REFEREED ARTICLE

DOI: 10.5836/ijam/2020-09-79

The Drivers of the Double Cropping System Adoption in the Tropics

ALTAIR MOURA[1] and PETER GOLDSMITH[2]

ABSTRACT

The practice of the double-cropping system (DCS), whereby farmers plant two different crops in the same field, in succession, within the same crop year, has been growing in the tropical regions of Brazil for the last 40 years. The DCS, also known as the ''safrinha'' system, has been responsible for an important revolution in cropping production in the tropics, a region historically challenged by low agricultural productivity. The system allows the intensification of land use, raises total production per hectare per year, and improves asset use efficiency, for example machinery, facilities, and human capital. The goal of this paper is to better understand the DCS system for tropical agricultural managers. Specifically, the manuscript achieves that goal by exploring the decision-making by farm managers through direct semi-structured interviews with experienced DCS managers. The direct engagement is unique as it intentionally complements previous more indirect survey-based and econometric methodologies. The setting is Mato Grosso Brazil, the center of DCS farming in the tropics. The findings directly apply to producers in other tropical regions of the world, where some of the poorest countries reside. Policymakers and investors can integrate the findings from this paper to better design farming systems to improve productivity and profitability among small and medium sized farmers operating in the tropics.

KEYWORDS: Brazil; maize; management; Mato Grosso; soybean

1. Introduction

The practice of the double-cropping system (DCS), whereby farmers plant two different crops in the same field, in succession, within the same crop year, has been growing in the tropical regions of Brazil for the last 40 years (Cruz *et al.*, 2019). The wide window of rainfall season and favorable temperature in Mato Grosso, located in Brazil's tropical Center-West region, allows farm managers to lead the nation in DCS application (APROSOJA, 2019). The DCS, also known as the ''safrinha'' system, has been responsible for an important revolution in cropping production in the tropics, a region historically challenged by low agricultural productivity. The system allows the intensification of land use, raises total production per hectare per year, and improves asset use efficiency, for example machinery, facilities, and human capital (Silva, 2012; Goldsmith and Montesdeoca, 2018).

In terms of total grain production in Brazil, Mato Grosso state now leads the nation by producing 28.2% of the soybean and 31.6% of the maize (CONAB, 2019c). The soybean crop, alone, is responsible for the 49.2 % of annual grain production in Brazil (CONAB, 2019b). The DCS system has become an essential feature behind the productivity improvements and rural economic development in Brazil where farmer's incomes are growing at 4.28% per year. Farmer productivity too shows improvement at a compound pound annual growth rate of 3.1% between 2008 and 2018 in terms of grain production per hectare (Brazil, 2018).

As a result, the goal of this paper is to better understand the DCS system for tropical agricultural managers. Specifically, the manuscript achieves that goal by exploring the decision-making by farm managers that operate the DCS in Mato Grosso, Brazil. The DCS, which still is relatively new, has great potential to address the rapidly increasing demand for food as global population and incomes rise. So understanding the managerial features of this new system can support the private sector elevate productivity in other regions of the world. Finally, there are direct applications to producers in other tropical regions of the world, where some of the poorest countries reside. Policymakers and investors can integrate the findings from this paper to better design farming systems to improve productivity and profitability among small and medium sized farmers operating in the tropics.

2. Literature Review

Double cropping or succession cropping is one practice that belongs to a wider group called multi-cropping. Multi-cropping refers to several ways producers can use

Original submitted November 13 2020; accepted November 13 2020.

[1]Federal University of Vicosa in Brazil.

[2]Corresponding author: University of Illinois, USA. Email: pgoldsmi@illinois.edu

a particular piece of land in a single period of time, usually, a growing season or calendar year. In general, multi-cropping comprises the following main kind of practices: a) double/succession cropping; b) cover cropping; c) integrated crop-livestock systems; d) woodland-based systems (Borchers *et al.*, 2014), and e) intercropping, where two crops occupy simultaneously the same piece of land during part of the life cycle of each (Hexem and Boxley, 1986).

The double/succession term refers to the sequential growing of crops. Farmers plant and harvest a second and or even a third crop within the same calendar year. Conventionally, double or triple cropping involves irrigation, and matching crops in terms of growing period length, agronomic complementarity to optimize yield, and overall profitability. The system in Mato Grosso, strictly speaking involves double cropping without irrigation, which involves much higher levels of uncertainty and risk.

Double cropping is synonymous with intensification of production, which may relieve pressure to develop less productive land for agricultural uses (Phalan *et al.*, 2011). Or others argue incentivizes farmers to expand their production and clear new lands (Cohn *et al.*, 2014). While double cropping presents economies of scope in terms of input and capital use (Goldsmith and Montesdeoca, 2018), intensification can also promote more intensive use of pesticides, herbicides, fertilizers, and water resources, which have negative environmental impacts (Heggenstaller *et al.*, 2008; Borchers *et al.*, 2014). In Mato Grosso, the safrinha two crop system principally involves rain-fed production, rather than irrigation, due to the long rainy season in the region (Shapiro *et al.*, 1992)

Double cropping in Brazil has expanded due to rising global demand for key commodities such as maize, soybean, and cotton, as well as technology improvements in the area of farm equipment and machinery, and advances in agronomy and plant breeding (Hexem and Boxley, 1986; Shapiro *et al.*, 1992). The practice more efficiently uses mechanization and labor, which reduces fixed costs per unit of land and raises overall profitability of the farming enterprise (Goldsmith and Montesdeoca, 2018; Beuerlein, 2019). With advanced managerial practices safrinha maize production now exceeds first crop maize production in Brazil. Mato Grosso not only now leads the nation in maize production, but makes Brazil one of the world's largest maize exporters (Cruz *et al.*, 2019; CONAB, 2019a).

It should be noted that while the dominant DCS involves soybean followed by maize, the second crop can be cotton, sunflower, or sorghum due to changing weather, economic, and managerial conditions, (Silva, 2012). Producers' decisions in any year depend on their expectation of the costs and returns of double-crop production, associated with the realities of variable rain patterns. In general, the double cropping becomes feasible when rains arrive early to successfully establish the first crop, and then sustain long enough to allow the planting and maturation of the second (Hexem and Boxley, 1986).

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. Greater risks translate into greater pressure on managers to effectively plan for the cropping year, and then execute that plan under changing weather and pest pressures. 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. Additionally, the choice of early-maturing varieties, row spacing, and plant population become key decision variables for both crops when managers optimize their double cropping (Hexem and Boxley, 1986; Watt, 2019).

In the context of Mato Grosso, farmers have dramatically expanded double cropping practice over the last 20 years as they successfully adapted their management to the agro-ecological conditions (Goldsmith *et al.*, 2015). The tropical location of Mato Grosso allows the double-cropping soybean-maize system to increase significantly the amount of protein, starch, and oil produced per hectare compared with temperate and subtropical regions (Goldsmith *et al.*, 2011). However, the tight operating window of the soybean-maize succession system also creates important post-harvest loss management considerations for the first crop (soybean) (Goldsmith and Montesdeoca, 2018). Managers optimize grain production and profitability across both crops, which leads to higher post-harvest losses and poor grain quality of the first crop (soybean), as farmers expedite harvest in order to assure sufficient growing time for the second crop ahead of the impending dry season (Goldsmith *et al.*, 2015).

The study presented in this paper provides new insights into this complex decision space for managers in the tropics by leveraging the case study method. A better understanding of the safrinha system becomes particularly important in a rural economic and social development context because agricultural productivity in tropical regions, such as Mato Grosso can be so transformative (Richards *et al.*, 2015; Goldsmith, 2018).

3. Research Data and Method

We employ the case study method to derive a deeper understanding of the planning and decision processes of double crop managers. Case studies allow an understanding of the ''why'' and, or, ''how'' things happen, rather than trying to measure a phenomenon's frequency (Yin, 1998). In this way case studies allow an understanding of phenomena and their context. Case studies utilize both primary and secondary sources, as well as quantitative and qualitative data (Yin, 1998). Even though case studies can involve the gathering and analysis of quantitative data, the approach mainly relies on the analysis of testimony and descriptions of phenomena by actors through the use of content analysis (Butterfield *et al.*, 1996; Burnett and Badzinski, 2000). The benefit of using qualitative research method relates to the flexibility and freedom for an in depth exploration of the phenomenon of interest (Strauss and Corbin, 1990).

Following Yin (1998), we used the above literature review to inform the construction of a semi-structured interview instrument (Appendix 1). We tested the instrument on a subset of farmers. The final interviews took place via telephone in Portuguese (Brazil's official language) by a native speaker with experience in farm management in the tropics. The enumerator recorded each interview with the farmer's permission. The research team initially analyzed each interview for clarity, completeness, and theoretical

saturation to see if a follow up call was necessary (Strauss and Corbin, 1990). The non-probability sampling method was used to choose cropping farmers belonging to a list of all farmers provided by Aprosoja (Brazilian Soybean and Maize Farmers' Association). Diversity across a number of variables guided researchers in terms of their sampling, such as a farmer's age, cropping region inside Mato Grosso, number of years practicing DCS, and cropping area (hectares). The researchers sequentially conducted the interviews, initial analysis, and final analysis individually for each farmer. Doing so incrementally built a body of understanding to a point where additional interviews began to show repetition and added little to the understanding of safrinha management. The team conducted a total of 16 interviews between November 2017 and November 2018 (Table 1).

The interview instrument design sought to provide insights into ten questions related to managerial decision making:

i. What is the essential element that allows you to engage in the DCS?
ii. What would be a second, or next most important element for you when thinking to engage the DCS?
iii. What are additional benefits of engaging in the DCS?
iv. How do planning for the first and second crop differ?
v. What role does the previous cropping season play in planning for the current year?
vi. What challenges are there when selecting your DCS crop combination?
vii. Are there particular challenges to first crop management, specifically soybean, when thinking about the second crop?
viii. Are there particular challenges to second crop management, specifically maize?
ix. Under the DCS system you harvest the first crop in the middle of the rainy season. Are there challenges maintaining grain quality?
x. Describe the unique risks when you adopt the DCS.

The research team transcribed each audio interview file into a text file for analysis using the MaxQDA (2019) software package. The content analysis followed the coding process suggested by Miles & Huberman (1984). In this process, the researcher establishes "codes" based on key-words suggested by the research objectives and literature review. The coding process involves categorizing the text (interview content) into the code structure. The principle behind the coding process is the "pattern-matching" approach, in which the issues related to the research are identified and stored for the analytical stage of the research process.

The 16 interviews produced a total of 1,550 different words ranging in usage from a singular use to 160 times (soybean). The research team employed pattern matching to six categories relevant to the subject matter: weather; crops; safrinha management; economic decision making; general management; and quality. As expected most words (71%) or 4,749, were not relevant and fall outside the six categories of interest. The words of interest comprise 29% or 1,978 text units.

4. Results and Discussion

The research's general focus is to understand the complexities of the decision making setting facing DCS managers, as expressed by the managers themselves (Figure 1). The use of interviews for data gathering is an important strategy to understand the context of a phenomenon, as it provides flexibility through the semi-structured interview format to explore important gaps in the literature. The enumerator follows the unique direction taken during each interview without the constraints of a structured survey, which in turn allows for a clear understanding of the inquiry by the respondent, a thorough elaboration of context, and greater data richness.

It is also important to highlight that in the interviewees' quotations cited in this document, the presence of text between brackets "[ ]" indicates extra information added by the researchers to improve the readers' understanding. The interview quotations were translated from Portuguese into English. As with any translation, nuance, context, and interpretation become essential in order to derive the full meaning of the response. So the

Table 1: List of farmers interviewed in the research and their profiles

Interviewee #	Name	Municipality	Region in MT*	DCS** (Ha)	DCS** Experience (years)	Farmer's Age	Cropping Season
1		Feliz Natal	North	450	17	34	2017-18
2		Diamantino	North	860	8	>35	2017-18
3		Nova Mutum	North	1,350	15	>40	2017-18
4		Alto Taquari	South	1,300	10+	>50	2017-18
5		Rondonópolis	South	1,200	21	>50	2017-18
6		Alto Garças	South	4,000	16	>50	2017-18
7		Canarana	East	80	1	>50	2017-18
8		União do Sul	North	850	20+	>40	2017-18
9		Nova Mutum	North	120	18+	>40	2017-18
10		Canarana	East	1,000	10	48	2018-19
11		Canarana	East	200	11	>50	2018-19
12		Sorriso	North	1,250	13	33	2018-19
13		Alto Taquari	South	1,100	12	54	2018-19
14		Santa Rita do Trivelato	North	120	6+	59	2018-19
15		Jaciara	South	1,300	20	29	2018-19
16		Tapurah	North	1,300	15	48	2018-19

*MT: Mato Grosso State (Brazil); **DCS: Double-cropping System.

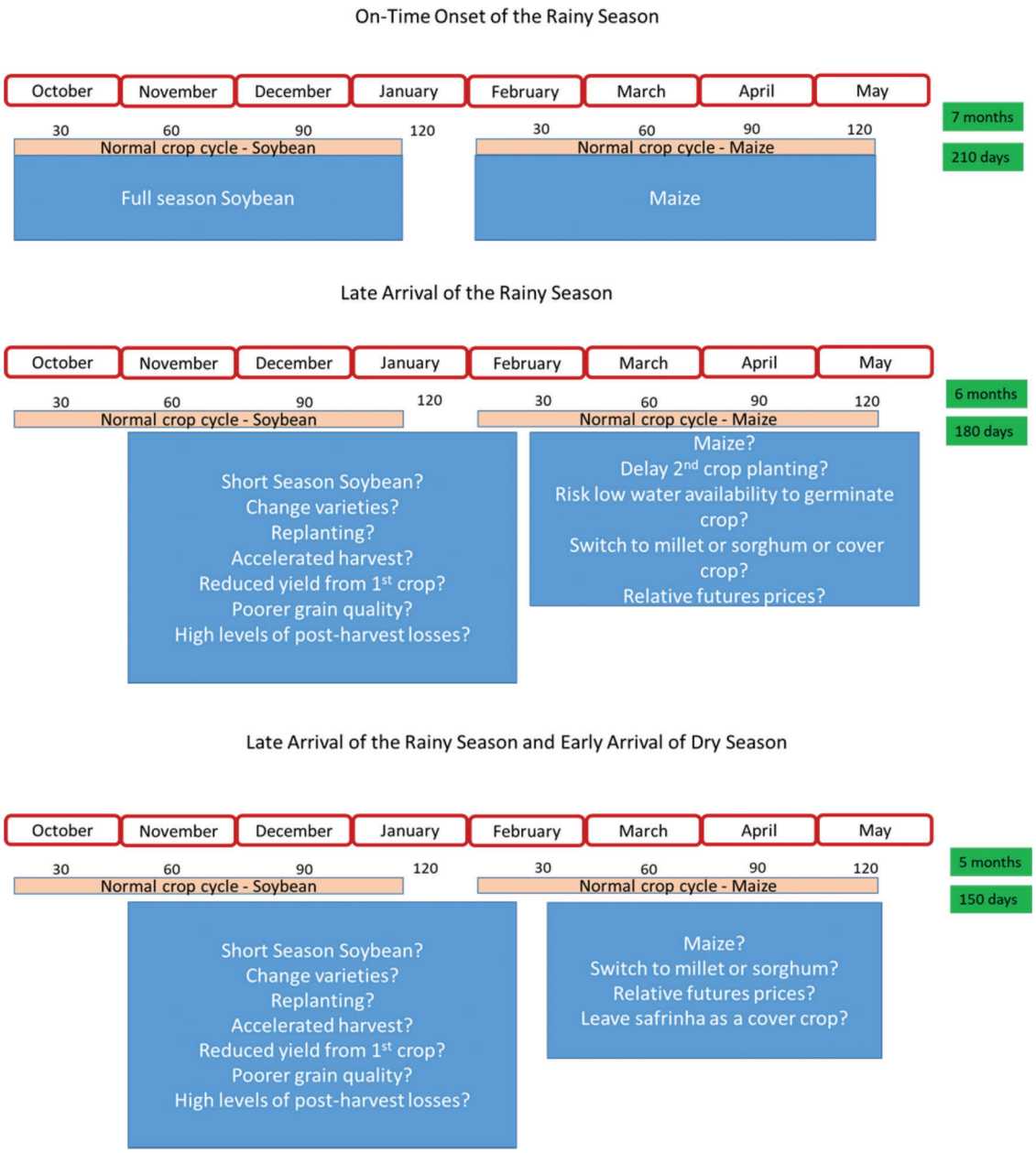

Figure 1: The Complex Decisonmaking Environment Facing DCS Managers

researchers added contextual translation to support respondent's answers.

I. What is the essential element that allows you to engage in the DCS?

> *Basically it's climate only. Because it depends on the soybean harvest to generate the area to plant maize. Sometimes there is a shortage of rain, right? [**Farmer 12**]*
>
> *It's always the weather, right? [We need to consider the weather.] to avoid the risk of planting and losing the crops, then, [the second factor affecting DCS] it is pest management. [**Farmer 10**]*
>
> *The main one is the weather. We depend on the weather. If soybeans are planted early, you can increase the crop area slightly. But if the weather isn't favorable, the rainy season takes a long time to start, and it is delayed; then, the planting window of the "safrinha" is shorter. So, we reduce the area a little. [**Farmer 8**]*

The weather category, fifth out of the six categories in terms of frequency, accounted for 13% or 252 of the 1,978 categorized words. The top three weather related words, totaling 40% of the weather utterances, were not surprisingly, rain, climate, and climatic period (época).

Responses are consistent with previous research (see Shapiro, 1992) that present the long rainy season in certain regions of the tropics as the key enabling condition for the DCS. Soybean maturity ranges from 90-120 days, while time to tasseling in maize is about 75-80 days, thus a 165-200 day rainy season would theoretically allow two full crops. The north central city of Sorriso, Mato Grosso, in the heart of the soybean belt, receives an average total of 1,883 mm of rain per year, with 94% (1,761) occurring in seven months, October – April (Climate-Data.org, 2020).

II. What would be a second, or next most important element for you when thinking to engage the DCS?

*If you cannot do the planting of maize [which would be the preferable crop], we enter with millet to prevent the soil to be uncovered, right? Planting millet, planting sorghum, something like that, right? Because everything you plant will cost. So, I try to establish a crop that has the lowest possible cost, to avoid leaving the soil without anything, right? [**Farmer 9**]*

*I seek to improve the soil. So, if the maize income and expenses are even, if I can put the extra nutrients that the maize needs, avoiding the maize to extract the nutrients already in the soil, and leave a coverage, it's okay for me. [**Farmer 1**]*

The discussion of crop choice, third out the six categories in terms of frequency, occurred 339 times, or 17% of the time during the interviews. The farmers mentioned seven different crops in total, but as expected soybean (47%) and maize (40%) led with 87% of all words spoken within the crops category. The other mentioned crops were, cotton (6%), sorghum (3%), millet (2%), sunflower (1%), and black bean (1%).

Second crop choice becomes the second key element for farmers engaged in the DCS. Second crop brings a key agronomic element, protecting the soils from water erosion, essential when harvesting a first crop mid-rainy season. The thin tropical soils covering the rolling farmland of Mato Grosso present significant erosion risk if exposed post-harvest to an additional 3.5 months of precipitation.

Farmers highlight that the second crop also improves soil organic matter, and breaks pest and weed cycle, and elevates yields of both crops, much like annual maize-soybean rotations in temperate and sub-tropical climates. As a system, the DCS economics and agronomics are interrelated in terms of second crop choice and rainfall timing. While maize is the most profitable and preferred, delays in the beginning of the rainy season and difficulty in first crop establishment then pushes the second crop closer to the dry season window. So crops that can handle dryer conditions or a shorter growing season, like millet and sorghum, become options when rains are slow to come during first crop establishment.

III. What are additional benefits of engaging in the DCS?

*[My first objective regarding DCS] is increasing the income, right? And you also end up with more weed control, because you can use some products that you won't use in the soybean season. [**Farmer 4**]*

*In addition to the financial part [of adopting the DCS], [which is] to have an extra income, is to take advantage of the farm machinery and labor. [**Farmer 12**]*

Economics, fifth out of six categories in terms of frequency, comprises 14% or 282 of the 1,978 relevant words spoken during the interviews. The dominant words comprising 36% of all words within the economics category are prices (20%), markets (10%), and costs (6%).

The second crop really is a secondary crop, hence the name safrinha, as a follow on crop to the primary crop soybean. However, the second crop choice is an economic choice. Farmers for example leverage the second crop to utilize excess inputs in inventory, such as glyphosate, which is a herbicide for both broadleaf and grass weeds, thus has value in both safrinha crops (soybean and maize). The safrinha system also improves operational efficiency by utilizing equipment, infrastructure, and labor over a second crop. Such a practice lowers fixed costs per unit of grain produced or hectare of land.

IV. How do planning for the first and second crop differ?

*Yes, yes [we may speed up operations in the first crop], as long as it doesn't harm the first crop [primary 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. [**Farmer 5**]*

*I wait for the right time to harvest soybean, which is the first crop [primary crop], and then I start planting the second crop. So, I don't speed up, I always harvest [primary crop] at the right time. [**Farmer 2**]*

*In fact, I prioritize the first crop [primary crop] right? The second [secondary crop] if it works, it's okay. If it doesn't work, it's okay, too. You may have to delay the harvest of the first crop, and then delay the planting of the second crop. So, I invest less [in the secondary crop]; although, I have already bought the inputs, sometimes I store one fertilizer from one year to the next, [and] change the seed for a cheaper one. [**Farmer 2**]*

*No, never [speed up the first crop]. And it will not happen. Perhaps only if you plant cotton [if cotton is the primary crop], and maize is the "safrinha" in the case [secondary crop]. However, if you plant a soybean crop and then a cotton crop, I think that in fact cotton would have priority [primary crop], which is what happened to farmers who have not yet planted in some fields around here [this season], [because] it has not rained enough. In the soybean fields where seeds didn't germinate very well, farmers are now desiccating, grading, leveling [the field] and they will not even grow soybeans anymore. It is better to plant straight the cotton crop [primary crop]. [**Farmer 3**]*

*It is always very difficult to advance [the operations in the primary first crop]. I always harvest it at the right time [**Farmer 11**]*

*It doesn't happen because soybeans need to close its cycle. (…) Yeah, you can apply desiccant a little bit in advance, but you can't complete the cycle a lot more than a week in advance. [**Farmer 4**]*

As expected, discussion of safrinha management occupied the largest set of text units among the six categories with 548 or 28% of the text units. System (14%), inputs (4%), and availability (3%) comprise the top three most commonly used words within the category.

Soybean really is the first or primary focus for farmers in the tropical DCS. Maximizing system profitability entails not accelerating or reducing managerial focus on that first crop. These comments appear contrary to

Martins *et al.* (2014) that posit an integrated set of production decisions during the critical 1st crop harvest- 2nd crop planting window, who suggest that moderate levels of post-harvest soybean losses result from accelerating harvest to permit 75 days for the maize crop to flower. System optimality involves focusing management on that first crop, and then being flexible with the second crop, whether that be in terms of planting date, input usage, cost management, or crop choice (maize, millet, or sorghum). However, the respondents describe a second DC model where 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.

V. What role does the previous cropping season play in planning for the current year?

*(…) it all depends on the weather [decision about the second crop]. If it's a little late it's going to be cotton, if it's late it's going to be maize, and if it's very late, it's just straw for organic matter. [**Farmer 6**]*

*[We decide on the second crop] depending on the year, on the price, and on the demand. We analyze the market and use other [than maize] crops as well. [**Farmer 12**]*

*[The crop combinations in the last season] were soybeans [first crop], maize and sunflower [second crop]. ...[sunflower] because it requires less rain, less water. [**Farmer 12**]*

*I vary [my decision on the second crop] according to [the conditions] of each year. (…) Because, for example, this year, I started planting soybeans on October 20th [which is late]. I was scheduled to plant cotton and I couldn't do it because of the late planting [of the soybeans]. [**Farmer 15**]*

*(…) then I'll have to be aware of the area's rain [to decide on the second crop]. If it dries I make the maize intercropped with brachiaria which produces a little more straw [organic matter]. Or I'll have to either plant a more drought-tolerant soybean variety, or a more drought-tolerant maize. [**Farmer 15**]*

There appear to be two components of the intertemporal decision making. The first being the in-season relationship between the first crop experience affecting management of the second crop. Managers closely monitor the first crop and continually update their planning for the second crop as that first crop nears maturity. Thus, flexibility becomes key, and appropriate cost management become key to maximizing profitability of that second crop. For example, as discussed above, that second crop can be late, thus a critical decision is not to over invest in the second crop because a full crop may not be possible. Additionally, maize prices too change over the season, as first crop maize in southern Brazil and Argentina is harvested first, as well as the US maize crop, which comes in early in the season. All this information feeds back to inform managers as to the level of investment to make in the second crop.

VI. What challenges are there when selecting your DCS crop combination?

*It's always the market, the price and the weather. It comes down to that. And the price of seeds, too. [**Farmer 10**]*

*Thus, one of the biggest challenge is the production costs. That's why we order and buy inputs in advance, to get better prices. The other challenge is really the climate, which defines which maize [second crop] to use and which technology to use, as well. [**Farmer 16**]*

*[**Interviewer**]: In addition to what you said, which is rain affecting the planting of soybean, would there be any more challenges that you face? [**Farmer** 9]: Yes, several. Costs matter, this influences a lot, [and]. the [product] future price, right?*

***[Farmer 2]:** Not, not at all. I always choose maize or sorghum [as the second crop, having soybean as the primary first crop].*

***[Interviewer]:** (…) and what were the DCS combinations you used over the last three years?*

***[Farmer 6]:** Soybean [primary first crop] and maize [secondary second crop]*

***[Interviewer]:** Is it rare to change this combination?*

***[Farmer 6]:** It is very rare!*

***[Interviewer]:** Do you already have the DCS combination decided for each year or it may vary?*

***[Farmer 7]:** No, it is always maize, right? [as secondary second crop and soybean as the primary first crop]*

***[Interviewer]:** what were the DCS combinations you used over the last three years?*

***[Farmer 8]: (** …) It has always been maize [secondary second crop]. After soybean [primary first crop] I plant maize.*

The second inter-temporal decision involves the annual pattern where experiences in one year carryover to inform planning for the following year, similar to management decision making in temperate and subtropical systems. Farmers rely on past experiences and well known efficient DCS combinations for their farm context and regions. Thus, they follow the same DCS combination year after year. By doing that, they seem to expect that in the long run, their annual decision will result in an efficient and economic DCS combination choice. In the context of the DCS overall dynamics and drivers, both the economic and technical experiences from previous cropping seasons influence on farmers' decision regarding DCS for the next season.

VII. Are there particular challenges to first crop management, specifically soybean, when thinking about the second crop?

*More or less, we have the history of the area - rainfall and such. But, in my case, I wait a little for the definition of soybean planting [first primary crop] to know what my window of the ''safrinha'' [second crop] will be. So, for example, we do not do soybean planting just because the date has come to allow the window of the ''safrinha'' [time window to plan the second crop]. We wait for the rain to do the soybean planting, and once the window of the ''safrinha'' is set, I decide the technology package that I will use [in the second crop]. So this normally occurs in early November. [**Farmer 5**]*

By the time we already have the soybean crop planted [first crop], then, we have to decide on the second crop. We already set plans for the second crop [preliminary plans for the second crop]. But, since the "safrinha" [second crop] is kind of risky for us here, because of the rain issues, right, we wait at least start planting [the soybean] to plan the planting of maize [second crop] (…) ***[Farmer 9]***

(…) from the time I plant the first crop is that I know when I will harvest [and decide about the second crop]. ***[Farmer 4]***

Interestingly, farmers wait well into the season before making a decision. Thus farmers face significant uncertainty and must remain nimble as the rain patterns reveal themselves early in the season. Managers form initial plans and make decisions in the off season with respect to some input purchases. Final decision making, even as to crop choice, is not made until first crop establishment.

VIII. Are there particular challenges to second crop management, specifically maize?

[Due to] the productivity issue of last years' maize, this year I planted only 250 hectares [less area than last season] to invest in a more productive material, with better performance, correcting with limestone. I'll be [planting] only half the area [comparing to last year]. ***[Farmer 1]***

Yes (…) This is also a problem [the climate risk]. It is a very big risk, we even made larger investments in the second crop of the DCS [in the past]. This year we reduced our investment in maize seed. We planted cheaper varieties that were producing the same as the most expensive ones. So, it does not justify using the most expensive. So, under the weather conditions, sometimes the crop goes well, then it lacks a little moisture [water from rain]. It is also a fact that disturbs and worries us a lot. ***[Farmer 13]***

Last year, what influenced a lot was the price issue [price of the second crop] which dropped a lot. So, this year I will invest less than I invested last year [in the second crop]. ***[Farmer 2]***

The DCS not only presents farmers with two crops over which to maximize annual profitability, but also two distinct production activities, both that present significant risk and uncertainty. Much like temperate and sub-tropical farmers who struggle to plant crops when rains are excessive or fail to come, respectively, the tropical DCS farmer worries about the arrival of rain to plant the first crop, and then an early end of the rainy season that can negatively affect yields for the second crop. Then there is the substantial price risk facing DCS farmers. Maize prices can be variable, especially in Mato Grosso, where due to its distance from ports, and harvest timing relative to southern Brazil and the US, the basis can be very weak.

IX. Under the DCS system you harvest the first crop in the middle of the rainy season. Are there challenges maintaining grain quality?

I don't know if you know Mato Grosso at harvesting [time], but here you shouldn't underestimate the rain. It's dry, soon comes rain and you lose your crop because of water ***[Farmer 1]***

(Y)es, because the quality of the grain is an important point at the time of delivery. So, if its wetter, or it's more broken, right? If we get a good grain quality, sometimes we can negotiate better [with buyers]. So we perform this control too. ***[Farmer 5]***

Yes, I do, because when you are going to unload the grain in the elevators [buyers], you have to be careful all the time, right? ***[Farmer 3]***

Yes, because they all go to the warehouse. In fact, if [you (interviewer) mean] the quality in terms of protein and oil content, then I don't know. I know the quality of the warehouse, if it is warehouse standard [grading system standards]. ***[Farmer 2]***

Also, this [grading system quality] is all analyzed, but it is not a problem that will cause a delay or an increase in my planning [DCS planning]. ***[Farmer 9]***

Well (…) You have to see what the weather is like [to harvest first crop]. If it's raining too much, if the crop is starting to be lost, if it's not [raining], its okay! [However] If it's raining too much [in a specific period of days], [if] the grain is swollen and won't come back; [even] If it's raining [at a specific time of a day], sometimes you have to come in and harvest to avoid losses, right? This is it. ***[Farmer 3]***

Farmers sparingly discussed grain quality with only 2% of the text units involving quality. The word quality led the category, while farmers mentioned (grain) moisture only twice among the 1,978 key words. This is surprising given the attention managers pay to weather, rain, and timing. Farmers failed to mention other key quality-related grain terms such as foreign matter, mold, or cracks.

Two unique characteristics arise that make harvest especially challenging and relate to grain quality. The first results from a first crop harvest during the rainy season (January and February), where harvested grain; sits out in combines waiting for fields to dry in between rain events, travels long distances moving from field to storage, originates from green plants desiccated to advance the planting of the second crop, does not properly dry down during the demands of a frenetic harvest period.

The second presents the opposite challenge of excessively dry grain that results from a quick dry down if the dry season ends early or abruptly. Overly dry second crop maize then becomes vulnerable to cracks and breaks during harvest and across the numerous transfer steps as the grain moves from the field to customer or distant ports.

X. Describe the unique risks when you adopt the DCS.

Actually, I think [DCS] increases the risk, right? The advantage is that we get the straw [organic matter], if we do not harvest the "safrinha", if the maize is not good, the straw is for the next year ***[Farmer 2]***

*In fact, we increased the risk [when adopting DCS]. Because "safrinha" [second crop] has a much riskier planting and there may be a lack of water at the end. Over time we are adapting. (…) We would divide soybean planting better in stages when we didn't have a [second] crop. In that sense, I had enough material [varieties] for 100 days, 120 days, 140 days. Today [with DCS], we plant all the materials of 110, 120 days; so, as we shortened the harvest time [of the first crop], we put it all at the same time, increasing our risk of losing [the first crop] in rainy weather. [**Farmer 5**]*

*There is also the concentration of efforts in the harvest. It has to have greater agility, more efficient machinery, well-trained employees to take every minute of opportunity within the harvesting time [of the first crop], right? [**Farmer 16**].*

*(…) so, of course, in the year with a better price forecast for maize [second crop] and longer rain period, of course, this influences; so, we accelerate, we work 24 hours [to plant the first crop]. This increases the risk at harvest, because it concentrates more the planting [of the first crop], so it is a risk that we have to calculate to see if it is worth it. We're having a good result with maize [as second crop], but it increases the risks. [**Farmer 16**].*

There are clearly economic gains from planting two crops both from increased revenue and better utilization of the farm's assets. However, the DCS adds significant risk and uncertainty to the enterprise compared to when farmers plant only one crop per year. Heightened levels of management become essential from crop and input planning ahead of planting, synchronizing operations across wide geographies and tight weather windows during the growing season and at harvest, and training and optimizing the deployment of field and maintenance employees throughout the year.

5. Conclusions

The central objective of this research was to understand the context of the DCS decision making process. Interviews with operators provide insights into the unique management environment of the DCS. The findings, while set in Mato Grosso, Brazil, will prove helpful to both researchers, investors, and policymakers exploring the potential for DCS's productivity gains in other tropical settings.

Specifically, the DCS involves a very tight relationship between the dynamics of the weather and the practice of adaptive management. As the weather changes at planting, say due to delayed rains, then the farmer needs to replant, possibly multiple times, adjust varietal selection for maturity, and change up the second crop choice accordingly. Such dynamics play out throughout the crop year. For example, late planting, or an early end to the rainy season too can mean farmers make the difficult choice to harvest second crop grain or simply plow the crop in to maximize organic matter as a second best outcome.

DCS requires a sophisticated planning process, and the analysis reveals two types of management profiles. The first profile, refers to management intensive farmers that closely monitor the weather and market conditions and prepare themselves to adjust plans in case of any unexpected event from planting through to harvest during the first crop. Management intensive farmers maintain appropriate levels of physical and human capital to take advantage of tight weather windows so they can expedite cropping activities across broad geographies and maintain grain quality. They monitor the market, invest in technology and equipment, and set different DCS plans and possible combinations each year.

Alternatively, there are also more rule based managers, such as corporate farms, where planning needs to be more routine and less adaptive as farming operations are extensive. Smaller farms being less well capitalized behave similarly but for different reasons. They invest less in their management systems and, like the corporate farms, rely on a DCS combination that has, in general shown success over time, such as, a soybean-maize succession system that uses standard varieties and hybrids, respectively.

Another interesting finding from the interviews is that land allocation between the first and second crop often do not align, so rotations are not always complete. First crop planting for example is not a singular event, but plays out over weeks as some fields establish due to adequate moisture, while others do not and require replanting. Similarly, at 1st crop harvest, rains can delay field activities, which also then also disrupt the second crop planting plan. Some fields may receive the intended crop, while others, an alternative grain, while still others simply a cover crop. The lack of a complete alignment then carries over to complicate the following year's plans and implementation as individual fields with different cropping histories require altered fertilizer, liming, or chemical regimes.

The farmers inform us as to a nuanced understanding of the terms "primary" and "secondary" crops. There is the traditional model, where the first crop is the primary crop, often soybean, and it receives the greatest focus, investment, and management within a two crop system when maximizing profitability across the crop year. The manager adapts the second crop, often maize, depending on outcomes from the first crop. S/he may delay planting, switch out the maize for an alternative crop, or even plow under an immature crop.

DCS farmers though, depending on relative prices, costs, and yields, may opt to make the second crop the primary crop, such as cotton, to take advantage of the drier periods later in the growing season. In such cases the farmer may employ an early maturing soybean so that harvest takes place as early as Christmas, which allows a lengthy growing period before the dry season arrives in May.

In either case, managers recognize the importance of the quality of the grain or cotton from the primary crop, in addition to yield, compared with yield and quality from the secondary crop. It is important to note that first handlers in Mato Grosso grade the grain they buy, and provide that information, including discounts, to farmers on the weigh slip. As a result farmer are both informed and incentivized to prioritize quality appropriately.

Lastly, farmers self-report that adopting the DCS creates more stress in the workplace for them and their employees, compared to a single crop system common in temperate and sub-tropical settings. This makes sense as

the weather is so variable, tropical soils have poor water holding capacity, and disease and pest pressure is significant, so risk and uncertainty are high. Managerial decision making becomes a continuous activity, thus there may be more pressure compared with single crop systems. Managers must closely monitor and adapt from pre-season planning through the harvest and sale of the second crop because of the multiple dynamic features of the DCS.

Formally comparing double and single cropping systems as to their level of management required, both qualitatively and quantitatively, as well as the level of risk, becomes a logical next step for researchers investigating farm management in tropical settings. Anecdotal evidence shows single crop managers from the US or Argentina struggle when operating investor owned (large) farm enterprises in Mato Grosso. Martins *et al*. (2014) may shed some light as they discuss the challenge of hierarchical management structures, which present a principal (owner) – agent (operator) problem, when operating in the management intensive environment of Mato Grosso. Though the authors focus on post-harvest loss management, they raise the important point that adaptive management or nimbleness in decision making may suffer when managerial bureaucracies associated with investor-owned farms operate within dynamic environments. In this way the DCS may challenge the investor model as they look to expand professional farming systems into other tropical regions, such as Africa, while being better matched when owners directly operate the farm.

About the authors

Dr. Altair Moura is a professor at the Federal University of Vicosa in Brazil. His email address is: altair.dias.moura@gmail.com

Dr. Peter Goldsmith is a professor at the University of Illinois in the USA. He is the contact author and his email address is: pgoldsmi@illinois.edu

Acknowledgement

Funding: The ADM Institute for Post-harvest Loss and the Aprosoja-MT (Mato Grosso State (Brazil) Soybean and Maize Farmers' Association) provided financial and in-kind support, respectively, for this research.

REFERENCES

APEX-Brazil. (2018). Brazil makes strides in agriculture all over the country. Brazilian Trade and Exporting Promotion Agency. Available at: http://www.bebrasil.com.br/en/news/brazil-makes-strides-in-agriculture-all-over-the-country.

APROSOJA-MT. (2019). A história do Milho. Associação dos Produtores de Soja e Milho do Estado de Mato Grosso. Available at: http://www.aprosoja.com.br/soja-e-milho/a-historia-do-milho.

Arvor, D., Meirelles, M.M., Dubreuil, V., Bégué, A. and Simabukuro, Y.E. (2012). Analyzing the agricultural transition in Mato Grosso, Brazil, using satellite-derived indices. *Applied Geography* 32:12.

Beuerlein, J. (2019). Relay cropping wheat. Agricultural-Land.com – Practical Advice Interesting Facts. Available at: https://www.agricultural-land.com/article/Relay_Cropping_Wheat_Soybeans.html

Borchers, A., Truex-Powell, E., Wallander, S. and Nickerson, C. (2014). Multi-Cropping Practices: Recent Trends in Double Cropping Economic Information Bulletin N.125. Economic Research Service. United States Department of Agriculture.

Brazil. (2018). Brazilian agriculture shows strong output and productivity. Presidency of The Republic of Brazil. Available at http://www.brazil.gov.br/about-brazil/news/2018/08/brazilian-agriculture-shows-strong-output-and-productivity.

Burnett, A. and Badzinski, D.M. (2000). An exploratory study of argument in the jury decision-making process. *Communication Quarterly* 48:380-396.

Butterfield, K.D., Trevino, L.K. and Ball, G.A. (1996). Punishment from the manager's perspective: A grounded investigation and inductive model. *Academy of Management Journal* 39:1479–1512.

Climate-Data.org. (2020). https://en.climate-data.org/south-america/brazil/mato-grosso/sorriso-32542/. Accessed April 2020.

Cohn, A.S., Mosnier, A., Havlík, P., Valin, H., Herrero, M., Schmid, E. and Obersteiner, M. (2014). Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. *Proceedings of the National Academy of Sciences*, 111(20), 7236–7241.

CONAB, Companhia Brasileira de Abastecimento. (2019a). *Acompanhamento da safra brasileira de grãos* 6(11). Brasília: CONAB.

CONAB, Companhia Brasileira de Abastecimento. (2019b). *Indicadores da agropecuária* 28(7). Brasília: CONAB.

CONAB. (2019c). Série histórica das safras. Companhia Brasileira de Abastecimento. Available at: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=20.

Cruz, J.C., Pereira Filho, I.A. and Duarte, A.P. (2019). Milho safrinha. Embrapa - Agência Embrapa de Informação Tecnológica. Available at: https://www.agencia.cnptia.embrapa.br/gestor/milho/arvore/CONT000fya0krse02wx5ok0pvo4k3mp7ztkf.html.

Dury, J., Schaller, N., Garcia, F., Reynaud, A. and Bergez, J.E. (2012). Models to support cropping plan and crop rotation decisions. A review. *Agronomy for Sustainable Development* 32(2):567-580.

Goldsmith, P.D. (2011). Maize and Soybean Production in Brazil: The Safrinha Miracle. Paper presented at The Soy and Grain Trade Summit. St Louis.

Goldsmith, P.D., Martins, A.G. and Moura, A.D. (2015). The economics of post-harvest loss: a case study of the new large soybean - maize producers in tropical Brazil. *Food Security* 7(4):875-888.

Goldsmith, P.D. (2017). The Faustian Bargain of commercial crop agriculture in Africa. *Tropical Conservation Science*, 10, 1-4.

Goldsmith, P.D. and Montesdeoca, K. (2018). The productivity of tropical grain production. The International Journal of Agricultural Management Volume 6, Numbers 3-4, pp.90-99.

Heggenstaller, A.H., Anex, R.P., Liebman, M., Sundberg, D.N. and Gibson, L.R. (2008). Productivity and Nutrient Dynamics in Bioenergy Double-Cropping Systems. *Agronomy Journal* 100:1740-1748.

Hexem, R.W. and Boxley, R.F. (1986). Trends in double cropping. Agricultural Economic Report N.553. Economic Research Service United States Department of Agriculture.

Martins, A.G., Goldsmith, P.D. and Moura, A.D. (2014). Managerial factors affecting post-harvest loss: The Case of Mato Grosso, Brazil. *International Journal of Agricultural Management*, 3(4), 200-209.

MaxQDA. (2019). All-in-One Qualitative & Mixed Methods Data Analysis Tool. https://www.maxqda.com/

Miles, M.B. and Huberman, A.M. (1984). *Qualitative data analysis: a sourcebook of new methods*. Beverly Hills: SAGE Publications, Inc.

Phalan, B., Onial, M., Balmford, A. and Green, R.E. (2011). Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science*, 333 (6047),1289–1291.

Richards, P., Pellegrina, H., VanWey, L. and Spera, S. (2015). Soybean Development: The Impact of a Decade of Agricultural Change on Urban and Economic Growth in Mato Grosso, Brazil. *PLos ONE* 10(4). Available: https://doi.org/10.1371/journal.pone.0122510.

Shapiro, B.J., Brorsen, B.W. and Doster, D.H. (1992). Adoption of double-cropping soybeans and wheat. *Southern Journal of Agricultural Economics*. December:33-40.

Silva, R.A. (2012). Mato Grosso desenvolve cultivo de soja e milho de safrinha. *Visão Agrícola* 10:67-69. Available at: https://www.esalq.usp.br/visaoagricola/sites/default/files/VA10-visao-setorial08.pdf

Strauss, A. and Corbin, J. (1990). *Basics of qualitative research - grounded theory procedures and techniques*. Newbury Park: SAGE Publications, Inc.

Watt, S. (2019). Help for growers Investigating Double Cropping. New South Wales - Grains Research & Development Corporation - Australian Government. Available at: https://grdc.com.au/news-and-media/news-and-media-releases/south/2017/09/help-for-growers-investigating-double-cropping

Yin, R.K. (1994). *Case study research*. second ed. Thousand Oaks, California: Sage Publications.

Appendix

Interview Outlines

FIRST PART: Personal Information:

- Name:
- Age:
- Farm location:
- Cropping area (last cropping season)
- Double-cropping area (last cropping season)

SECOND PART: Challenges and Characteristics of the Double-cropping System (DCS) Decision Making Process

1. How long have you been practicing ''safrinha'' (DCS)?
2. What are the main reasons for adopting the DCS?
3. In which part of the year do you make decisions regarding DCS ? Why?
4. What are the main challenges regarding the DCS planning? Why?
   - Reminders for the interviewer:
     - Crop choices;
     - Price and market information and forecast;
     - Weather information;
     - Credit;
     - Input purchase;
     - Crop conduction; etc.
5. What happens after you decide the DCS combination?
6. During the first crop management and afterwards, in the management of the second crop, what are the main challenges you face? Why?
   - **6.1**- What is the dynamics of the first crop harvest and the sowing of the second crop?
     - **6.1.1-** What are the main challenges at this time? Why?
     - **6.1.2-** How do you decide the best time to harvest the first crop and sow the second crop?
     - **6.1.3-** Which factors can bring problems or lead to changes in the date of the first crop harvest and the sowing of the second crop? How can this happen?
     - **6.1.4**- Which are the procedures to be adopted in case of harvesting earlier the first crop?
       - **6.1.4.1-** What are the consequences of speeding up the machinery during the harvest of the first crop?
     - **6.1.5-** Is it common to change the amount of area from the first to the second crop? If so, why?
7. What is the common combination of crops used in the DCS of the last three cropping seasons? Why?
8. Do you keep records that allow you to know:
   - The first crop expenses and income;
   - The second crop expenses and income;
   - The overall expenses and income from the DCS;
   - The grain quality of the first crop harvest (and why).
9. Which factors happened in the last cropping season and affected your decision making process regarding the DCS of the current cropping season? Why?