover crops;
- Triple cropping: an agricultural rotation that includes a first, second and third crop, and may also include one or more cover crops.

The potential for multiple cropping is of particular interest from the perspective of biofuel feedstock production, as it is seen as a way of reducing net land demand for and therefore reducing indirect land use change emissions (IEA Bioenergy, 2015). Increased harvest could be delivered by adding a cash crop where either no crop or an unharvested cover crop was previously grown. Increased harvest could also be delivered by improving the yield performance of an existing cover crop to make it economically viable to harvest it as a cash crop. Biofuels from a second crop or cover crop have therefore been considered as possible examples of 'low ILUC-risk' feedstocks (e.g. UPM, 2018). It must be noted that biofuel production from cover crops provides a definitional challenge, because most definitions of cover cropping (including that in the Renewable Energy Directive) state that cover crops

2 In the northern hemisphere the agricultural year matches the calendar year, but in the southern hemisphere if is counted from July to June.

are not harvested except for forage. In this report, when we discuss the potential to produce biofuel feedstock from a 'productive cover crop' we are referring to potential opportunities to deliver an additional harvest of grain or oilseeds from a crop planted in a period during which a cash crop would not currently normally be considered viable.

It should be noted that because Brazil is such a large country, and because the equator passes through northern Brazil, there are important differences in climate between regions. In this report we are primarily focused on the centre-east and south-east regions, both in the southern hemisphere, that account for the bulk of Brazil's soy production. Unless otherwise indicated, when we talk about winter we mean the period from June to August which corresponds to the dry season in these regions. States in the north and northeast of Brazil in particular may have quite different agricultural calendars so that first crop harvest (and therefore also any second crop harvest) can occur at different times of year than in the more southerly regions. It should also be recognised that there is a division in agricultural practice in Brazil between the agribusiness model of production, characterised by monocultures, and the peasant/family model of production which tends to involve polyculture (Conab, 2010). Here we focus on the agribusiness model as more relevant to potential biofuel feedstock production.

This report provides a review of the status of multiple and double cropping in Brazil, and discusses the potential of those crops to contribute biofuel feedstock and whether such feedstock could potentially be considered low ILUC-risk.

2. Double cropping

One distinctive feature of the cropping system in much of Brazil is the widespread implementation of double cropping – the harvesting of a second 'safrinha' crop in the late summer/autumn after the first summer crop has been harvested (Waha et al., 2020). Growing a safrinha crop is dependent on the relatively high temperatures that persist through all of the year in northern Brazil and most of the year in southern Brazil, and on the availability of water. Whereas double- or multi-cropping systems in some parts of the world are dependent on the availability of irrigation, the Brazilian safrinha crop is largely rainfed. The planting and harvesting of the two main crops are therefore dependent on the duration of the rainy season (Giachini et al., 2018; Moura & Goldsmith, 2020). Safrinha cropping is most common in locations where the rainy season is longer and more predictable (Arvor et al., 2014). The dominant double cropping system is soy as first crop and corn as safrinha crop. It has also been suggested that it would be possible to grow sunflower, cotton, sorghum, peanuts (Silva, 2012) or safflower (Guidorizzi et al., 2021) as safrinha crops.

It is generally not possible to grow a third comparably productive crop over the winter. In central Brazil the winter months (June to July) are warm but dry, for example average winter temperatures in Rondonopolis in the key agricultural state of Mato Grosso are around 25°C but there is only about 10 mm of rain per month, less than a twentieth of the peak of the rainy season[3]. In the south of Brazil, the rainfall is more evenly distributed through the year, but in the sub-tropical zone winter temperatures are lower, including occasional frosts (Soybean And Corn Advisor, 2021).

It is common to refer to three corn harvests in Brazil. The first harvest is primarily associated with first-crop corn produced in regions where the growing season starts in August/September after a relatively dry southern hemisphere winter. The second harvest is primarily associated with second crop safrinha corn in those same regions. The third harvest, however, is associated with corn grown as either a first or second crop in the north-eastern part of the country where the dry season may occur at a different time of year (for example running from June to December in parts of Ceará and in November/December in Sergipe). Unless otherwise indicated the discussion in this section is most applicable to the south, southeast and centre-east regions.

To achieve full-year ground coverage, the safrinha crop will often be followed by a winter cover crop. These winter cover crops will generally not be harvested, though there are parts of Brazil in which a third crop of dry beans can be harvested after soy and safrinha corn. In cases where the weather is not favourable for a successful safrinha second crop (e.g. delays to the first crop harvest) a cover crop such as millet or sorghum may be planted immediately after the first crop and left in place through the winter.

2.1. Safrinha corn (corn-soy double cropping)

The most important safrinha crop in Brazil is corn planted after soybeans. In the standard soy-corn double cropping system, farmers will generally plant soybeans in the spring (around October) for harvest around February, and then immediately plant a corn crop for harvest between May and July. The rise of the soy-corn double cropping model has been made

3 Weather data taken from (Climate-Data.org, 2021).

possible by the development of soy varieties that can be planted increasingly early in the season, as shown in Figure 1. The start of soy planting is now limited in most parts of Brazil by the need to wait for the onset of the rainy season.

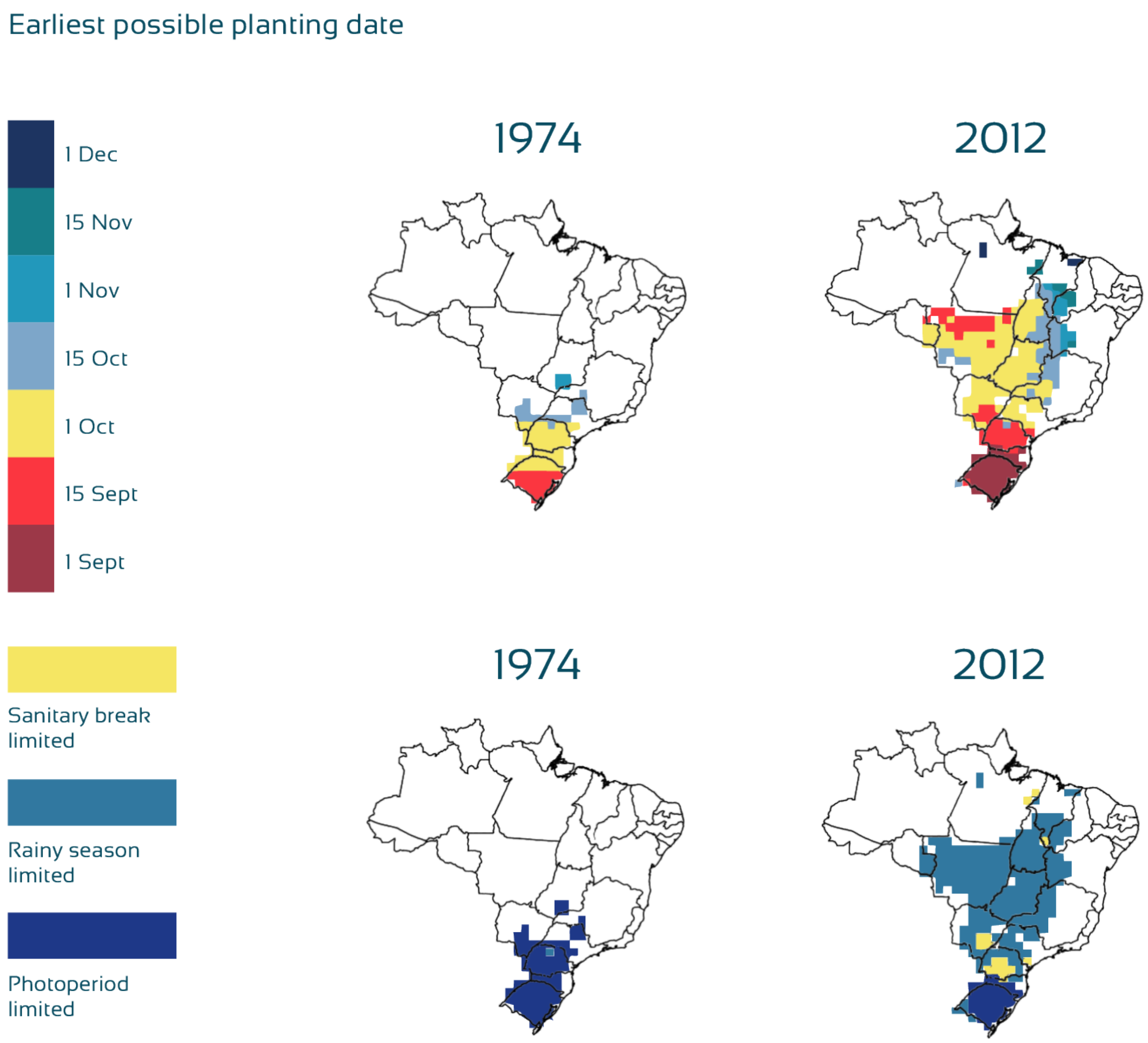

Figure 1. Earliest date at which soy can be planted in soy producing regions, change from 1974 to 2012, and cause of limit to early planting

Source: Pires et al. (2016)

Similarly, as the system has been developed the last possible planting date for the soy crop that would allow a second safrinha crop has moved later in the year, as shown in Figure 2. Again, the limiting factor is rainfall – in this case the need to bring the safrinha crop to maturity before the end of the rainy season. With safrinha corn viable with a degree of flexibility in so much of the country, by 2018 over 50% of soy production in the warm savannah was accompanied by a corn safrinha crop (DePaula & Fortes, 2019).

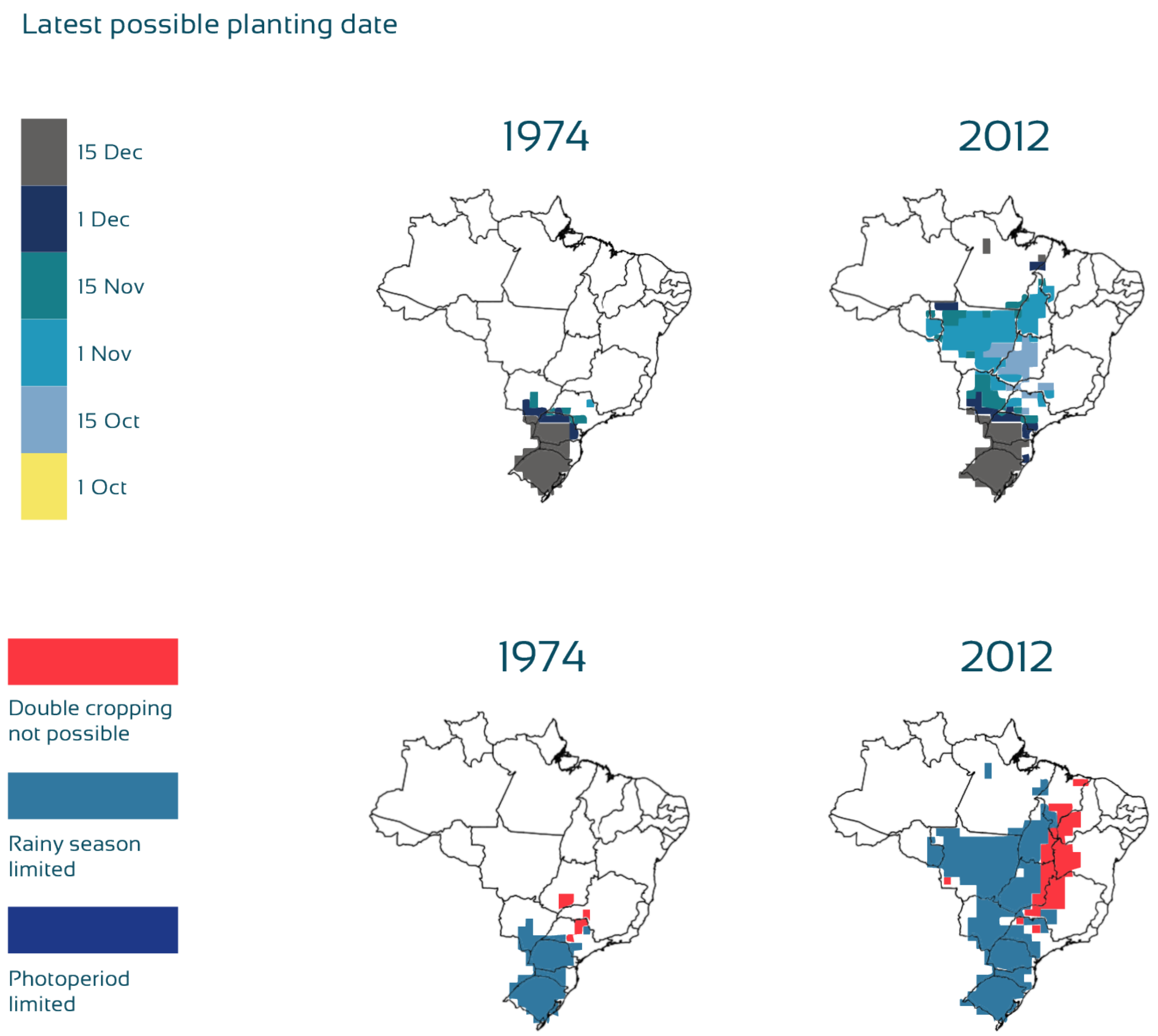

Figure 2. Latest date at which soy can be planted in soy producing regions for double cropping to be possible

Source: Pires et al. (2016)

The growth of the safrinha corn crop has led to safrinha corn production overtaking first-crop corn production in Brazil, and in recent years the safrinha corn harvest has produced two to three times more corn than first-crop corn harvesting, as shown in Figure 3. Safrinha corn expansion has allowed Brazilian corn exports to increase by a factor of 6 between 2000 and 2015 (Allen & Valdes, 2016).

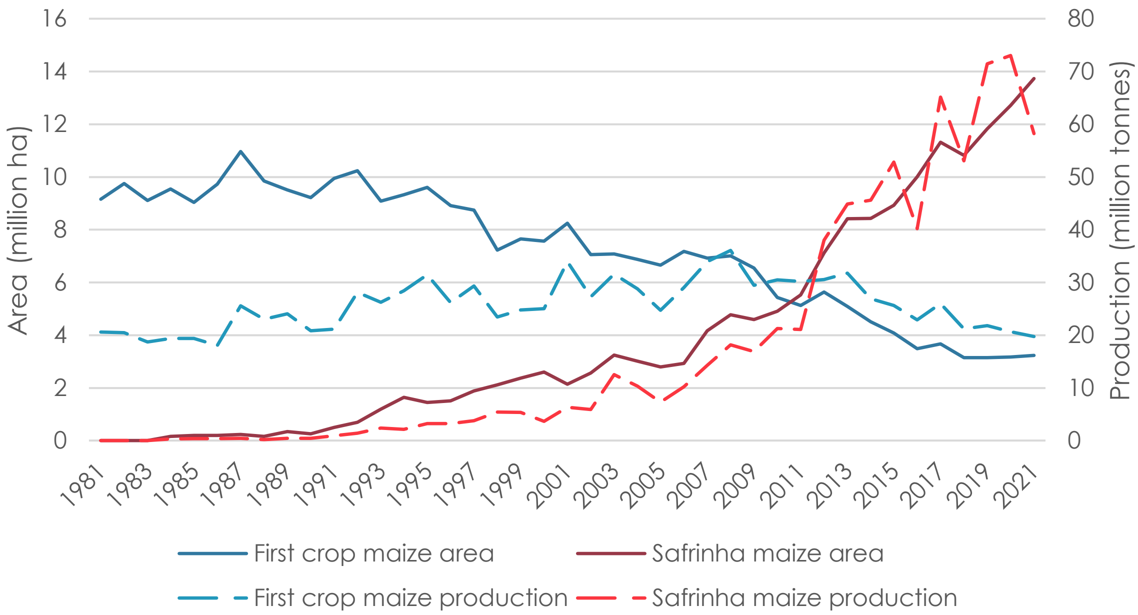

Figure 3. Brazilian first crop and safrinha crop corn production and harvested area

Source: Conab (2021), excludes Northeast region.

The safrinha crop is planted not only for its value at harvest, but also for its broader contribution to the health of the farm system. There is a degree of complementarity between soy and corn in a rotation. The crops have different root types allowing them to seek nutrients in different soil niches, and host different pathogens (Douglas Jandrey et al., 2018). They also have somewhat different nutrient requirements and contribute to mutual nutrient cycling. In principle it would be possible to produce successive soybean crops, but continuous monocultures increase susceptibility to pests and therefore continuous soy cultivation is discouraged or banned. For example, the Brazilian Government and Brazilian states introduced regulations for soy-free periods following the spread of Asian soybean rust in the early 2000s (Abrahão & Costa, 2018; DePaula & Fortes, 2019), and in 2015 the southern state of Paraná introduced a soybean sowing deadline of 31 December, ruling it out as a safrinha crop (Adami et al., 2018).

Successful production of a second corn crop is dependent on local weather conditions, and in particular the length of the rainy season and reliability of onset of the rainy season. For example, comparing practices across the state of Mato Grosso, Arvor et al. (2014) reports that the proportion of land that is double cropped is two and half times greater in locations with annual rainfall above 1900 mmm than in locations with rainfall below 1500 mm, and similarly that the proportion of land double cropped is three and a half times greater in locations where the rainy season typically lasts until the start of April than in locations where it is over by the 25th of March.

An estimate of the adoption in Brazil of double cropping and in particular the safrinha corn system can be made by consideration of statistics published by Brazil's Companhia Nacional de Abastecimento (Conab, 2021).[4] Conab report planted area by state for first, second and

4 Conab is a Brazilian-Government-owned company responsible for managing agricultural and

third crop corn; first, second and third crop black beans; and first and second crop peanuts as well as a number of crops including soybeans for which there is no disaggregation by harvest number[5]. Figure 4 presents indicative estimates of: a) the fraction of temporary cropland in Brazil[6] that was double cropped in the 2019/20 season; and b) the fraction of soy area that was followed with a safrinha corn crop in the 2019/20 season. For the second calculation, the area identified as double cropped in 2019/20 with a second crop of either corn, dry beans or peanuts (safrinha corn area is the dominant term in this calculation in most states) was divided by the total area identified as 'under temporary crops' in the 2017 agricultural census (IBGE, 2017). Northeast Brazil is excluded because (as noted above) the difference in agricultural calendar makes it difficult to identify second crops in the statistics.

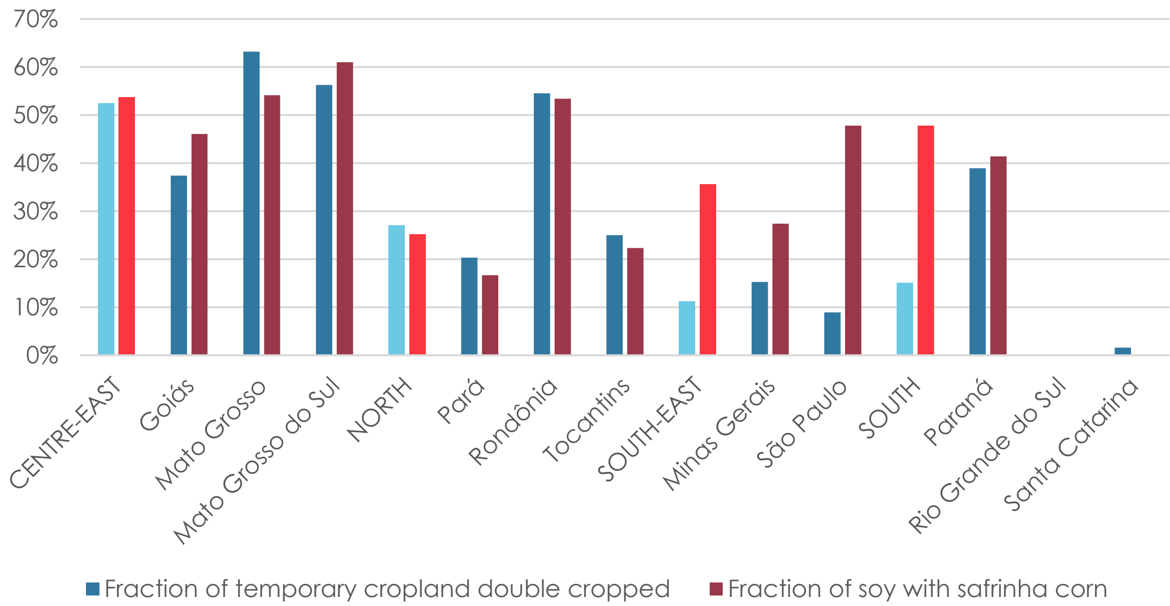

Figure 4. Estimation by state of: a) fraction of total temporary cropland area that is double cropped; b) fraction of soy area that is followed with a safrinha corn crop

Source: Estimation based on Conab (2021), IBGE (2017)

Graph excludes states with relatively little soybean planted area and states in the northeast and north regions for which the 1st/2nd/3rd crop characterisation is likely to be misleading because of a different growing season. Assumes 750 thousand hectares of Safrinha cotton in Mato Grosso.

Average grain yields for both the safrinha corn crop and for first-crop corn have increased significantly over the last forty years. Figure 3 shows that safrinha yields have been generally around three quarters of first-crop corn yields, though with quite a bit of annual variation.

supply policies.

5 It should be noted that categorisation as 1st/2nd/3rd crop is done by reference to harvest date rather than to the actual number of crops in the year. For parts of Brazil with a different agricultural calendar, in particular in northern Brazil, the corn area reported as the 2nd/3rd corn crop should in fact by understood as the first and only cash crop produced in the year.

6 Including area planted with sugarcane.

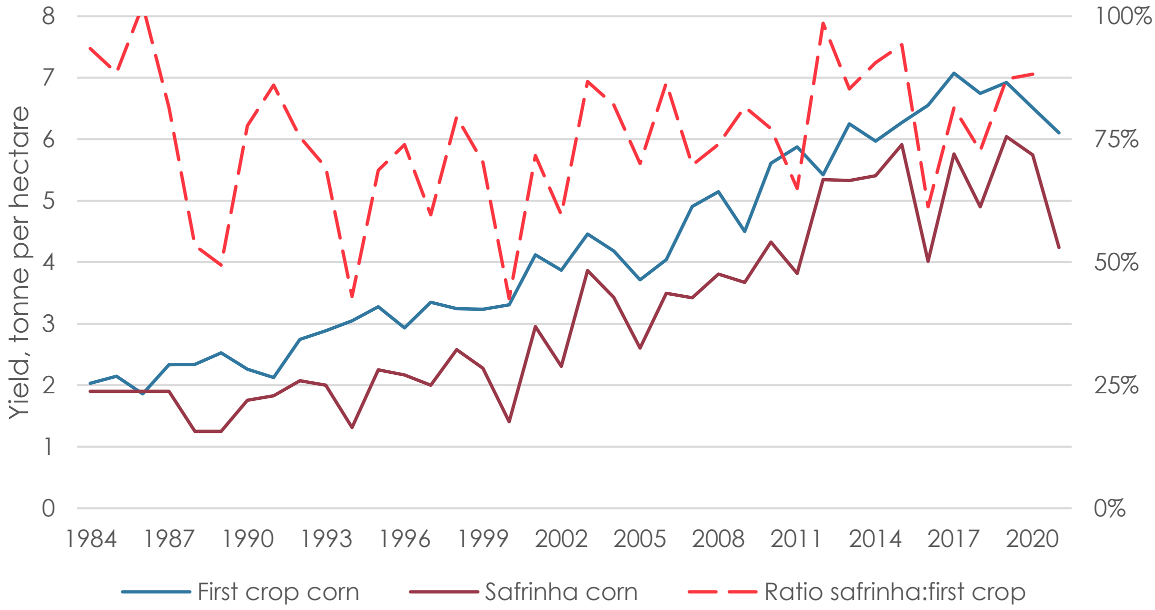

Figure 5. Yields of first crop and safrinha corn (left hand axis), and ratio of the two (right hand axis)

Source: Conab (2021); excludes Northeast region.

As noted above, safrinha corn is understood to have a beneficial role in the rotation with soy. Soy is considered the priority crop, and farmers seek to avoid a negative impact on soy yields from the safrinha system; nevertheless, accelerating the soy harvest to allow safrinha corn planting may have some impact on the former[7] The safrinha crop is seen as risky in relation to weather conditions because the timetable for producing two crops has less flexibility than for single cropping; if necessary, farmers will delay the soy harvest to increase yields at the expense of missing the safrinha planting window.

The development of the safrinha corn model has run alongside ongoing improvements in first crop soy yields, but it is difficult to conclude with confidence whether the management decisions required for the safrinha corn crop have had any effect on soy yields. As shown in Figure 6, the states where safrinha corn production has been more widely adopted have historically had the most productive soy production systems. As adoption of the safrinha corn cropping model has increased, the yield gap between these states and other states has narrowed, and provisional soy yields for 2021 are extremely similar between the states. Since 1980, the states that have the highest rates of safrinha corn cropping have increased soy yields by an average of 0.037 tonnes per hectare per year, while other states have increased soy yields by the slightly higher rate of 0.048 tonnes per hectare per year. It is not possible without a more detailed analysis to draw any conclusion as to whether the adoption of the safrinha corn model has imposed a slight yield drag on the soy crop. For the reasons noted

7 One farmer interviewed in (Moura & Goldsmith, 2020) said that, "[we may speed up operations in the first crop], as long as it doesn't harm the first crop. [If possible] we try to streamline it to benefit second crop as well. But we have the focus that the first crop comes first, and that must be guaranteed. It's no use losing too much on it [first crop] trying to recover in the second crop."

above it seems likely that safrinha crop management results in some soy losses in years with unfavourable weather, but the data available is inadequate to clearly determine whether any such losses are offset by the agronomic advantages of adding corn to the rotation.

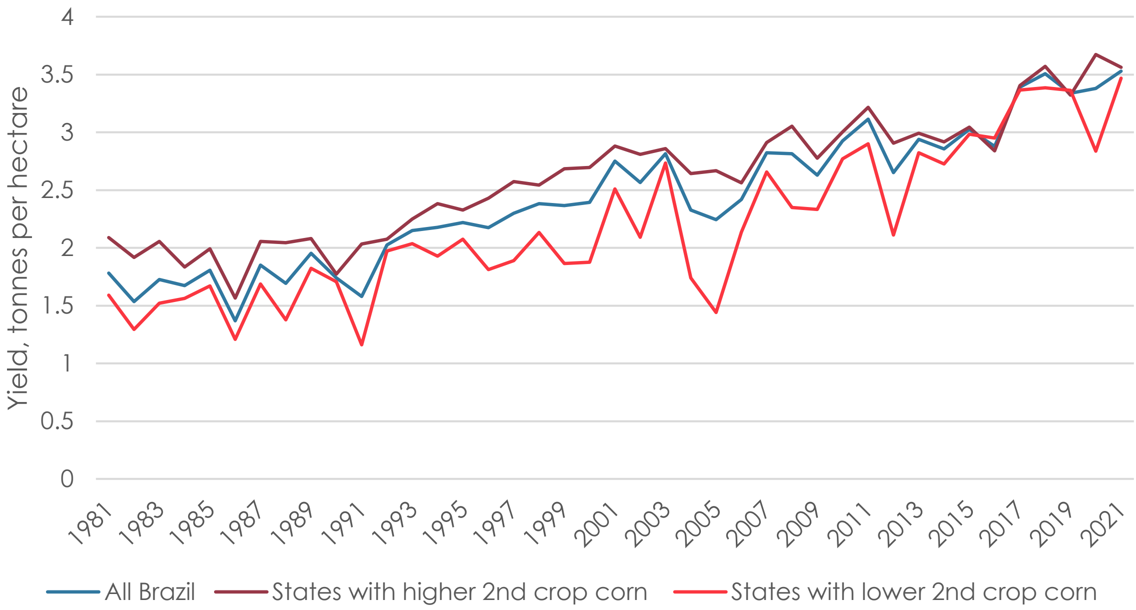

Figure 6. Soy yields in Brazil, for states with higher and lower penetration of safrinha corn cropping (split by whether 2019/20 safrinha corn area was greater or less than 30% of soy area)

Source: Conab (2021); excludes Northeast region

2.1.i) Fertilization of safrinha corn

Corn has high nitrogen demand, and safrinha corn is fertilized with nitrogen to optimise yields. The quantity of fertiliser required is dependent on targeted productivity – the higher the expected yield the higher the N requirement. Safrinha corn has the advantage of coming in succession after soybeans, which are nitrogen fixers and leave the soil relatively nitrogen rich.

To deliver 4 t/ha from continuous corn Coelho et al. (2011) recommends 80 kg/ha of N application. For safrinha corn grown after soy or another legume the recommended nitrogen application to chieve the same yield is reduced to 30 kg/ha, applied more or less 50:50 at planting and as top dressing. Similarly, Duarte et al. (2009) recommends up to 30 kg/ha, though suggesting that this can all be applied at planting. Simão et al. (2021) presents nitrogen response results for high yielding safrinha crops (yield of 7.5 t/ha or better without fertilisation) and reports a positive response up to 90 kg N/ha (at which application rate yields were achieved from 8.5 to 9.9 t/ha across the six plots considered). For a yield of 9 t/ha from continuous corn Coelho et al. (2011) suggests 190 t/ha of nitrogen. Coelho et al. (2011) suggests similar P and K fertilisation rates for continuous and safrinha corn at the same target yield. Overall, we see that while safrinha corn still requires nitrogen application for yield optimisation, the application is significantly less (a third to a half) of the recommended application for continuous corn. This helps reduce the cost to farmers of the safrinha crop and reduces the greenhouse gas emissions due to associated fertiliser production.

2.2. Safrinha corn, weather risk and climate change

The safrinha double cropping system in Brazil is largely rainfed, and therefore crop yields are sensitive to annual variations in rainfall and in the start/end of the rainy season. Moura & Goldsmith (2020) notes that,

> *"Double-crop farming presents greater production risks than single cropping because the weather tolerances are narrower when striving to utilize all the rain optimally that the season presents… Drought management for example, becomes central at both ends of the cropping season, as farmers may replant and adjust varietal choice several times when early rains are spotty and plants fail to establish, and then hurrying to get the second crop fully flowered and seed set before the rains cease and the dry season begins."*

While the safrinha system is intended to be applied with minimal yield loss for the first crop, pressures associated with getting a second crop planted may push farmers to harvest before the optimal time, and can contribute to "higher post-harvest losses and poor grain quality of the first crop" (Moura & Goldsmith, 2020). Goldsmith et al. (2015) shows that farmers consider some reduction in soybean output due to post-harvest losses to be an acceptable trade off for a safrinha crop. Giachini et al. (2018) notes for the case of Mato Grosso that risk levels for second-crop corn are sensitive to the planting time, which is dictated by harvest of the soy crop. Planting the safrinha crop by 15th February is lower risk – planting any time after 25th February becomes high risk as water availability becomes more restricted. We are not, however, able to attempt a precise quantification of the impact of safrinha cropping on soy output.

Given the reliance of double cropping on the length of the rainy season, concerns have been expressed that weather changes associated with climate change and with ongoing Amazon deforestation, could reduce the viability of the double cropping model. Arvor et al. (2014) suggests that further deforestation may induce shorter rainy seasons in the Amazon region, reducing the viability of double cropping. Other studies (Abrahão & Costa, 2018; Brumatti et al., 2020; Carauta et al., 2021; Pires et al., 2016) discuss the possibility that climate change will reduce double cropping options. Pires et al. (2016)finds that by 2050 climate change could reduce the area that can be double cropped by between 15 and 20% in Mato Grosso and Central Brazil, and by as much as 60% in the agricultural frontier region of MATOPIBA. These results are sensitive to the climate assumptions used, however - Carauta et al. (2021) consider weather projections from two climate models, predicting very significant impacts on double cropping potential under outcomes taken from the Statistical Analogue Resampling scheme (STAR), but a relatively modest impact under outcomes taken from the Weather and Research Forecasting model (WRF).

The impact of climate change may be moderated by the ongoing development of new varieties of soybeans and corn able to mature on a shorter growing cycle or by increased use of irrigation to extend the growing season, but such measures are considered unlikely to fully compensate (Abrahão & Costa, 2018; Brumatti et al., 2020).

2.3. Safrinha cotton

An alternative to safrinha corn after soy is to instead plant a safrinha cotton crop. The safrinha cotton crop needs to be planted earlier than safrinha corn in order to have time to develop, and therefore second crop cotton is associated with planting 'early cycle' soy which results in a lower soy yield than in the soy-corn double cropping system (Aguiar et al., 2006; Arvor et al., 2011).

In Mato Grosso, for example, cotton can be planted in January after an early soy crop and harvested at the end of July. Moura & Goldsmith (2020) present interviews with farmers In Mato Grosso in which several interviewees discuss cotton as a second crop, but suggest that whereas a soy crop would take priority over the safrinha corn crop, a second cotton crop would be given priority over soy, commenting that when cotton is grown after soy in Mato Grosso, "the early crop is the 'safrinha' allowing cotton to benefit from the more ideal weather during the latter part of the rainy season when conditions begin to dry out." Arvor et al. (2011) shows the soy harvest in the soy-cotton system occurring two to three weeks before the soy harvest in the soy-corn system. The yield of safrinha cotton is expected to be sensitive to sowing time, making early harvest of soy important for a successful cotton crop. Ferreira et al. (2015) report from field trials that planting cotton in mid-February instead of late January depressed yield by up to 25%.

Conab statistics do not distinguish between first and second crop cotton, which makes it much more difficult to develop an estimate of the prevalence of the practice. Arvor et al. (2011) reports that in one region of Mato Grosso (Sapezal municipality) second crop cotton accounted for as much of half the 2006/07 cotton harvest. The USDA Global Agricultural Intelligence Network (GAIN, Ustinova & Flake, 2021) reports that in Mato Grosso, which accounts for 71% of Brazilian cotton hectares planted for the 2021/22 season, cotton is "mostly grown as a second crop" and competes with corn. With over a million hectares of cotton planted in Mato Grosso this suggests that between 500 thousand and 1 million hectares of cotton are planted as a second crop. Batista & Ramos (2014) suggests that 65% of cotton produced in Mato Grosso in 2013/14 was safrinha and that as much as 90% could be in the 2014/15 season. This compares to 5.4 million hectares in Mato Grosso planted with safrinha corn (Conab, 2021). The yield for second crop cotton in Mato Grosso is reported by Ustinova & Flake (2021) as 1.7 tonnes per hectare, which is a little below the average yield (1.9 tonnes per hectare) in Bahia where cotton is grown as a single crop.

2.4. Other double cropping systems

While soy-corn and soy-cotton are the most important double cropping models in Brazil, other combinations are possible, including soy followed by sunflower, or sorghum[8] (Moura & Goldsmith, 2020). Backes et al. (2008) reports on experiments with sunflower as a safrinha biodiesel crop in which yields from 0.5 to 2 tonnes of seed per hectare were achieved. Another oilseed with safrinha potential is safflower. Guidorizzi et al. (2021) identifies safflower as a crop with potential following a soy summer crop in regions with relatively high winter temperatures but variable rain, reporting trial results in which safrinha sowing resulted in a low harvest index

8 Note that sorghum is also identified as a cover crop, and it is unclear to us whether there is any significant production of sorghum as a safrinha crop for harvest.

compared to spring sowing, with a yield of 1.4 tonnes of seed per hectare (about a third of the potential yield as a main crop).

Dry beans are also produced as a double crop. Like corn, there are three harvests of dry beans in Brazil, which are detailed In statistics from Conab (2021). The third bean harvest is produced primarily in irrigated areas in the Cerrado which enables production through the dry season (Hrapsky & Morin, 2010). Conab (2021) report 700 thousand hectares of second crop beans outside of the northeast, which we take to be second crop beans. Another 700 thousand hectares is identified as second harvest in the northeast, but given the more varied agricultural cycle in the northeast states, some of this bean production likely reflects a single bean crop.

3. Cover crops

The use of cover crops in Brazil is linked to the widespread adoption of no-till practices as part of conservation agriculture systems. One of the principles of conservation agriculture is to maintain soil cover all year round (FAO, 2021). In no-till systems, referred to in Portuguese as 'sistema de plantio direto' (SPD), seeds are planted without ploughing the soil, which allows crop residues to remain on the soil surface. While adoption of no-till agriculture does not in itself guarantee the use of cover crops, the SPD couples no-till planting to permanent ground cover, management of soil organic matter and minimisation of the interval between harvest of one crop and sowing of the next (Denardin et al., 2012). Cover cropping is an important corollary of no-till agriculture because adopting no till practices without soil cover can actually lead to worsened soil degradation (Bolliger et al., 2006).

The application of some form of no-till agriculture in Brazil has grown from essentially nothing in the early seventies to covering over 30 million hectares today, around half of total Brazilian cropland area, although there is significant variation in the specific practices adopted (Bolliger et al., 2006; Saueressig, 2019). The adoption of no till agricultural practices in Brazil started in the south, especially Paraná state, but has since spread north, notably to the Cerrado, and also into neighbouring countries, starting with Paraguay. The development of no-till systems was made possible by the introduction of no-till planting machinery, and by the availability of herbicides such as paraquat and later glyphosate (Bolliger et al., 2006). No till can be associated with increased herbicide use for weed control, as in conventional till ploughing plays a role in disturbing weed establishment (Ofstehage & Nehring, 2021).

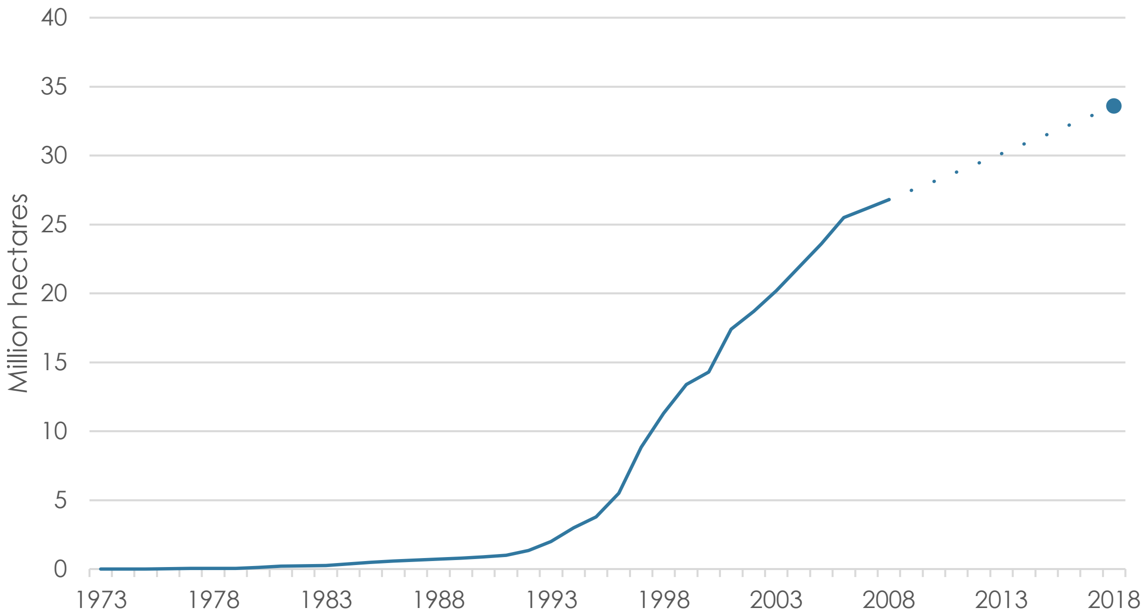

Figure 7. Area of Brazilian farmland under no till, 1972 to 2018

Source: Federação Brasileira do Sistema Plantio Direto (2021); dotted part of line from 2007-2017 is an interpolation through a period with no explicit annual data given.

According to the Brazilian no-till association, by 2017 75% of the area used for grain crops was under the SDP and the total area under no-till in Brazil had reached 33 million hectares by 2018 (Figure 7). This constitutes about 60% of the area used for temporary crops in Brazil[9]. While it is likely that there are some farms identified as implementing the SPD that do not always plant cover crops, and some farms not identified as implementing SPD that do, we believe that this is a reasonable proxy estimate for the area of Brazilian farming where cover cropping is practiced. Over 5 million hectares of the no-till area is in Paraná state where 92% of cropland was under no-till management by 2014 (Figure 8), and reportedly over 15 million hectares in the Cerrado[10].

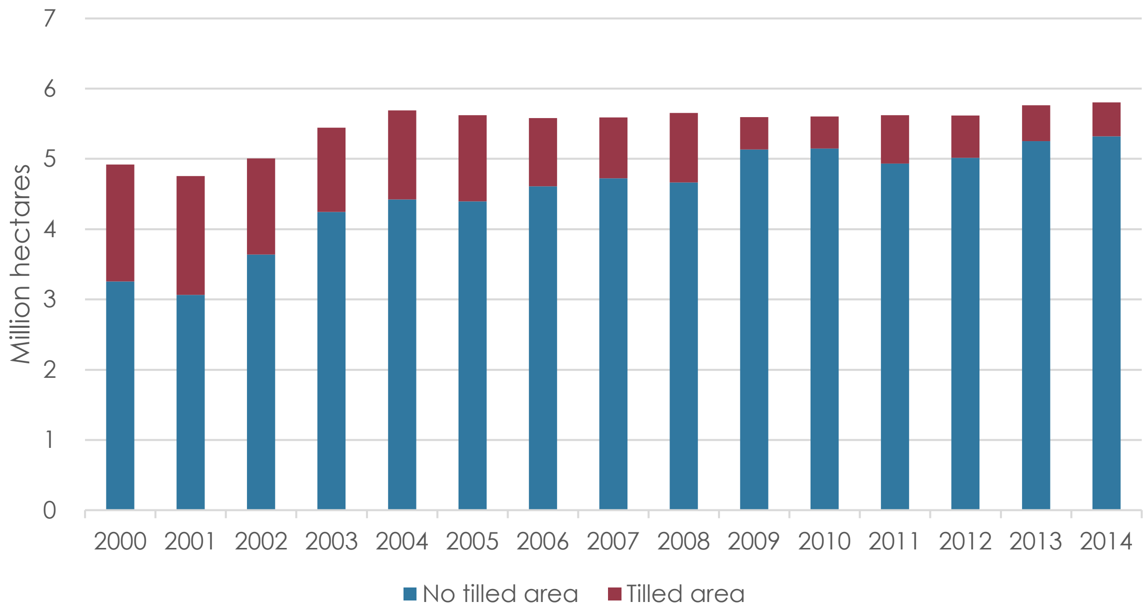

Figure 8. No-till area in Paraná state

Source: Federação Brasileira do Sistema Plantio Direto (2021)

Cover is achieved through a combination of leaving residues on the field after harvesting or desiccating[11] crops, and quickly establishing the next productive or cover crop. This planting is often directly into the residues remaining following harvest or desiccation with herbicide of the preceding crop, but in some cases planting can occur while a previous crop is still in the field. Cover crops are used in association with both single and double main crop systems. Some cover crops are used for livestock forage, but cover crops are still grown for the agricultural benefits they provide even if there is no potential harvest or forage use of the

9 We calculate 54 million hectares based on data for harvested area of temporary crops (including sugarcane) from (IBGE, 2017) minus the estimated second crop area identified based on (Conab, 2021) - this is comparable to the area of 56 million hectares identified as arable land in 2018 by FAOstat (UN Food and Agriculture Organisation, 2020).

10 See e.g. https://groundswellag.com/speakers/john-landers/ – we were not able to identify recent statistics (from either government or industry) directly identifying no till adoption in the Cerrado.

11 Crop desiccation involves the application of contact or systemic herbicides to defoliate or kill plants.

material produced. Many of the species planted as cover crops could in principle provide a grain harvest, for instance millet or grain sorghum. The reason that these cover crops are not harvested for grain for human consumption is that it is simply not economically attractive. Potential grain yields in the off-season are lower than if grown as first crops, making it hard to justify the costs of attempting a harvest. The safrinha corn crop is a highly productive and valuable second crop, and even so some farmers will choose not to attempt safrinha corn in years when conditions are less favourable. Managing less valuable cover crops for grain or seed production is even harder to justify. Varieties that are well suited for cover crops use, for instance because of greater biomass production, may also not be the best suited for grain production.

Crop cover protects the soil from rain erosion, and can assist with nutrient cycling – nutrients that might otherwise be washed out of the soil over the winter can be absorbed by the cover crop in growth and then released from the resulting residues later in the year (Giachini et al., 2018). The most important first crops grown in Brazil (in particular soy and first-crop corn) are planted in the spring, and therefore it is important to have cover crops in place over the winter. The situation is somewhat different for winter wheat and barley, which are sown before the winter for harvest the following summer, and for which a cover crop is therefore most relevant in the late-summer and autumn.

Cover crops are intended to provide a number of agricultural services that support the long-term productive status of the land and the productivity of harvested crops. In addition to erosion reduction, these include (de Oliveira, 2014):

1. Nutrient accumulation/cycling;
2. Physical soil improvement;
3. Weed emergence reduction;
4. Pest management;
5. Enhanced soil microbial activity and microfauna.

Cover cropping decisions are informed by these considerations, cross referencing the conditions under which the crop will be grown with the main crops to be produced with the characteristics of the cover crop. In the Cerrado, for example, the winter months are dry but still relatively warm. These warm conditions result in a relatively high rate of decomposition of surface biomass compared to the situation in Brazil's southern states, where the winter is less dry but colder (Pacheco et al., 2011). For this reason, cover crops are favoured in the Cerrado that are drought tolerant (to cope with the dry period), that produce larger quantities of biomass (so that the material from the cover crop does not decompose before the next crop is able to provide cover) and that have a higher carbon to nitrogen ratio (as plants with a higher C/N ratio tend to decompose more slowly) (Crusciol et al., 2005; Pacheco et al., 2011). Saueressig (2019) reports that in Matopiba 10 to 12 tonnes of straw could be naturally decomposed over the course of a growing cycle, and that therefore if cover is to be provided through the whole cycle, high levels of biomass production are important.

In the southern states considerations are different – for example farmers might favor cover plants with a lower carbon to nitrogen ratio as such plants will release more nitrogen for the subsequent productive crop, and in the colder winter excessive decomposition is not such a concern.

Nutrient management with cover crops is based on the concept that cover crops can absorb available nutrients remaining in the soil after a productive crop has been harvested and store those nutrients in biomass. This reduces leaching of nutrients from the soil and allows for cycling of nutrients from deeper soil layers into biomass which can in due course be mulched on the soil surface. Reducing nutrient leaching is important in terms of reducing impact on the local environment, but also important for farmers as a way to reduce expenditures on fertilization. For example, Duarte et al. (2009) suggests that cover crops could contribute 60 to 90 kg/ha of nitrogen towards the nitrogen needs of a summer corn crop. The choice of the best cover crop for nutrient cycling purposes will be informed by nutrient release rates and the nutrient needs for the following productive crop. If the productive crop has high nitrogen utilization in the period immediately after germination, this may favor the use of a cover crop that will release nitrogen relatively rapidly when mulched.

Cover crops can assist with pest management by breaking up the crop cycle, and for pest management the most important factor is the choice of cover crops that do not support the pests that may develop during the productive period. Some cover crops also release allelopathic chemicals during decomposition that can suppress development of some weeds (Tokura & Nóbrega, 2006).

Given the complexity of relationship between cover crops, productive crops and soil fertility, decisions about the cover crops to use in rotations should ideally be informed by a long-term view. The cover crop that is most beneficial in a single season may not be the cover crop that is the best choice from a long-term perspective, and cover crops that can potentially be harvested for sale may not be the economically optimal choice when the longer-term impact on main crop yields are taken into account.

3.1. Cover crops in use in Brazil

A wide range of crops have been considered and used for cover cropping in Brazil. Grasses tend to perform better in terms of biomass production (Torres et al., 2005), whereas legumes have advantages through potential for nitrogen fixation. Not all crops are suitable for all regions and all sowing times. A cover crop that is considered desirable for planting in February or March after harvest of a single crop may not be considered a good candidate for planting in May or June after harvest of a second crop. This section lists and provides brief descriptions of the most relevant crops considered.

3.1.i) Millet (Pennisetum glaucum)

Pearl millet is a hardy cereal grass with good tolerance of drought, high temperatures and acidic soils. It is a common cover crop in the Cerrado; Ministério da Agricultura (2020) states that it occupies 4 million hectares as a cover crop and a survey or farmers primarily producing on the Cerrado presented by de Oliveira (2014) found that about 70% of respondents stated that they had planted millet in the past. It is identified for example as one of the three most commonly grown on areas not planted with a safrinha crop in any given year in Mato Grosso (Giachini et al., 2018). Relatedly, Saueressig (2019) suggests that millet or other alternative cover crops should be grown once every three years instead of safrinha corn in soy-corn systems in order to deliver the biomass production required to maintain year round cover.

Millet has high biomass productivity, delivering considerably higher biomass yields in the

Cerrado compared to legumes such as sunn hemp and pigeon pea (Carvalho et al., 2004). It has a high carbon to nitrogen ratio (Ministério da Agricultura, 2020) and it also has good performance in potassium cycling (Perin et al., 2004). Millet roots are poor hosts to nematodes and thus help reduce nematode infections (Ministério da Agricultura, 2020).

Millet may also be an alternative off-season crop to safrinha corn following soy in cases where the soy harvest is delayed (for example due to late onset of the rainy season) and the window for off-season cropping is foreshortened (Moura & Goldsmith, 2020).

3.1.ii) Black oat (*Avena strigosa*)

Black oat is a grass that is widely used in southern Brazil as a forage plant (Bolliger et al., 2006; de Oliveira, 2014) in rotation with main crop soybean, due in part to its strong performance as a livestock feed for dairy cattle, with high protein content and digestibility.

3.1.iii) Sorghum (*Sorghum bicolor*)

Similarly to millet, sorghum is considered well suited to high temperatures and dry conditions (Ministério da Agricultura, 2020). It is tolerant to acidic soils and the presence of aluminum; like millet, it helps to reduce nematode infestation and is a good forage crop.

Like millet, sorghum may be grown as an alternative safrinha crop to corn, especially in cases where water availability is too limited for optimal corn growth.

3.1.iv) Fodder radish (*Raphanus sativus*)

Fodder radish is a brassica. It has deep roots which may allow nutrient cycling from greater depths of soil, and can help reducing soil compaction (Bolliger et al., 2006). It has rapid growth after planting and can provide 70% soil cover within two months of emergence (Crusciol et al., 2005).

3.1.v) Sunn hemp (*Crotalaria juncea*)

Sunn hemp is a legume widely planted as a cover crop in Brazil. The survey reported by de Oliveira (2014) found that about 80% of respondents had previously used sunn hemp as a cover crop, and it is reported that sunn hemp is a popular cover crop to use when the weather does not support establishment of a safrinha crop.

3.1.vi) Brachiaria

Brachiaria or signalgrass is widely grown as pasture grass in the Cerrado, accounting for 50 million hectares in 1999 (de Oliveira, 2014). Brachiaria has good dry matter productivity, and is adaptable to low fertility soils (Pacheco et al., 2011). Brachiaria is identified as having strong potassium recycling properties and as a potential winter cover crop with beneficial impact on soybean yield compared to bare soil (Caetano et al., 2014). Torres et al. (2005) finds that brachiaria accumulates high levels of N compared to some other cover options (though less than millet) and that it has a relatively high residue decomposition rate compared to other grasses. In the survey presented by de Oliveira (2014) 17% of respondents stated that they had used brachiaria as a cover crop.

Silva (2012) suggests that early planted brachiaria as winter cover can support crop-livestock integration, using the forage from the cover crop to support cattle rearing, producing beef as a commodity for sale. Optimising biomass production in this system requires planting the brachiaria simultaneously with the safrinha corn crop. The brachiaria develops more slowly, and after the safrinha corn crop is harvested the brachiaria provides a high-quality winter pasture that can complement traditional pastures that have reduced support capacity through the dry season.

3.1.vii) Pigeon pea (Cajanus cajan)

Pigeon pea, also referred to as Guandul, is a legume with a relatively low biomass yield compared to some other cover cropping options (Carvalho et al., 2004). Baldé et al. (2011) suggests pigeon pea grown as a relay crop planted shortly after first crop corn as a fodder crop appropriate for smallholders, due to a large increase in total biomass generation from the intercropped system versus corn alone. Pigeon pea performs strongly in terms of increasing nitrogen availability, making it a good candidate for a cover crop in fields growing corn (Maltas et al., 2009).

3.1.viii) Black velvet bean (Mucuna pruriens)

Black velvet bean is a legume native to South and Southeast Asia that grows well in warm humid climates. It is identified by de Oliveira (2014) as one of the cover crops less commonly used by survey respondents. Ortiz Ceballos et al. (2012) report that velvet bean can help soils recover from compaction, and that it is particularly effective in weed suppression due to rapid growth and production of allelopathic compounds. That study also reports that experiments adding a velvet bean cover crop either in rotation or intercropped with corn generally show significant corn yield improvement, linearly related to dry matter yield of the velvet bean.

3.1.ix) Crambe

Crambe is an oilseed in the family Brassicaceae, and is apparently notable for its potential to produce an oil with characteristics similar to whale oil (Zhu et al., 2016). Crambe is identified as the third most used cover crop by respondents to the survey in de Oliveira (2014), which also notes that crambe has high resistance to water stress and rapid nutrient releases after cutting, but has relatively low dry matter production compared to other cover crops.

3.1.x) Vetch

Vetch is a legume with potential to support corn yield through nitrogen fixation. Amado et al. (1998) reports that in a corn cropping system with a vetch cover crop the vetch was able to provide 2/3 of the nitrogen requirement for optimum corn yield. It is one of the less common cover crops according to respondents to the survey in de Oliveira (2014).

4. Opportunities for brassica carinata as a 'productive cover crop'

One crop that has been identified as a potentially productive second crop with biofuel applications is *Brassica carinata*, sometimes known as Ethiopian mustard (henceforth carinata for short). Carinata cultivation as a winter crop after soy has been demonstrated in Uruguay by UPM (UPM, 2018) and proposed as a crop with high potential in the Southeastern United States (Seepaul et al., 2019). It has been identified as a disease-resistant alternative to rapeseed in Argentina (Ríos, 2020), but has not been specifically identified as a crop with potential in Brazil. The UPM production model in Uruguay is based on half the year for the main summer crop and half the year for the second carinata crop (UPM, 2020), and it is not considered viable to deliver a productive carinata crop in the gap between harvesting safrinha corn and planting first crop soy.

Seepaul et al. (2021) describes the characteristics and agronomy of carinata as a potential biofuel crop. Carinata seed has an oil content of 40-50% and a protein content of 20-30%, which is comparable to sunflower seeds. The oil generally has a high erucic acid content which makes carinata oil inappropriate for human consumption. Carinata is described as an appropriate winter crop in the humid subtropics or spring crop in humid continental climates. It has lower water use than other brassicas. Carinata is responsive to nitrogen fertilization and carinata grown for oil would require the use of nitrogen fertilizer – positive seed yield response is reported up to 117 kg N/ha, with an economic optimum application of 103 kg N/ha (Seepaul et al., 2020), and some studies suggest further yield increase for higher N application. Total nitrogen uptake to deliver a seed yield of 2800 kg/ha in Florida is reported by Seepaul et al. (2021) as 150 kg N/ha. Carinata seed yield is also responsive to sulfur application with an economically optimal rate reported as 36 kg S/ha, and Seepaul et al. (2021) state that response to other nutrients has not been well studied.

As noted above, winter crop carinata has been pioneered in Uruguay. Uruguay's climate is identified as humid subtropical[12], which is the same climate classification as parts of the southernmost Brazilian states – notably most of Rio Grande Do Sul, and the north western half of Paraná (Alvares et al., 2013). Carinata is unlikely to be an appealing option in the Cerrado and west/central Brazil as these regions tend to have less winter rainfall, and carinata is not very drought tolerant compared to other cover crop options. The productive cover crop carinata model that is viable in Uruguay may therefore also be viable in southern parts of Brazil.

Figure 9 compares characteristic weather statistics taken from climate-data.org for the area around Toledo in western Paraná and the area around Paysandú in Uruguay. While the typical weather is similar for the two locations (average summer temperature around 25 °C, less rainfall in winter) there are significant differences – in particular, Toledo has more winter rainfall and warmer winter days. This would suggest on face value that achievable winter carinata yields may be higher in Paraná than in Uruguay. This may however mean that carinata would face more competition from already established productive second crops in Brazil.

12 Cfa on the Köppen-Geiger climate classification methodology.

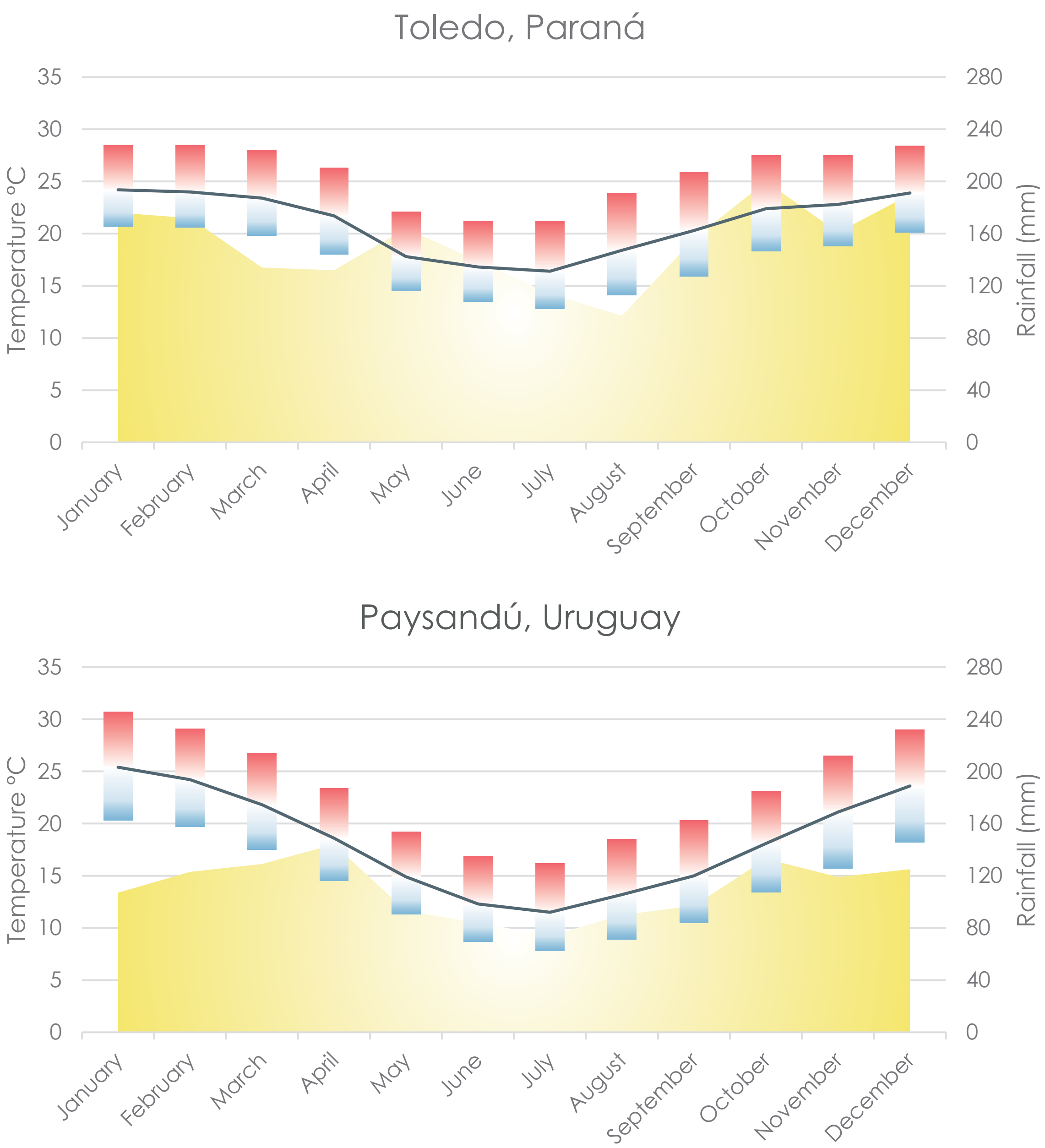

Figure 9. Comparison of typical weather for Toledo in Paraná state, Brazil and Paysandú in Uruguay (average, min and max temperature on left axis, rainfall on right axis)

Source: climate-data.org

There may be potential for carinata as an alternative safrinha crop in Paraná and other southern states to be considered as an option where farmers do not consider a safrinha corn crop economically attractive. This could be relevant in cases where a delayed soy harvest increases the risk of failure for a safrinha corn crop, in years with a lower price for corn or in areas where the climate or soil is marginal for successful safrinha corn. It might also be investigated as a productive winter cover crop to complement the high-yield first-crop corn that is produced in the southern states.

The lack of apparent interest from Brazilian farmers to date could reflect the availability of safrinha cropping options that have better economic returns than could be delivered by carinata cropping, but may also reflect a lack of investigation and understanding of the potential for carinata in the Brazilian context. Given that carinata oil is not appropriate for human consumption, interest in it as a second crop would be contingent on establishing the existence of a market for carinata oil as biofuel feedstock (or for other non-food applications). Brazilian biodiesel producers may be slow to consider new opportunities given the close ties to the soy industry. If carinata oil could be supplied at a price competitive with soy oil this market could develop domestically. Partnership with European biofuel producers (in a similar model to the engagement of UPM in carinata farming in Uruguay) might help catalyse interest in carinata as an alternative cropping opportunity. It would also be valuable to develop an evidence base on the performance of carinata as a cover crop – biomass productivity, nutrient cycling, speed of establishment etc. We were not able to identify any results of tests with carinata in Brazilian conditions. Bassegio & Zanotto (2020) consider the potential for two other brassicas to be produced as winter oil crops in Brazil – brown mustard (*Brassica juncea*) and field mustard (*Brassica rapa*) – by running field trials in Botucatu, Sao Paulo state, in the south of the Cerrado. Planting the brassicas in May with fertilizer applications of 30 kg/ha N, 84 kg/ha P_2O_5 and 48 kg/ha K_2O, the time from seedling emergence to maturity was about three months for brown mustard and 3.5 months for brown mustard. Oil yields achieved for these test crops ranged around 500 kg/ha, with a minimum achieved yield of about 250 kg/ha for the field mustard and one plot of brown mustard achieving 900 kg/ha (against total seed yields largely in the range from 1,000 to 2,000 kg/ha). It is likely that better yield results than this will be neede to convince Brazilian farmers to buy into a new production model.

4.1. Carinata meal as livestock feed

After oil extraction from the carinata seed the remaining meal (constituting 50-60% of the seed mass) is about 50% protein, three quarters of that rumen digestible protein (Seepaul et al., 2021). Carinata meal can contain glucosinolates, however, which reduces palatability of animal feed (Nega, 2018). For very high glucosinolate content Seepaul et al. (2021) even suggest applications as a biofumigant soil amendment. The problems associated with high glucosinolate can be readily overcome through solvent treatment for example with hexane (Bekele et al., 2020). Any carinata meal produced in Brazil would therefore be likely to find a market with livestock producers relatively easily. There may also be opportunities to breed varieties of carinata with lower glucosinolate content. Rodriguez-Hernandez (2018) finds for dairy heifers that solvent-extracted carinata meal delivered comparable growth performance to canola or soybean meals with inclusion rates of up 10% - given that carinata meal production will be limited compared to the size of the Brazilian beef industry for the foreseeable future, a 10% inclusion rate is not likely to be limiting.

5. Potential contribution to biofuel demand

5.1. Safrinha corn

The Brazilian safrinha corn crop produced 73 million tonnes of corn in 2019. This was over 6% of global corn production in that year according to FAOstat, and if converted to ethanol at the standard dry mill ethanol yield given by GREET, 73 million tonnes of corn could be used to produce 30 billion litres of ethanol, equivalent to more than a quarter of global ethanol consumption. There is already a significant use of safrinha corn as feedstock for Brazil's growing corn ethanol industry. Barros & Woody (2020) note that in centre-east[13] states such as Mato Grosso the combination of increased safrinha corn production and limited transportation options has led to corn prices in the centre-east that are lower than in other parts of the country. These low corn prices have encouraged the development of a corn ethanol industry in this region, and there are now 16 corn ethanol plants operating in Brazil, primarily in Mato Grosso. and that these produced about 2.5 billion litres of corn ethanol in 2020. That is about the same as Europe's total corn ethanol consumption in 2020 (Flach et al., 2020). Given that corn production in Mato Grosso, Goiás and Paraná, where these plants are located, is dominated by the safrinha harvest, we can reasonably assume that the bulk of the corn processed by these facilities is safrinha corn. This represents about 6 million tonnes of annual corn demand, about 8% of the safrinha corn harvest. Barros & Woody (2020) reports that if announced corn ethanol projects are all completed as planned production capacity could grow to 5.5 billion litres.

5.2. Productive cover crops

There may be opportunities to introduce productive cover crops as second crops where safrinha corn is not cultivated (effectively alternative safrinha crops) in order to generate a biofuel feedstock yield. Carinata, sunflower and safflower are all candidates that might be able to generate an economically viable oil yield with additional agronomic work. This said, if it was readily possible to produce a profit from growing cover crops for oilseeds in Brazil, then we would expect farmers to already be doing it, especially given that vegetable oil prices are currently high. It is impossible to draw any conclusions about how widely applicable future production systems might be without having those systems demonstrated in the field or a clear understanding of the associated costs and revenues of such systems. We know, however, that there is still a large area in Brazilian agriculture that is not yet double cropped. This is estimated to include around 20 million hectares of soy grown as a single crop, and around 7.5 million hectares of other single cropped annual crops. With additional research there may be opportunities identified to produce a second crop on at least some of that land.

13 USDA in fact refer to Mato Grosso as centre-west, but we have followed the regional designations used by the Brazilian government.

6. Safrinha crops, cover crops, land use change and the RED II

The EU Renewable Energy Directive (RED II), which governs incentives for biofuel use in the EU, places a cap on the use of food crops[14] to meet EU targets, but "intermediate crops" are excluded from the definition of food and feed crops and therefore from this cap. The Directive states that, "'food and feed crops' means starch-rich crops, sugar crops or oil crops produced on agricultural land as a main crop excluding residues, waste or ligno-cellulosic material ***and intermediate crops, such as catch crops and cover crops, provided that the use of such intermediate crops does not trigger demand for additional land***" (our emphasis).

Multiple cropping in general, and the Brazilian safrinha crop in particular, do not fit neatly into the main versus intermediate crop characterization provided for in the RED II. The RED II states that a food or feed crop is identified as "a" main crop rather than as "the" main crop, which suggests that it would be possible to treat more than one crop produced in a year as main – but it remains to be seen whether Member States tasked with implementing the Directive will share that interpretation. This question could be important for the determination of the status of safrinha corn under RED II. As noted in the introduction, the safrinha crop does not meet the definition given in the Directive for a cover crop because it does not have a low starch content and is used for more than fodder. The RED does not give an explicit definition of catch crops, but the term is generally used to refer to a crop grown either in a window between 'main' crops or alongside a main crop as it develops, generally for forage and to reduce nutrient leaching – the terms cover crop and catch crop are considered interchangeable by some sources. The safrinha crop is not generally understood as a catch crop, although one paper from the literature (Felipe et al., 2014) does refer to it as one. Given the value of the safrinha corn crop (both to the individual farmer and to Brazil as a whole) we believe that it would be appropriate to treat the soy and safrinha corn crops as 'co-main' rather than intermediate for the purposes of the RED.

Even if one did identify safrinha corn as an intermediate crop, the RED II also sets a condition that intermediate crops can only be considered outside the food and feed cap if their use "does not trigger demand for additional land". It is difficult to see how the diversion of safrinha corn for biofuel feedstock could be considered to satisfy this condition. Safrinha corn is already firmly integrated in the world's grain economy, and global gain prices are sensitive to the production of safrinha corn[15]. Using safrinha corn for ethanol feedstock would have the same sort of market impacts as using corn from the EU or U.S. first crop, i.e. it would be expected to impact food markets and lead to indirect land use change.

In practice, giving Brazilian safrinha corn favourable treatment under the RED II would undermine the purpose of introducing a cap on the use of food- and feed-based fuels in the first place. The same would apply to adding favourable treatment for feedstocks from any established commercial second cropping system. If the use of intermediate crops for biofuel production is to avoid driving additional land demand, it would need to be by

14 Sugar, starch and oil crops.

15 See e.g. https://ahdb.org.uk/news/analyst-insight-the-brazilian-safrinha-crop-could-drive-global-grain-markets.

driving faster adoption of new cropping systems. As an example, if a carinata model could be introduced in southern Brazil for farms where safrinha corn is not profitable, this might deliver truly additional feedstock. Of course, if the entire safrinha corn harvest were to be treated as an intermediate crop it would destroy any incentive for the development of new intermediate cropping models. If the RED II is truly to provide support to the implementation of new agricultural models, it would be helpful to clarify and tighten the intermediate crop definition.

7. Discussion

The deployment of double cropping and cover cropping in the Brazilian agricultural system have delivered advantages in both economic and ecological terms. The adoption of the SPD[16], which includes maintenance of continuous soil cover, has had considerable success in terms of reducing soil erosion and stabilising soil quality. The introduction of the safrinha corn crop has allowed Brazil to significantly increase its corn production and is believed to had at worst a modest impact on soy yields.

The safrinha corn crop has already supported the development of a Brazilian domestic corn ethanol industry producing 2.5 billion litres per year. It has been suggested (Baldino & Searle, 2021) that the RED II could create an opportunity for an increase in the use of safrinha corn as a feedstock for biofuels consumed in the EU by treating safrinha corn as an 'intermediate crop', and exempting it from limitations on food-based biofuels. We have argued that safrinha corn should not be exempted from these limits on food- and feed-based biofuels. Firstly, given the value of the safrinha crop we have suggested that it should be treated as a main crop alongside the first crop soy rather than as intermediate. Secondly, even if safrinha corn were to be treated as intermediate, the RED II states that an intermediate crop should only be excluded from the food and feed crop catrgory if its use for biofuel production, "does not trigger demand for additional land." As the safrinha corn crop is already well integrated into the global grain supply it would be very hard to argue that diverting it for biofuel use would not create new land demand.

If the EU and its Member States come to the same conclusion, then Brazilian safrinha corn will have no advantage in EU markets compared to domestic or U.S. corn production. If, however, safrinha corn is determined to meet the standard to be exempted from the food and feed cap in the RED II, this could potentially create a large market opportunity to both ship Brazilian corn ethanol to EU markets, and to ship Brazilian corn to EU markets for processing. This would have direct impacts on other crop markets, and drive indirect land use change and marginal food commodity price increases. It would be useful if the EU could clarify and ideally tighten the definition of intermediate crops during the current round of amendments to the RED framework as part of the Fit for 55 package.

While safrinha corn is already an established major part of global grain production, there may be opportunities to develop other second cropping systems, either finding ways to deliver economically viable grain and oilseed harvests from cover crops already in use, or by adapting crops such as brassica carinata to Brazilian conditions. Despite the great success of the safrinha model less than half of Brazil's planted area of soybeans is currently double cropped. Even recognising that not all areas will be appropriate for any model of double cropping, this suggests that there could be a considerable opportunity to increase agricultural production if models could be developed that would allow economically viable double cropping on some meaningful fraction of the remainder. If the European biofuel industry could support the development of such models, this could provide very great long-term benefits in terms of food production.

16 Sistema de plantio direto.

8. References

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