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Assessing Crop Portfolios: Diversification versus Monoculture for Biodiesel

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Abstract:
The selection of crop patterns for agricultural areas is usually guided by the maximization of expected income. This variable is, however, influenced by the fluctuations of both crop productivity and prices. The annual variability is directly related to the risk of a crop portfolio and, according to the so called Modern Theory Portfolio (MTP), it is a fundamental aspect to be taken into account during the selection of crops. This is true especially in case of those farmers who are not wealthy. Crop diversification is considered an effective solution able to alleviate the abovementioned inter-annual fluctuations and to guarantee a safe minimum income. This being the context we assess different alternative crop portfolios for biodiesel production in Brazil, where many small and resource-poor ones co-exist with capital-intensive and large-scale farms (units of less than 20 hectares constitute more than 60% of the total farm number). By adopting the MTP approach, we aim to compare two alternative and opposite strategies: monoculture and crop diversification for biofuel crop production. In particular, we evaluate the effectiveness of crop diversification in reducing the risk of crop portfolios and estimate possible losses in terms of expected incomes. The obtained results confirm that the choice of a mixed crop portfolio can guarantee the minimum risk in the majority of the analyzed cases, but the incomes are considerably lower than the ones obtained with monocultures. Nevertheless, the obtained outcomes vary considerably depending on the considered crop. Finally, an increment of diversity could have improved both expected income and risk of actual average national crop portfolio, which is close to soybean monoculture.

***Keywords**:* Portfolio assessment; Crop diversity; Biofuel production; Brazil; Modern Portfolio Theory

1. INTRODUCTION

The selection of crop patterns for agricultural areas is a typical resource allocation problem usually guided by the maximization of expected income (Dury et al., 2012). The latter mainly depends on the expected productivity of crops, which is commonly assumed to be a deterministic function of known variables like, for instance, soil characteristics, local climate and farming practices (Dury et al., 2012). Nevertheless, actual data prove that, even for the same soil at the same location, the variability of crop productivity may be high (Fiorese and Guariso, 2014). This variability is directly related to the risk of a crop portfolio: it is, indeed, usually represented by the variance of incomes (Markowitz, 1952).
In general, farmers wish both to maximize income and to avoid income fluctuations (Libbin et al., 2004). In particular, not wealthy farmers are attentive to minimize the risk of their crop choice in order to avoid to be trapped into the so-called *poverty trap* (i.e., condition in which poverty persists and cannot be recovered without 'outside' intervention). For this reason, any program focused on income generation and asset formation should take into account the risk dimension together with the income one (Dercon, 2007).

This dual approach was proposed by the so-called economic Modern Theory Portfolio (MTP) (Markowitz, 1952): investment strategies are selected by taking into account both the expected income and the risk. Given different possibilities for investment, MPT allows to assess what combination of investments has the lowest risk to realize a certain revenue (most stable income). According to the MTP, the choice of diversified investments can reduce the risk of the overall investment (if selected investments are non- or low correlated). Concerning the agricultural context, since crops (and the dedicated areas) can be

thought of as assets within an overall portfolio, agricultural producers should consider crop diversification in their operations as solution for reducing the risk of their crop patterns (Libbin et al., 2004).
Therefore, besides agro-ecological benefits (Cavigelli et al., 2013; Firth et al., 2008; Flint and Roberts, 1988; Smith et al., 2008; van Ittersum and van de Geijn, 1997), crop diversification is considered an effective tool to reduce the economic risk of a crop portfolio and for poor farmers to avoid poverty traps. On the other hand, actions aimed to reduce the impact of risk can have poverty implications due to their low mean incomes, when compared to more profitable but more risky portfolios, like some monocultures (Dercon, 2007).

This being the context, adopting the MTP, we assess different alternative crop portfolios in Brazil based on the last 20 years of data. In this country, capital-intensive and large-scale farms co-exist with many small and resource-poor (units of less than 20 hectares constitute more than 60% of the total farm number, but occupy less than 5% of farmland, while holdings of over 1,000 hectares account for only 1% of the total farm number and occupy 44% of farmland) (OECD and FAO, 2015). Moreover, more than 25% of Brazil's poor population is living in rural areas where the poverty rates exceeded 45% (OECD and FAO, 2015). We aim to compare two alternative and opposite strategies: monoculture and crop diversification for biofuel crop production. In particular, we evaluate the effectiveness of crop diversification in reducing the risk of crop portfolios and estimate possible losses in terms of expected incomes (in comparison with monocultures). Of course, in practice, all the intermediate combinations (obtained as trade-offs between risk and expected income) are feasible.

2. MATERIALS AND METHODS

The analysis carried out in this study is based on the database of the Istituto Brasileiro de Geografia e Estatística (IBGE, 2015). The time series considered were the cultivated area (ha) and value of production (Mil Reals) from 1994 to 2014. We focused on four among the major crops used for biodiesel production: soybeans, cottonseed, castor seed and peanut (USDA, 2015). Concerning the spatial level of detail, we considered both the whole Brazil and the 5 Brazilian macro regions (i.e., North, Northeast, Southeast, South and Central West), to take into account the wide climatic and territory variability due to the continental dimension of this country. All the considered crops are cultivated in the five regions, except for castor in North, where it has been sparsely cultivated during the analyzed period.
Starting from the two data series available, we calculated the value of production per unit of area (Mil Reals/ha) for each crop in each region, in order to take into account both agricultural yield and crop price and to have the economic value referred to the unit of area, which is the object of our allocation problem. As a preliminary assessment, we consider the gross economic value of crop while assuming constant cultivation costs. For the purpose of our analysis and given the strong positive trend in the time series, we consider only annual variations after removing the trends from the time series. We evaluated the economic performances of different crop portfolios in terms of expected income and risk.

The crop portfolios are defined through the allocation factors for each considered crop (z_c). The constraints of the problem are:
- the use of land should equal the land available (i.e., 1 ha)

$$\sum_{c=1}^{4} z_c = 1 \quad (1)$$

- the non-negativity of decision variables

$$z_c \geq 0 \quad \forall c \quad (2)$$

where z_c is the decision variable (i.e., fraction of each crop) *c* is the crop.

MPT can be applied when four conditions are guaranteed (Elton et al., 2009; Fraser et al., 2005): (1) at any given time there is more than one possible investment (i.e., different biodiesel crop types, which are easily substitutable (Fiorese and Guariso, 2014), (2) risk affects these investments, (3) information about the historical and / or expected revenue of the investments is available and (4) different investments are heterogeneously affected by the same external conditions (i.e., low correlation among investments). These conditions are met when deciding on a cropping pattern (Werners and Incerti, 2007).

As a first step, we solve a minimization problem in order to find the portfolio with the minimum risk. The risk V_{cp} of a crop portfolio is represented by the variance of its revenue, which can be estimated with the following formula (Werners and Incerti, 2007):

$$V_{cp} = \sum_{c=1}^{n} z_c^2 V_c + 2\sum_{c=1}^{n} \sum_{d=c+1}^{n} z_c z_d \sigma_{cd} \quad (3)$$

Where z_c (and z_d) the share of each crop in the crop portfolio, V_c the variance of the revenue of crop cover the analyzed period and σ_{cd} the covariance of the revenue of the crop *c* and *d*. Once found the best crop portfolio in terms of risk, we compare its performance with the best portfolio in terms of expected revenue. Following MPT (Harvey, 1995), the expected mean revenue of a cropping pattern (R_{cp}) with n different crops (each with expected revenue R_c) each grown at a share z_c can be estimated:

$$R_{cp} = \sum_{c=1}^{n} R_c * z_c \quad (4)$$

We then compared the probability distributions of incomes (Mil Reals/ha) of the crop portfolios analyzed. As a last step, we simulated the different crop portfolios for the whole Brazil and we derived the set of Pareto-efficient alternatives and compared the current crop mix (i.e., 2014 data) with the obtained set.

3. RESULTS

3.1. Variability of crop yield and value

We first analyzed data series regarding the considered crops in Brazil (i.e., the average of the five regions) between 1994 and 2014 (IBGE, 2015). In Figure 1 we report the yield of considered crops in Brazil. They are likely to be caused by the improvement of agricultural practices, expansion of mechanization and the availability of more productive varieties. Additionally, annual oscillations (e.g., due to the specific yearly climatic variables) characterize the time series.

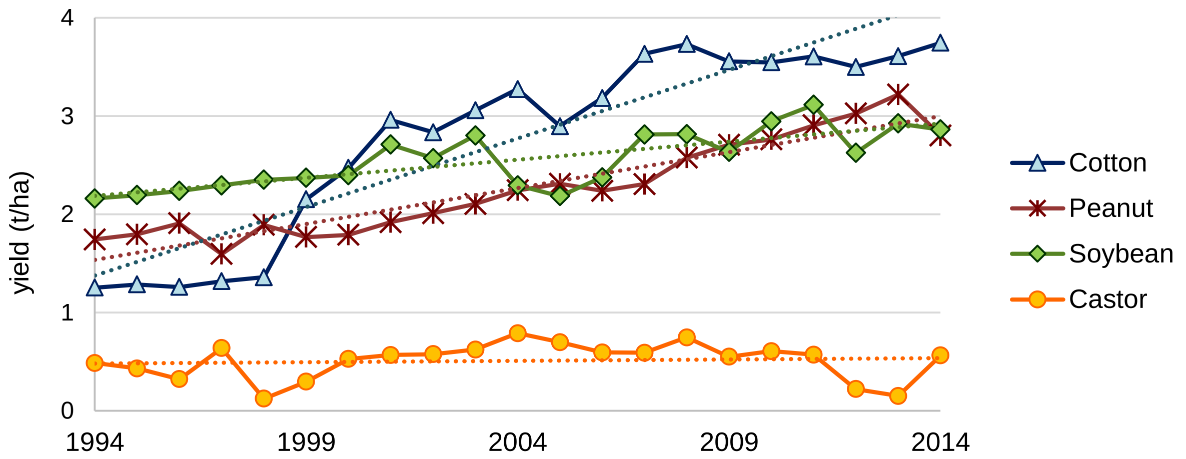

Figure 1. Crop yields (t/ha) in Brazil between 1994 and 2004 (peanut, cotton, castor, soybean)

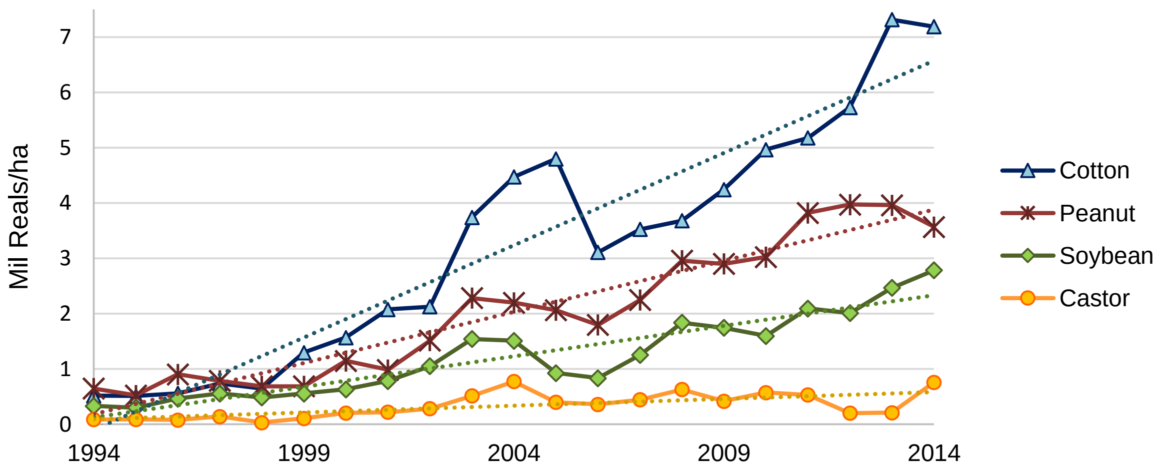

Figure 2. Value of crops per hectare (Mil Reals/ha) in Brazil between 1994 and 2004 (peanut, cotton, castor, soybean)

These trends are reflected also in the economic values per unit of area (Figure 2). Among the crops considered, cotton is characterized by a higher economic value than other crops. It necessary to specify that the available data about cotton refer to the whole product (i.e., both fiber and seed). Nowadays, the main product from cotton is fiber and farmers do not typically count on cottonseed (from which oil is extracted) revenues when they make their planting decisions, but it is expected to become a good option for additional revenues in the future (USDA, 2015).

Given these trends, we de-trended the time series assuming linear increase in time. A Kolmogorov-Smirnov goodness-of-fit test proved that the obtained residuals (except for the all the crops in Northeast and castor in all the states) have a normal distribution at the standard 5% significance level. In this study, we can thus assume that the revenue (Mil Reals/ha) of the oleaginous crops can be described by an increasing trend plus a random stochastic variable with zero mean and a Gaussian probability distribution.

3.2. Assessment of crop portfolios

After the depuration of time series from trends, we solved the allocation problem by minimizing the risk (V_{cp}) for each macro-region. The results confirm the effectiveness of mixed crop patterns in achieving the minimum risk (Figure 3). The only exception is North region, where only three of the four crops have been cultivated to date, and the monoculture of soybean is able to guarantee the minimum risk.

As a second step, we compared the obtained crop portfolios with the best monoculture in terms of both expected value and risk. In case of risk minimization, the expected income (i.e., average over the last 5 years) would be considerably reduced with respect to the maximum performance achievable with the best achievement, which is obtained with monoculture: the overall loss ranges between 54%-87%, depending on the region. Regarding the risk minimization, except in North (where no crop mix is found to minimize the risk), crop diversification can reduce the risk from 18% to 64% (for Northeast and Southeast, respectively) if compared to the best results achievable with a monoculture choice.

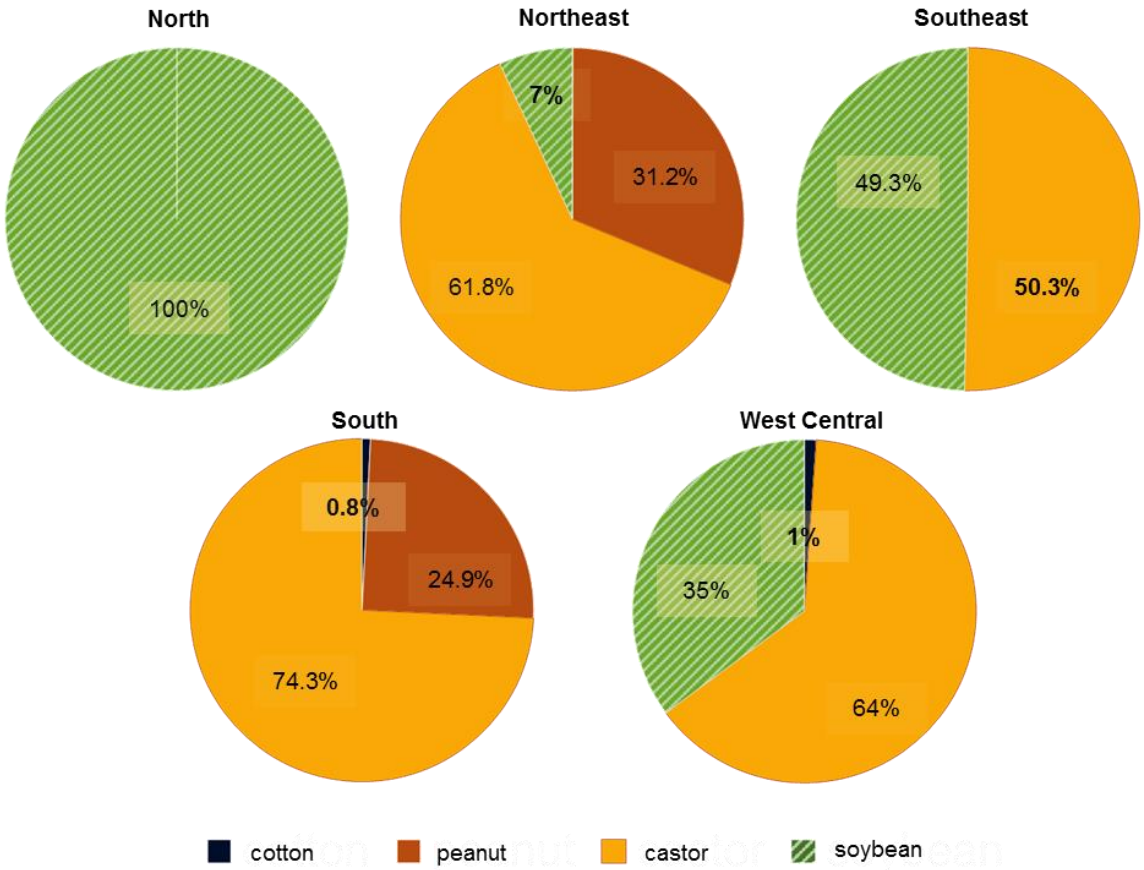

Figure 3. Crop portfolios with the minimum risk (i.e., variability of profitability per unit of area along the considered time period)

Finally, by analyzing the probability that the best crop mix previously found would perform better than each monoculture (Table 1), different situation can occur (Figure 4, we excluded North from this analysis): the crop mix with minimum risk can perform worse (e.g. in the case of cotton) or can perform better than a specific monoculture (e.g., in the case of castor), or can only have some chances to perform better than monoculture.

Table 1. Probability that the crop portfolio with minimum risk performs better than each monoculture in each macro-region (North is not reported since the best crop portfolio in terms of minimum risk is not a crop mix but the soybean monoculture)

Region	cotton	peanut	castor	soybean
Northeast	~ 0	0.02	0.973	~ 0
Southeast	~ 0	~ 0	0.999	0.001
South	0.08	~ 0	0.999	0.06
Central West	~ 0	0.002	0.986	0.05

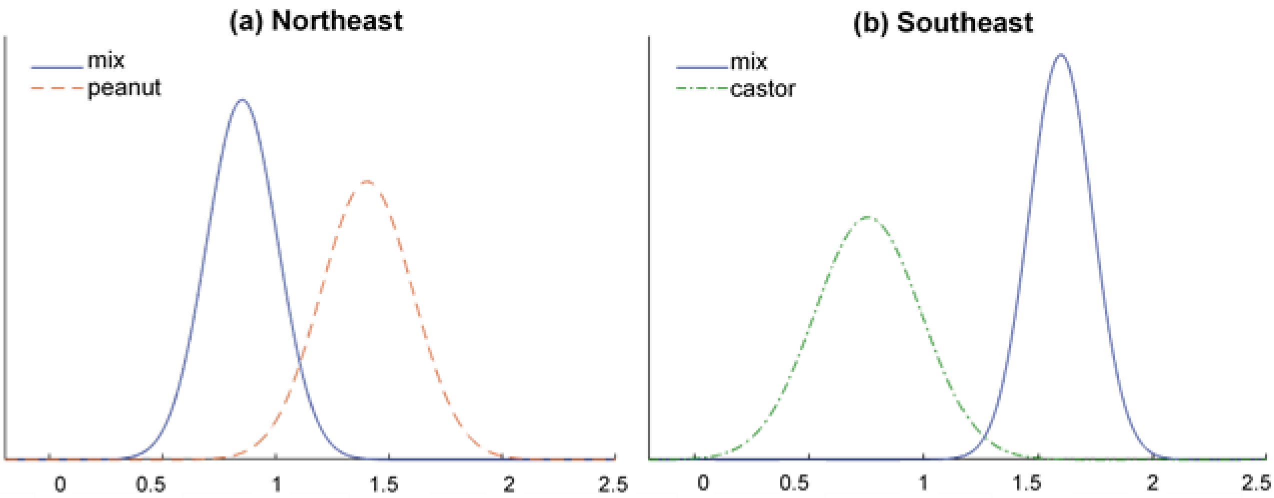

Figure 4. Comparison between the best crop portfolio in terms of risk and the considered monocultures (density probability)

In particular, the economic performance of cotton (in terms of R_{cp}) is difficult to be achieved while pursuing the minimization of risk. On the other hand, given the high variability of cotton revenue, this crop is only marginally included in the solution with minimum risk. To be closer to reality, we increased the level of diversity in the crop mix (Figure *3*) by introducing cotton at the actual fraction present (2014 data), and we recomputed the minimization of risk. For the sake of simplicity, we only reported the case of Northeast. The performance of crop mix increased as expected (the “mix (fixed-cotton)” curve moves closer to the one of cotton than the one of “mix (minimum risk)”), but the economic performance of the monoculture of cotton are still higher (Figure 5).

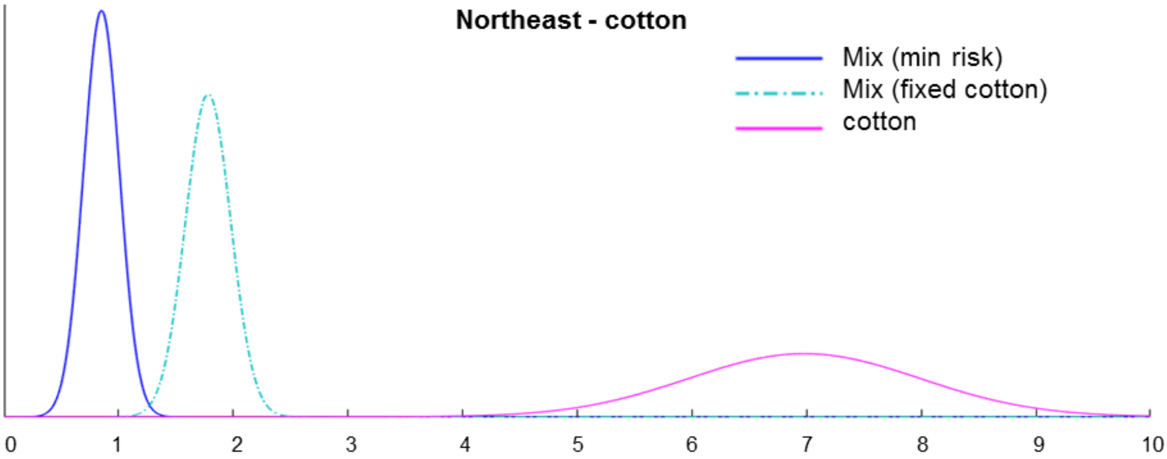

Figure 5. Comparison of crop mix and cotton monoculture in Northeastern region: by fixing the current fraction of cotton cultivated in the region in the crop mic, we can increase the performance of crop mix, but the performance of cotton monoculture remains higher

3.3. Current situation and possible improvement in the whole Brazil

As a final step, we computed the set of Pareto-efficient crop portfolios for the whole Brazil. In Figure 6, we reported the current (i.e., 2014) crop mix cultivated in the whole Brazil (represented with a star). It is characterized by low level of diversity and a strong predominance of soybean (i.e., about 96%). Its average performances are 2.95 Reals/ha and 0.072, for R_{cp} and V_{cp}, respectively, and it is a dominated solution. By moving towards the Pareto front, the results show an improvement of both objectives by increasing crop diversity. If we consider the two extremes among the dominating solution (represented with a circle and a square), we can reduce the risk by 51% (while maintaining the same revenue) or increase the expected revenue by 39% (while maintaining the same risk).

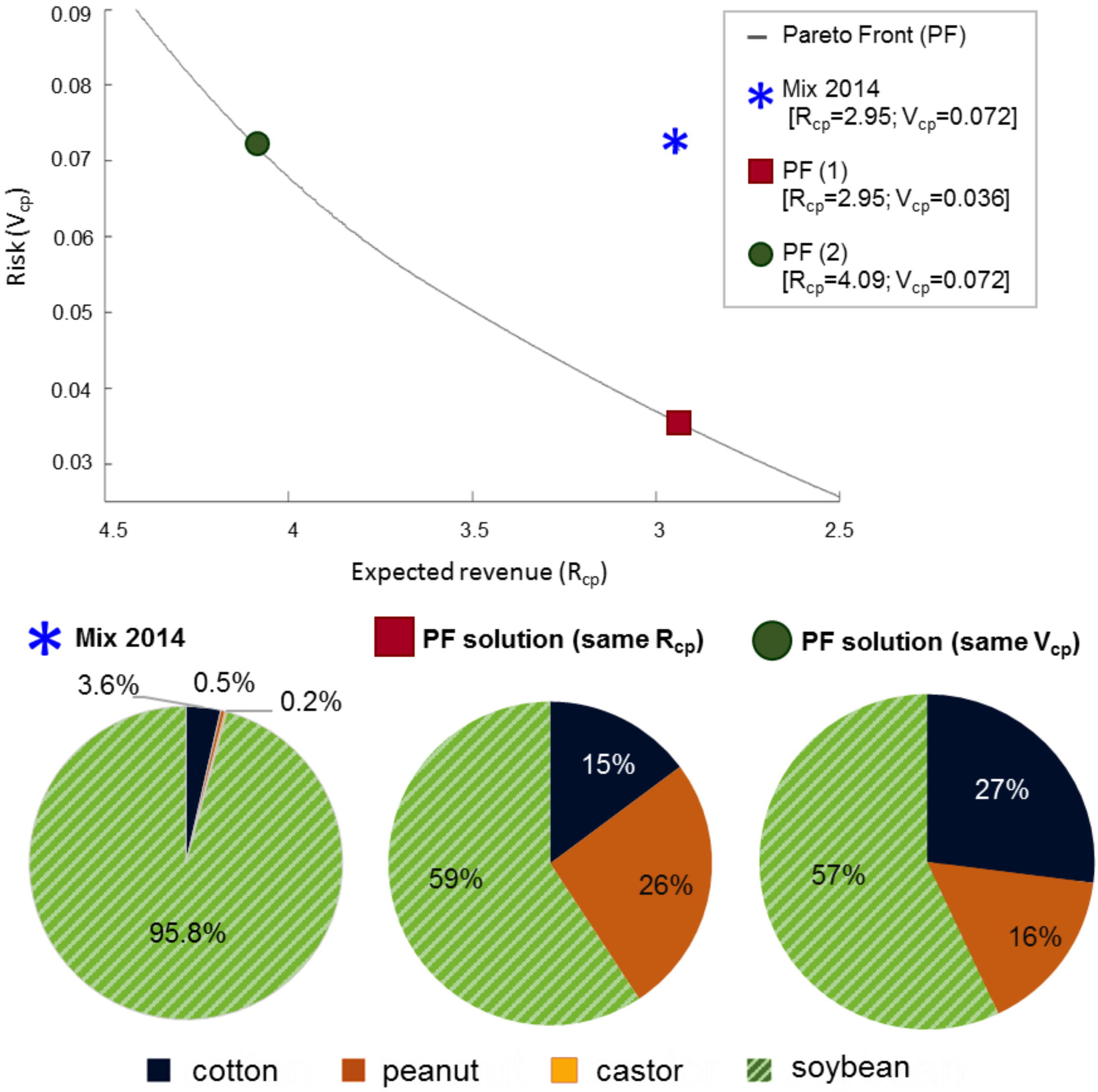

Figure 6. Pareto-optimal crop portfolios, current crop mix (2014) and Pareto-dominating alternatives for the whole Brazil

4. DISCUSSION AND CONCLUSION

This study constitutes a preliminary assessment of crop portfolios for the biodiesel in Brazil carried out by taking into account two fundamental aspects: the maximization of expected income and the minimization of risk (represented with the variance of revenue). The latter is an essential aspect to be considered in agricultural plans, especially in case of not wealthy farmers.

According to the Modern Portfolio Theory, crop diversification can be an effective solution able to reduce the inter-annual fluctuations of economic income. In order to explore this aspect, we focused on the biofuel crop cultivation in Brazil, by analysing the last 20-years data.

The obtained results at regional level confirm that the choice of a mixed crop portfolio can guarantee the minimum risk in the majority of the analyzed cases. Focusing on single crops, cotton is generally the most valuable, but it is also characterized by the highest inter-annual income fluctuation: for this reason, it is marginally included in the crop mix which minimize the risk (i.e., fractions equal to 0.8% in South 1% and in West Central). Among the others, castor is always widely chosen due to its low variability (i.e., fraction higher than 50%, but for North).The incomes obtained with the minimum-risky crop mixes are considerably lower than the ones obtained with monocultures (losses range between 54%-87%). The comparison of the probability distribution of economic incomes of different crop portfolios showed different outcomes depending on the monoculture considered: for instance, cotton is most likely to perform better than the crop mix, while castor is likely to perform worse. Finally, the actual tendency in Brazil is very close to monoculture: considering the analyzed four crops, the current crop mix is characterized by a strong presence of soybean. The obtained results showed that an increment of diversity can improve the performance of actual crop portfolio, both in terms of income and risk.

This analysis represents a preliminary step of crop portfolios assessment. Given the heterogeneity of possible outcomes, the assessment of different crop portfolios should be further performed by deeper analyzing the Pareto-efficient crop portfolios and by considering the aversion to risk of different decision makers (e.g., wealthy and not wealthy farmers). Moreover, a wider perspective should be adopted in the assessment, to take into account the ecological performance of different crop portfolios in terms of biodiversity and other ecosystem services.

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