Benefits of diversified horticultural systems: assessment with the modern portfolio theory

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Abstract: *In a context of a redefinition of farming system, innovative cropping systems have arose in the recent decades. Among them, diversified horticultural systems show a growing interest in Europe, especially among new entrants into farming. One of the main motivations for farmers to grow simultaneously a variety of vegetables and fruits is to reduce the overall risk on production through a diversification effect. On the theoretical point of view, risk reduction based on diversification of assets is a well-studied mechanism in economics that has been formalized in the Modern Portfolio Theory (MPT). In practice, farmers tend to build crop portfolios that generate the highest yield while minimizing the risk on the overall crop production. The objective of this study was to understand how different fruit-vegetable combinations shape the relationship between production and risk in a diversified farming system. Based on the MPT framework, we explored all possible crop portfolios composed of 1 to 5 crops chosen in a list of 22 commonly grown fruits and vegetables. Results showed that (i) increasing portfolio compositions from 1 to 5 crops progressively improves the production-risk trade-off that farmers have to face; (ii) fruit and vegetables classification does not show clear trends to conclude on the interest of diversification based on botanical aspects. These results led us to identify suitable diversification strategies for fruits and vegetables production that make it possible to reduce the overall risk on crop production while maintaining the same level of production.*

Keywords: *Horticulture, diversification, risk, Modern Portfolio Theory, yield, variability*

Introduction

The last decades have been marked by a growing interest in sustainable farming systems, with a fast-acting progress in its achievement (Warlop, 2016; Wezel et al., 2014). Within this general dynamic, farming strategies developed by innovative growers are highly diverse (Morel et al., 2017) but a common objective followed by these systems is the reduction of risk through an increased cultivated diversity.

In the literature, the relationship between agricultural diversity and risk has been explored from the point of view of ecological stability (Ives and Carpenter, 2007; Tilman et al., 2006) and agricultural systems resilience (Isbell et al., 2017; Liebman and Schulte, 2015). The underlying hypothesis is that an increased diversity of crops creates a stabilizing effect that preserves the production services and reduces crop failure risk (Altieri, 2004; Vandermeer and Schultz, 1990).

In parallel to these ecological studies, a widely used approach in economic sciences to evaluate the risk reduction obtained through diversification is the Modern Portfolio Theory (MPT) (Markowitz, 1959, 1952). This theory provides a mathematical framework for the analysis of diversified portfolios in order to minimize risk and maximize returns (Kolm et al., 2014).

In the present study, the effect of crop diversification is assessed within the MPT framework by the relationship between risk and the number of crops in the portfolio. Crops are expected to behave as assets, thus risk may be significantly reduced by combining several crops in a portfolio. By analogy, farmers would tend to build crop portfolios that generate the highest yield for a minimum acceptable risk (Figge, 2004; Fraser et al., 2005).

First, we present the theoretical portfolio selection model to minimize risk; we then explore the opportunities for application of this theory to a context of diversified horticultural systems.

Material and methods

Application of the Modern Portfolio Theory

The Modern Portfolio Theory (Markowitz, 2010, 1952) formalizes the notion of risk-reduction in economics, through an efficient diversification of assets within a portfolio. The general idea behind this theory is that when assets are combined in a portfolio and when asset returns are not perfectly correlated, the portfolio risk is reduced compared to single asset portfolios. Applying this theory to an agricultural context, a crop portfolio can be considered as a combination of *N* crops within a farm, with the returns R_n, (n = 1, 2… N). The **expected return** of a portfolio *P* is the weighted sum of the return of each individual crop in the portfolio:

$$E(R_P) = \sum_i w_i \, E(R_i) \qquad (1)$$

where w_i the relative weight of crop *i* (that is, the proportion of crop "*i*" in the portfolio) and $E(R_i)$ the expected return of crop *i.*

In addition, we assimilate the **risk** (σ_p) of a portfolio to the standard deviation of the crop returns. It is calculated as follows:

$${\sigma_P}^2 = \sum_i \sum_j w_i w_j \sigma_{ij} \qquad (2)$$

where σ_{ij} the standard deviation of the return for crop *i* when $i = j$, and the covariance of the return of crops *i* and *j* when $i \neq j$.

A portfolio is optimal on the risk dimension if, for a given expected return $E(R_p)$, the portfolio has the lowest risk σ_p. The variance of a portfolio can be reduced in two ways, either by favoring crops with low return variances, or by using specific combinations of crops. Although the first way is intuitive, the second way relies on choosing crops for which yield variability shows little correlation so as to compensate yield fluctuations between crops (Figge, 2004).

Equations (1) and (2) allow to build Figure 1. The expected return $E(R_p)$ of portfolios is represented on the y-axis. The risk is plotted on the x-axis as the standard deviation of $E(R_p)$. The coordinates for all possible portfolios are represented by the point cloud. The optimal portfolios (in the sense of Pareto) are located on the curve linking points A and B, known as *efficient frontier.* All portfolios below this curve have a lower expected return or a greater risk. For instance, Portfolio 2 will be preferentially chosen over Portfolio 3 because it offers a higher expected return for the same level of risk. Likewise, Portfolio 1 will be favored over Portfolio 3 because it offers the same expected return for a lower risk.

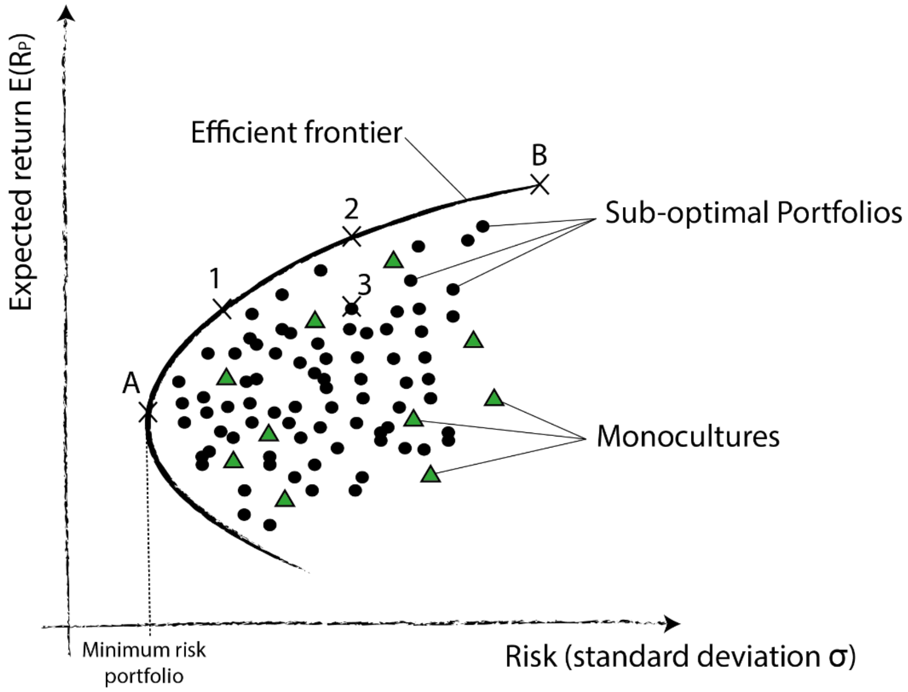

Figure 1. Risk-return relationship for hypothetical large portfolios

Systematic and unsystematic risk

Combining crops in a portfolio may reduce the risk of portfolio returns, as long as their correlation coefficient is less than 1. The part of the risk that can be reduced by diversification is known as *unsystematic risk* (or diversifiable risk). However, regardless of the level of diversification, there is always some risk that cannot be reduced, owing to the fact that crops are somehow correlated to each other. This part is referred to as *systematic risk* (or non-diversifiable risk). These features are illustrated in Figure 2, where the curve asymptotically approaches a minimum risk that cannot be crossed, when the portfolio is extended (Figge, 2001). This figure shows that beyond a given number of crops, the unsystematic risk reduction becomes negligible. The remaining variability of such portfolio will depend on external factors that are not specific to a crop or another (Turvey et al., 1988).

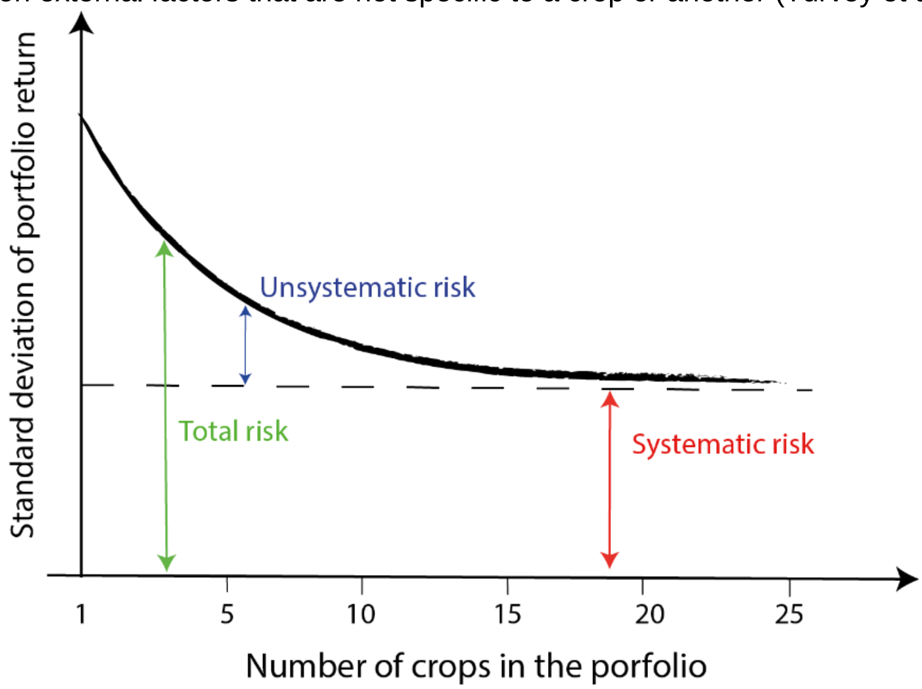

Figure 2. Systematic and non-systematic risk as a function of the number of crops in the portfolio

Data collection

In this study, data was collected from the French Interprofessional Technical Center for Fruits and Vegetables (Ctifl), which gathers information from the following sources: Agreste (National Agricultural Statistics), Eurostat and French Customs. We selected the three administrative regions of the South-East of France according to their relative soil and climate homogeneity. We selected 22 horticultural crops cultivated in these regions, 10 fruits and 12 vegetables, according to Pennington classification (Pennington and Fisher, 2009). For each crop, agronomic yield data was available for a range of 10 years (2006 to 2015 included). An estimation of the expected return for each crop has been made by multiplying the agronomic yield with the consumer price index (CPI) of the national statistical office (INSEE).

Generating portfolios of *N* crops

From the 22 horticultural crops selected, we generated every possible combination of portfolios from one to five crops (that is, the number of *k*-multicombination Γ_k^n). This led to 65,780 different unique portfolios. Risk and return combination has been calculated for each generated portfolio. Then we analyzed the generated portfolio according to two diversification strategies: first, based on the level of cultivated diversity from one to five crops (Figure 3a); second, based on the functional type of crops (Figure 3b).

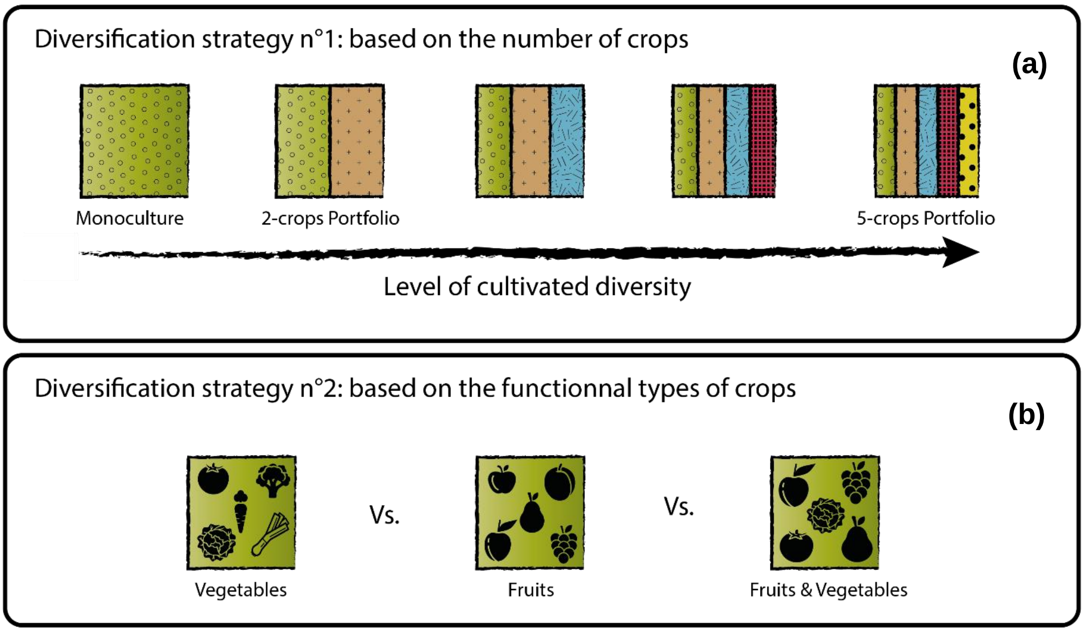

Figure 3. Representation of diversification strategies as alternatives to monocultures.

Due to the large number of possible portfolios, we could explore both diversification strategies for all portfolios composed of up to 5 crops. For simulation purposes, we only simulated a subset of the portfolios up to 22 crops. These remaining portfolios were generated for combinations of crops up to 22, that is, the number of *k*-combination C_k^n.

Results

Diversification strategy n°1: which level of cultivated diversity is suitable?

Combinations of crops within our sample led to 22 portfolios composed of sole crops, 924 portfolios composed of 2 crops, 9240 portfolios composed of 3 crops, 29260 portfolios composed of 4 crops and 26334 portfolios composed of 5 crops (Figure 4).

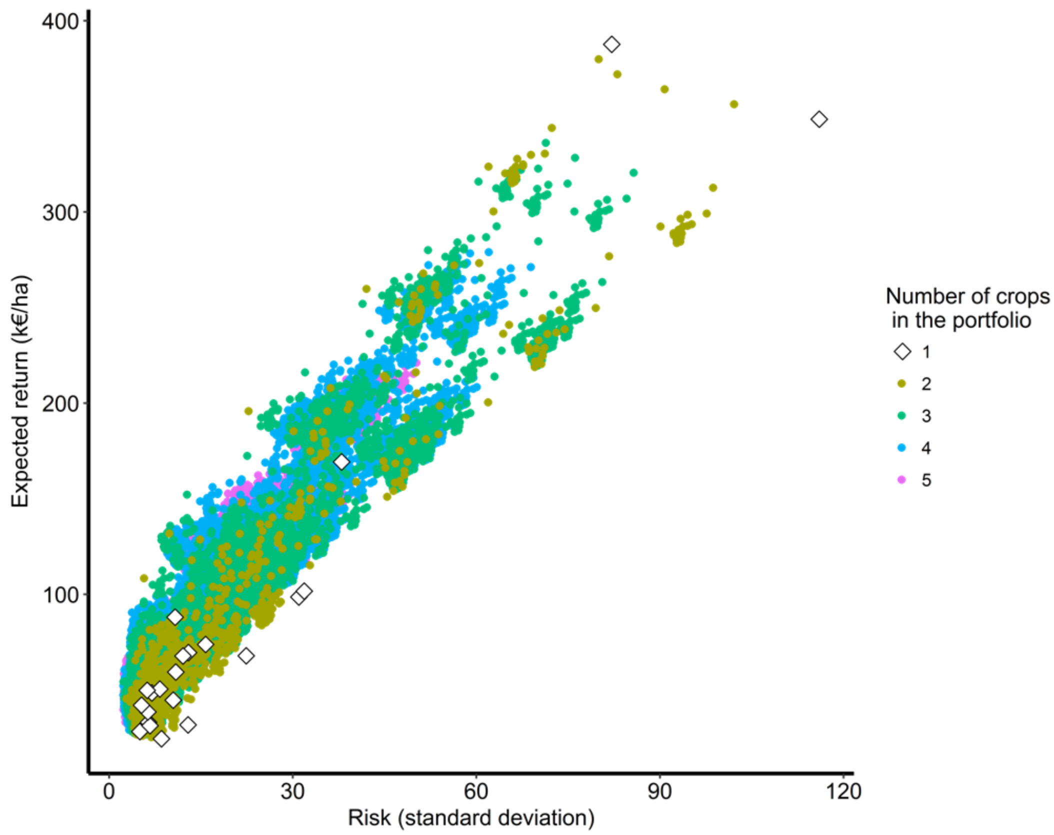

Figure 4. (a) Risk and return combinations for portfolios composed of 1 to 5 crops

The linear regression on each level of diversity shows that an increasing number of crops in a portfolio leads to a better risk and return combination ($p < 0.05$, Table 1). Indeed, the slope of the regression increases with the diversification level. Our data also indicate that the range of risk and return values decreases as the number of crops in the portfolio increases. The interest is that the maximum risk is reduced, but is goes together with a lower maximum expected return.

Table 1. Linear regression parameters for each level of crop diversity.

Number of crops in the portfolio	Slope	Intercept	Risk (portfolio standard deviation)
1	3.35[abc]	17.6[a]	21.2[a]
2	3.41[b]	25.2[b]	18.7[b]
3	3.46[c]	29.7[c]	17.1[c]
4	3.51[d]	32.9[d]	15.9[d]
5	3.58[e]	34.6[e]	15.1[de]

[a] Means followed by the same letter within a column did not show significant differences according to Tukey's Honestly Significant Difference (P≤0.05).

Systematic and non-systematic risk

The risk and return combinations were then calculated for all portfolios combining different crops. If we keep on adding crops to the portfolio, from 1 to 22 crops, the average standard deviation of portfolios drops from 21.2 to 13.9 respectively (Figure 5). For the same average return, 34% of the risk could be eliminated due to diversification. This part of the risk is called unsystematic risk. Furthermore, we can observe that the risk curve tends towards a threshold that represents the systematic risk and that seem incompressible even if the portfolio is enlarged. This observed saturation effect can be illustrated by the fact that two third of the unsystematic risk was eliminated with 10 crops.

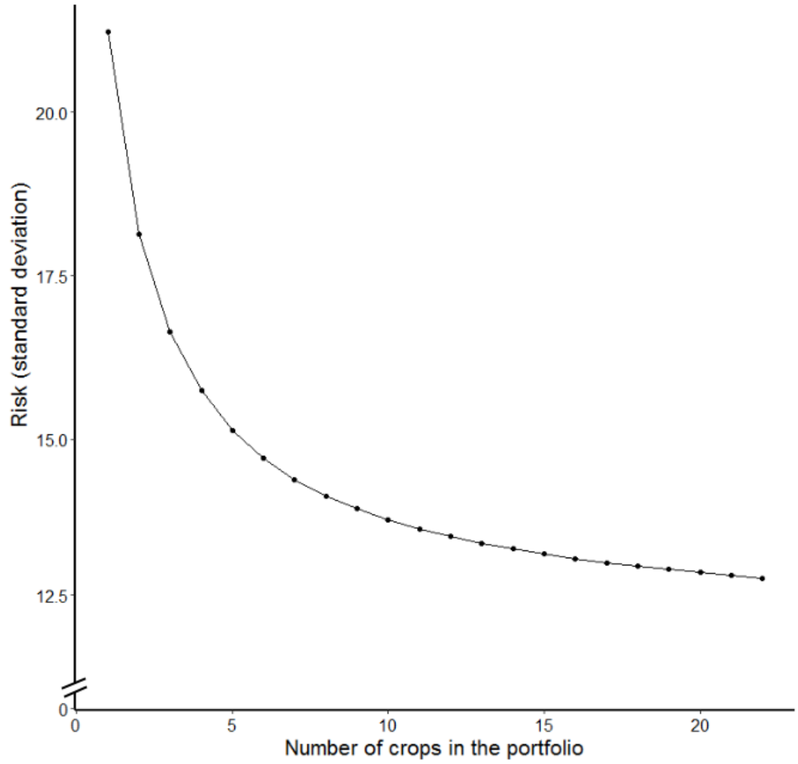

Figure 5. Effect of increasing portfolio compositions from 1 to 22 crops on the portfolio's standard deviation.

Diversification strategy n°2: Portfolios mixing fruits and vegetables production

The second diversification strategy tested led to 4368 unique portfolios composed of vegetables, 2002 portfolios composed of fruits and 59410 portfolios composed of both fruits and vegetables. Fruit and vegetables sorting does not show clear trends to conclude on the interest of diversification based on botanical aspects. The "fruit only" strategy is the one that is the least interesting because it offers less risk/return compromises than either of the other two strategies (Table 2). In addition, fruits and vegetables or sole vegetables seem slightly interchangeable. Therefore, we will have to look for other criteria to choose, especially in services provided by diversification that do not impact the production.

Table 2. Linear regression parameters for the different portfolio types

Type of crops composing the portfolio	Slope	Intercept	Risk (portfolio standard deviation)	Expected return (k€)
Vegetables only	3.50[ab]	31.7[b]	21.4[a]	106.5[a]
Fruits & Vegetables	3.51[b]	33.5[c]	15.6[b]	88.2[b]
Fruits only	3.84[c]	29.5[a]	9.9[c]	67.7[c]

[a] Means followed by the same letter within a column did not show significant differences according to Tukey's Honestly Significant Difference (P≤0.05).

Discussion and conclusion

Literature in the research domains of agriculture and biodiversity has acknowledged that diversified systems are better able to cope with future risks. However, they do not assess this risk in a quantitative way. Our aim was therefore to apply the MPT framework as a basis for the assessment of new farming arrangements based on a large cultivated diversity.

Results revealed that it is possible to highlight the relationship between return and risk of diversified crop portfolios. Based on the MPT framework, we showed that it is possible to reduce the overall risk through crop diversification, and to quantify it. One of our main results is that risk can be reduced by increasing the cultivated diversity (that is, by increasing the number of crops in our portfolio). These results are consistent with those reported for forestry (Crowe and Parker, 2008; Knoke et al., 2005), fishery (DuFour et al., 2015) or water resource management (Aerts et al., 2014; Beuhler, 2006). Specifically, there might be a particular interest in combining crop species whose yields behave inversely according to the cropping conditions, the weather or the presence of pests and diseases (Nalley and Barkley, 2010). Besides, portfolio theory formalizes the information that portfolios managers require to handle their crop portfolio efficiently. The two dimensions (risk and return) representation allows to define the appropriate level of crop diversification as a function of the risk aversion profile of each farmer.

Moreover, a diversification strategy based on botanical aspects (as suggested by Figge 2004) does not show identifiable patterns in our particular case study. This leads us to believe that other factors than a fruits/vegetables classification would be more suited to explain crop behavior in a diversification strategy. Indeed fruit and vegetables categories can be limited to explain the range of functional diversity provided by a large crop portfolio (Wood et al., 2015). As suggested by several authors (Pennington and Fisher, 2009; Song et al., 2014) other classification systems, such as botanic classification or functional response traits, may be relevant because they are based on physiological characteristics of plant development, growth and structure. Functional response types are groups of plant species that behave similarly to abiotic and biotic conditions, such as climatic conditions or fertilization regime (Díaz and Cabido, 2001). The greater variation of different response traits could then enhance the maintenance of agroecosystem functions (Lavorel and Garnier, 2002). It is also suitable for growers because plants within a functional group have similar cultivation requirements or pests and diseases sensitivity.

Finally, to further develop and improve our model, we identified three main questions that remain to be answered in future investigation. First, the expected return used in the present study does not reflect the effective profitability of crops. Additional information on crop production costs (Betters, 1988; Current et al., 1979) particularly in diversified systems would be needed. However, due to the scarcity of data, such an improvement of our approach would be likely to significantly reduce the pool of crops that we could consider. Secondly in a perspective of highly diversified horticultural systems, it has been observed that new farming arrangements often mix species within intercropping or agroforestry design, where crops interact together (Lauri et al., 2016; Warlop, 2016). Taking into account interactions between crops in the risk and return evaluation of such systems could be relevant (Blandon, 2004). Lastly, models simulating the impact of diversification practices on farm performances must account for farmers' objectives, aspirations and farming context (Fernandez et al., 2013; Morel and Léger, 2016). In other words, not all crop portfolios are equivalent to the farmer once agronomic or commercial dimensions are taken into account. Given the increasing value attributed to environmental, social and immaterial dimensions, a strictly income-based analysis is not sufficient and revised criteria have to be developed.

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