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MODELLING THE ADOPTION OF CROP ROTATION PRACTICES IN ORGANIC MIXED FARMS[1]

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Abstract

Taylor et al. (2001) noted that well designed rotations are fundamental to organic farming systems. Rotations help organic systems achieve a balance between crops which deplete fertility, in particular nitrogen, and soil organic matter, and crops which restore fertility. The paper discusses the choice of crop rotation in the context of organic mixed farm systems that include cereals and livestock. The analysis is performed by combining economics and biology with the intention of capturing a broader approach to measuring the resilience of farming systems. Thus, it considers that the farmer's choice of a specific rotation is based on the expected economic return derived from the rotation, and also the biological benefits provided by the selected rotation. The analysis is based on organic crop rotation trials ran from 1991 to 2006 at a site in the north-east of Scotland (Tulloch, Aberdeen) (Taylor et al., 2006).

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Introduction

Well designed rotations are fundamental to organic farming systems. Rotations help organic systems to achieve a balance between crops which deplete fertility, in particular nitrogen, and soil organic matter, and crops which restore fertility (Taylor et al., 2001).

In the case of rotations containing cereals the limiting plant nutrient is often nitrogen. Therefore, it is normally recommended that at least half the rotation should consist of fertility-building crops such as grass/white clover leys, leguminous crops such as peas, beans, and lupins or green manures such red clover and vetches which can be mulched and ploughed in.

Furthermore, soil organic matter is slowly depleted under annual crops which require ploughing and soil cultivation for their establishment. Grass/clover leys left in place for a number of years result in increases in soil organic matter and help to maintain soil biological activity, improve soil structure, workability and water holding capacity, and provide a source of organic material for nitrogen mineralisation.

The purpose of this paper is to discuss a framework for comparing crop rotations in the context of organic mixed farm systems, i.e., they include cereals and livestock. The selection of this specific case is mainly due to data availability, although the lines of the analysis can certainly be extended to other situations.

The framework used in the paper to compare organic rotations seeks to integrate economic and biological perspectives with the intention of capturing a broader approach to measuring the resilience of farming systems. From the economic point of view, it considers that farmer's choice of a specific rotation is based on the expected economic return derived from the rotation. From the biological point of view, the framework considers that the crop rotation has to satisfy all the pre-requisites demanded from the organic production, and in addition, provide a sustainable farm system.

The paper starts with a brief discussion of the role of crop rotations in the organic agriculture. This section is mainly based on research results accumulated by SAC crop soil scientists on the operation of organic crop rotations. The next section discusses a framework for comparing different crop rotations, and therefore, for the analysis of ex-ante adoption of the rotations. This framework is illustrated using a case study based on SAC's organic crop rotations in Tulloch (Aberdeen). Finally, we present some conclusions and final remarks.

I. The role of crop rotations in organic agriculture

The literature about the role of crop rotations in organic agriculture is vast as it is a key component of the operation of organic farm systems (e.g., Lampkin, 1990). Therefore, the purpose of this section is only to provide a brief overview of the issue.

The function of a rotation in an organic farming system is to maintain nitrogen fertility and to minimize weeds, pests and diseases. Fertility maintenance depends upon the balance of nitrogen-fixing legumes and fertility-depleting non legumes in the rotation (Watson et al., 1999).

In most organic systems nitrogen fertility is supplied by clover in grass/clover leys which are utilised by stock through grazing or conservation. It is generally considered that at least half the rotation should be devoted to such fertility-building crops (Soil Association, 2002). In areas where arable cropping predominates, farmers look for rotations with a lower proportion of crops devoted to livestock feed, specifically with less grass/clover leys. The alternative include vigorous nitrogen-fixers such as red clover, which can be cut and mulched but which give non financial return apart from the set-aside payment, and grain legumes, and although these fix nitrogen, most of the nitrogen is exported in the grain (Fisher, 1996).

The choice of crop rotation is fundamental to the success of organic systems and other low-external input farming systems. In particular, the ratio of fertility building to fertility exploitative cropping phases will have a major influence on the yield of arable crops such as cereals and roots. The main nitrogen input in organic farming arises from atmospheric nitrogen fixation by leguminous green manures and catch crops, grain legume crops, but primarily from grass/clover leys. In addition, to fixing nitrogen and improving soil organic matter content and soil structure, grass/clover provides the means for support of a ruminant livestock enterprise, which is the basis for a supply of farmyard manure, the currency for nutrient transfer between crops around the farm. Whilst these are positive effects of grass/clover leys on arable crop production, it should also be recognised that reliance on leys imposes a restriction on the design of the farming system in terms of its enterprise mix (Younie et al., 1996).

The proportion of grass/clover ley in the rotation influences not only total nitrogen input and soil nitrogen build-up in the farm system, but also affects ruminant livestock population and production of farmyard manure. This will have a direct bearing on arable crop growth, weed development and risk of nitrogen loss to the environment.

Regarding the control of weeds, pests and diseases, rotations are the principal means for controlling them in organic farm systems. One main aim of a rotation in organic systems is to build up high natural resistant to weeds, pests and diseases. This can be best achieved by promoting a high level of biological activity, in particular the microflora, so that harmful pathogens can be neutralised (Lampkin, 1990, p. 129).

Rotations allow for different types of cultivation to take place at different times of the year, so that no one weed species can be dominant. The same is true for the interactions between crop plants and weeds: certain crops have a weed suppressant effect (either by direct competition or by allelopathic interactions[2]) while others are less able to compete successfully. The rotation provides the opportunity to alternate these types of crop so the overall effect is one of minimising weed problems (Lampkin, 1990, p. 129-30).

An important element in organic farming and in the design of organic crop rotations is the principle of biological diversity, where as many plant animal species are present

[2] Allelopathy denotes the production of specific biomolecules by one plant that can harm, or give benefit to, another plant.

as possible, provides the most favourable conditions for an equilibrium to become established in an ecosystem. This means that the natural control of weeds, pests and plant pathogens is more likely to be effective and that the occurrence of specific population explosions of a pest or disease is less likely. For instance, the presence of certain "weed" species within the crop or on the headlands may provide a niche for beneficial insects which can keep pests under control, or may act as decoys for other crop pests.

II. A framework to compare crop rotations

The starting point for the elaboration of a framework to compare crop rotations in organic systems is the concept of sustainability, which is an important objective of organic farming. As discussed by Taylor et al. (2006) there is no accepted definition of sustainability in agricultural systems. In this paper, the description of a sustainable system produced by Taylor et al. (2006) will be used. According to them in the long-term, sustainable farming systems may be those where soil fertility is maintained through the recycling of nutrients and organic matter, while producers receive adequate economic returns (Taylor et al., 2006, p. 1).

Based on the previous definition of sustainability, this paper will consider that a crop rotation can be characterised by two broad categories of attributes or indicators (hereafter, it will be used indicators): productive/economic-related (e.g., production yield means and standard deviations, gross margins) and soil-related (e.g., weeds and soil properties) indicators.

Whilst the inclusion of soil-related indicators (and also productive ones) responds to the discussion presented in the previous section, the inclusion of economic indicators mainly responds to Taylor et al. (2004) position that from a farmer's point of view whole-farm value of output of output and costs of production are significant factors in determining the system to be adopted (Taylor et al., 2004, p. 263).

Once rotations have been characterised in terms of the aforementioned indicators, it is possible to proceed to compare them trying to establish the dominance of one or more rotations according to the selected indicators.

Regarding the comparison of alternative crop rotations, one might be tempted to construct an index that would encompass all the indicators into one, in order to simplify the task of ranking the crop rotations. This approach, however, has the drawback of obscuring the reasons why a determined crop rotation is placed in a better place than another. Instead, the aim should be to "map" all the rotations in terms of their indicators in order to produce some sort of crop rotations "frontier". Crop rotations located at the frontier are those ones that cannot be "defeated" by another rotation in at least one indicator. Or more formally, one crop rotation dominates another if they possess the same achievements in almost all their indicators but the dominant rotation performs better in at least one indicator. The idea of the frontier may be better understood by the use of figure 1.

Figure 1: Crop rotations frontier and dominance of alternatives

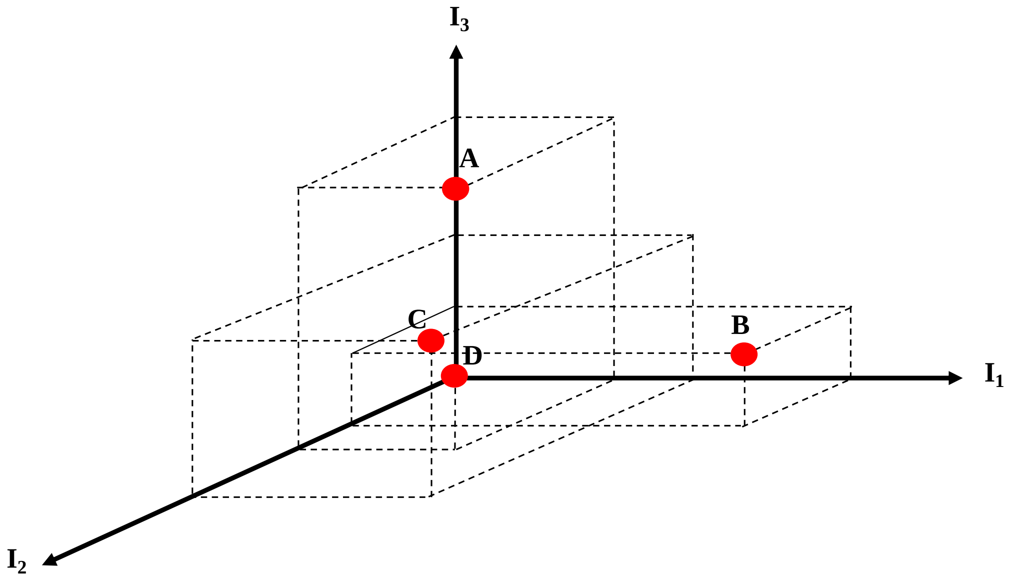
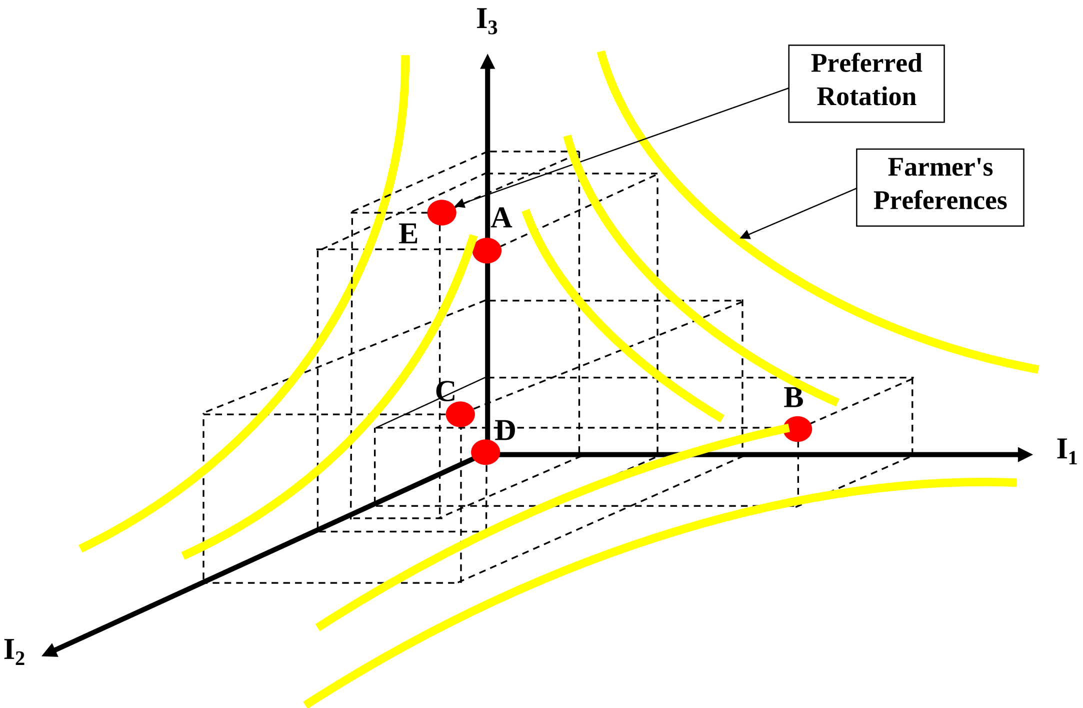


Figure 1 hypothesises the comparison of crop rotations, assuming that they can be characterised by 3 indicators (I_1, I_2, I_3). The figure considers four crop rotations (A, B, C, D). Rotations A, B and C are the strongest regarding one particular indicator and weaker regarding the other two (i.e., A, B, C, are part of the frontier). Rotation D (represented at the origin to simplify the comparison) is the weakest rotation as it is dominated by the other three in terms of all the indicators.

It should be noted that the previous approach allows to compare rotations but not to select the most appropriate one (except, of course, in the case that one rotation dominates all the others). The final selection (and adoption) is in the hands of the farmers as they may have preferences for the different indicators comprising the crop rotations. This can be represented in figure 2, where the yellow curve "Farmer's Preferences" represents his/her preferences for different indicators. These preferences are "maximised" by rotation E (i.e., "preferred rotation"), which is part of the crop rotations frontier. The final choice presented in figure 2 indicates that the farmer has a strong preference for the indicator I_3 and is willing to trade achievements in terms of I_1 and I_2 in order to reach a high score in I_3.

Figure 2: Crop rotations frontier and farmer's preferred choice



Having presented the criterion for comparing crop rotations, the next step is the discussion of indicators. Here the paper follows Taylor et al. (2006) and Walker et al. (2006) considered measures of physical and financial outputs (productive/economic related indicators) and changes in soil properties and weed populations (soil-related indicators) to compare the sustainability of crop rotations.

Regarding the productivity indicators, it is useful to measure whether production yields and their variances are changing over time, because of its effect on the proper evaluation of the rotation. If yields are growing over time (or decreasing) due to the effect to the crop rotation then it is important to evaluate it once the yield effect has reached its long term maximum (or minimum). This will also have an impact on the financial evaluation as changing yields are going to affect the economic return obtained with the rotation. Similarly, if yields variances are decreasing over time, then, this is something that should also be reflected on the evaluation of the rotation as the risk inherent in agricultural production is being reduced. Furthermore, in the context of the mean variance analysis (e.g., Newbery and Stiglitz, 1981) the reduction of the variance of one or more of crops will have impact on the variance of the farm income and also on its expected value.

Regarding the indicators of financial results, the most typically used is the gross margin of the entire farm -i.e., total output value minus variable costs- divided by the number of years of the rotation (e.g., Taylor et al., 2004, Battese et al., 1972 and Battese and Fuller, 1972). This measure is normally complemented with the variance of the income resulting from deviations from the average yields. In addition to these indicators one could expand this part of the analysis by including in the variance of the income also the effect of output and input price variability on the farm income. These factors might also be of importance as a consequence of the reform of the Common Agricultural Policy, where prices are expected to vary more freely than in the past. This is even more important as the crop rotation stays in place for several years.

With respect to the soil-related indicators, Taylor et al. (2006) and Walker et al. (2006) use average weed ground cover changes over a complete rotation to compare the presence of weeds between two rotations. Soil properties are measured through changes in soil phosphorus (P), potassium (K) and organic matter.

III. Case study: SAC demonstration field in Tulloch, Aberdeen

The case study considered in this paper is based on the data collected between 1991 and 2006 from two organic crop rotations trials set at a site in the north-east of Scotland (Tulloch, Aberdeen). These trials have received considerable attention and they are well documented in a number of publications (e.g., Younie et al., 1996).

The crop rotation trials consisted of two replications of two different six-year rotations. A full representation of the two trials over time can be found in figure A.1 in the annex. The first rotation (T1), which considered 50 per cent of fertility building crops, consisted of three consecutive grass/white clover leys (G1, G2, G3) followed by a consecutive sequence of a cereal (oats, C1), a root crop (swedes, R) and another cereal (oats, C2). The second rotation (T2), with 67 per cent of fertility building crops, is comprised of four consecutive grass/white clover leys (C1, C2, C3, C4) followed by two consecutive cereals (oats, C1 and C2). The dataset provides a total of 48 complete crop rotation sequences, 24 for each crop rotation trial and 12 for each replication (i.e., two rotation sequences per plot).

As noted by Taylor et al. (2004), these rotations were representative of traditional rotations from north-east of Scotland where farmers used a 3 years of a grass/white clover ley followed by a cereal, a root crop and a cereal and although these rotations are now largely abandoned on non-organic farms, they were considered as good starting point for the design of organic rotations in the area.

The starting point to compare T1 and T2 is to analyse the effect of the rotations on average cereal yields (C1 and C2) and in their variances (i.e., analysis of the physical output of the crop rotation).
The focus on the cereals is because they are the “high” value crops in the rotations; however, similar analyses can be done for each of the grass/white clover leys. The analysis was not done for Swedes as they only appear in rotation T1. Two analyses were performed here: first, we compare the sample means and variances for each cereal (C1 and C2) independently. Second, we analysed whether the crop rotations had effect on the yields over time using two different regression models.

The first analysis of the physical output consisted of testing a number of hypotheses regarding the mean and variance of both rotations for each one of the cereals (C1 and C2). The results are presented in table 1.

Table 1 starts testing the normality of the yield data, using the Jarque-Bera test (1980), as the subsequent tests require normality as a condition for their use. The test could not reject the yields normality for both cereals. Next, two sets of test were applied: first for differences of means (t tests) and then for the differences in variances (F tests). The null hypotheses in all the cases were that there were not differences in means or in variances between the different pairs specified in the table. At 5 per cent significance the results indicated that it was not possible to reject the hypotheses that means and variances of both rotations were equal.

The next analysis consisted of exploring whether there was an improvement in each cereal over time. Two analyses were performed: the first analysis consisted of regressing, for each cereal C1 and C2, the second observation of the yield at each plot with respect to the first yield at the plot. Thus, for each cereal the regression model used was:

$$Y_{1i} = \alpha_0 + \alpha_1 \cdot Y_{0i} + \alpha_2 \cdot Y_{0i} \cdot d_{re_2} + \alpha_3 \cdot Y_{0i} \cdot d_{ro_2,i} + \alpha_4 \cdot d_{re_2,i} + \alpha_5 \cdot d_{ro_2,i} + \varepsilon \quad (1)$$

Where Y_{1i} is the second observed yield in plot i, Y_{0i} is the first cereal in the plot, the α's are the different parameters of the regression and ε is the regression error. The variable d_{re_2} is a dichotomous variable that takes the value of 1 when the observation corresponds to the replication 2 and 0 otherwise. Similarly, the variable d_{ro_2} takes the value of 1 when the observation corresponds to the rotation T2 and 0 otherwise. Both dichotomous variables when combined in the regression allow testing whether the intercept and/or the slope were affected by the replication or by the rotation. In addition, one may generalise equation (1) by introducing non-linear terms in the regression, e.g., a squared term of first observed cereal yield.

The interaction of dichotomous variables allows considering a number of hypotheses. For instance, if α_1 is statistically significant and greater than 1 and α_3 is not significant, then, there might be an increase in yields which cannot be attributed to the crop rotation. However, if α_3 is also significant (or only this coefficient is significant) then the rotation has an effect on yields. In addition, ceteris paribus, if α_5 is significant then the rotation T2 might have some effect in the mean of the second observed yield at each plot. The results for both cereals are presented in table 2.

Table 1: Hypothesis tests for cereal average yields and variances

Normality test	χ^2	df		Test significance
Cereal 1	1.93	2		0.380
Cereal 2	1.14	2		0.566
Difference in means test (t)	**t**	**df**		**Test significance**
Cereal 1				
Rotation 1 - replication 1 and 2	-0.720	24		0.478
Rotation 2 - replication 1 and 2	-0.420	24		0.678
Rotation 1 and rotation 2	-0.249	50		0.804
Cereal 2				
Rotation 1 - replication 1 and 2	-1.258	20		0.223
Rotation 2 - replication 1 and 2	-1.263	20		0.221
Rotation 1 and rotation 2	-0.960	42		0.342
Difference in variances test (Levene)	**F**	**df 1**	**df 2**	**Test significance**
Cereal 1				
Rotation 1 - replication 1 and 2	0.997	1	24	0.501
Rotation 2 - replication 1 and 2	1.163	1	24	0.452
Rotation 1 and rotation 2	0.447	1	50	0.732
Cereal 2				
Rotation 1 - replication 1 and 2	0.134	1	20	0.915
Rotation 2 - replication 1 and 2	1.315	1	20	0.414
Rotation 1 and rotation 2	0.484	1	42	0.713
Difference in variances test (F)	**F**	**df 1**	**df 2**	**Test significance**
Cereal 1				
Rotation 1 - replication 1 and 2	0.458	12	12	0.905
Rotation 2 - replication 1 and 2	0.489	12	12	0.885
Rotation 1 and rotation 2	0.923	25	25	0.579
Rotation 1 - 1st and 2nd	1.287	11	11	0.341
Rotation 2 - 1st and 2nd	0.990	11	11	0.507
Both rotations - 1st and 2nd	1.004	23	23	0.496
Cereal 2				
Rotation 1 - replication 1 and 2	1.643	10	10	0.223
Rotation 2 - replication 1 and 2	2.809	10	10	0.059
Rotation 1 and rotation 2	0.782	21	21	0.711
Rotation 1 - 1st and 2nd	0.408	9	9	0.901
Rotation 2 - 1st and 2nd	0.721	9	9	0.683
Both rotations - 1st and 2nd	0.622	19	19	0.845

One of the issues that can be studied with the help of equation (1) is the “memory” of the crop rotation (Hennessy, 2006), i.e., whether 3 or 4 years of fertility building crops have a significant effect on cereal yields. If the dichotomous variables associated to the rotations are not significant, then it means that in terms of the properties contributed by the leys, it is basically the same to consider three or four years leys.
The results in table 2 show that in general an additional year of fertility building crops (G4) in the rotation do not have any significant effect on grain yields. The effect of

weather (i.e., average rain and air temperature) was also included in equation (1) but the variables were not significant. The only statistically significant effect was found in cereal 2 where the current yield in the plot is half of the previous yield measured in the same plot.

Table 2: Test of temporal improvement in cereal yields

Parameter	Variable	First cereal (C1)			Second cereal (C2)		
		Parameter Value	t	p value	Parameter Value	t	p value
α_0	Intercept	7.27	2.33	0.03	1.73	2.42	0.03
α_1	Y_{0i}	-0.37	-0.60	0.56	0.57	2.53	0.02
α_2	$Y_{0i} \times d_{re2,i}$	0.59	1.01	0.32	-0.35	-1.12	0.28
α_3	$Y_{0i} \times d_{ro2,i}$	0.38	0.84	0.41	0.07	0.28	0.79
α_4	$d_{re2,i}$	-2.83	-0.95	0.36	1.37	1.27	0.22
α_5	$d_{ro2,i}$	-1.85	-0.79	0.44	0.12	0.13	0.90
Observations		24			24		
Statistics							
Adjusted R^2		-0.04			0.48		
F statistic			0.83	0.54		4.50	0.01

The second analysis consisted of regressing yields for each cereal according to model (2).

$$(2) \quad Y_i = \alpha_0 + \alpha_1 \cdot d_{ro2,i} + \alpha_2 \cdot d_{re2,i} + \alpha_3 \cdot d_{orden2,i} + \sum_{j=1992}^{2006} \alpha_j \cdot d_{j,i} + \varepsilon$$

Where Y_i is the observed yield in plot i, the α's are the different parameters of the regression and ε is the regression error. The dichotomous variables d_{re2} and d_{ro2} are previously defined. The weather effect or any problem associated to specific years was analysed through dichotomous variables for the year $d_{year,i}$ with the value of 1 in a specific year and 0 otherwise. In order to test for an increase in yields in the second observation for each cereal in each plot, another dichotomous variable was created, $d_{order,i}$, with value of 1 if the observation was the second observe in the plot (i.e., the observation corresponding to the cereal in the second rotation observed in the plot).

The structure of equation (2) allowed studying whether an ARCH process (i.e., autoregressive conditional heteroscedastic process, Engle, 1982) was present in the conditional variance of the errors of the mean yield equation (i.e., ε).

The ARCH process is an interesting feature because if present, it indicates that the assumption of constant variance of the yield equation errors (i.e., the errors in equation (2)) is rejected.

The ARCH process is tested by running regression (3), where $\varepsilon^2_{t,i}$ are the squared estimated errors (i.e., conditional errors) from equation (2) and v is the error term of the equation (3), assumed independent and identically distributed. The results are presented in table 3.

$$\varepsilon^2_t = \beta_0 + \beta_1 \cdot \varepsilon^2_{t-1} + v \quad (3)$$

Table 3: Test of temporal improvement in cereal yields and ARCH process

Parameter	Variable	First cereal (C1)			Second cereal (C2)		
		Parameter Value	t	p value	Parameter Value	t	p value
α_0	Intercept	5.37	34.09	0.00	2.97	13.00	0.00
α_1	$d_{ro2,i}$	0.18	1.17	0.25	0.25	1.52	0.14
α_2	$d_{re2,i}$	0.29	1.88	0.07	0.47	2.79	0.01
α_3	$d_{order,i}$	0.10	0.42	0.67	0.86	3.41	0.00
α_4	$d_{1997,i}$				1.25	3.69	0.00
α_5	$d_{1998,i}$	-1.49	-4.99	0.00	-0.59	-1.73	0.09
α_6	$d_{1999,i}$				-0.98	-2.89	0.01
α_7	$d_{2000,i}$	-0.98	-3.27	0.00			
α_8	$d_{2001,i}$	0.64	1.93	0.06	0.73	2.14	0.04
α_9	$d_{2002,i}$	-1.36	-4.09	0.00			
α_{10}	$d_{2004,i}$	-0.72	-2.15	0.04	-0.68	-2.12	0.04
α_{11}	$d_{2005,i}$	0.67	2.01	0.05	-1.08	-3.38	0.00
α_{12}	$d_{obs\_29,i}$	-2.21	-3.88	0.00			
Observations		52			44		
Statistics							
Adjusted R^2		0.62			0.60		
F statistic			9.49	0.00		8.25	0.00
ARCH Component							
β_0	Intercept	0.14	2.58	0.02	0.24	2.24	0.04
β_1	ε_i^2	-0.06	-0.58	0.57	0.02	0.07	0.95
Observations		24			22		
Statistics							
Adjusted R^2		-0.03			-0.06		
F statistic			0.33	0.57		0.00	0.95

The implications of the presence of an ARCH process are, for instance, that if the conditional variance is decreasing over time then the mean equation of yields (equation (2)) is becoming more accurate in predicting the average yield.

If β_1 is positive (negative) and statistically significant then the conditional variance of (1) is increasing (decreasing) over time. If only β_0 is significant then the conditional variance is constant. The results are presented in table 3.

The results in table 3 are somewhat similar to the results in table 2, in the sense that the same temporal increase in yields is present in cereal 2 (i.e., the yields of the second observed cereal in the plot, ceteris paribus, increase by 0.86 in absolute terms). Regarding, the effect of the rotations, the coefficient associated to them was not significant for none of the cereals. The ARCH regressions showed that it was not possible to reject that the conditional variances of the errors of the mean yield equations were constant.

The financial results of the two results are presented in table 4. The table updates the mean yields and their standard deviations presented in Taylor et al. (2004) to the period 1992-2006; however, the prices and variable costs are from Taylor et al. (2004) and they correspond to the period 2002/03.

Following Taylor et al., the financial results for rotation T1 are presented considering stock-feed swedes and table swedes. In the first case, when stock feed swedes were considered, the results from both rotations are basically the same, slightly favouring T2 by £ 15. However, this result is turned in favour of T1 when table swedes are included the rotation plan.

As regards of soil-related indicators, two analyses are presented following Taylor et al. (2006). The first one, in table 5, presents the assessment of ground cover major weeds in two periods (May/June and October). The second analyses presented in table 6, shows the annual average of soil organic matter, and extractable soil phosphorus and potassium.

Table 4: Tulloch Crop Rotation Trials - Financial Results

	Units	Rotation					
		T1 1/			T2 1/		
		Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Area	ha	6			6		
I. Results considering stock feed swedes in the rotation							
Oats 2/							
Yield	Tonnes	8.5	1.3	22	8.7	1.5	22
Price	£/tonne	125.0			125.0		
Output value	£	1,062.6			1,089.6		
Swedes							
Yield	Tonnes	53.9	16.0	30	---	---	---
Price	£/tonne	25.0			---	---	---
Output value	£	1,347.5			---	---	---
Silage							
Yield	Tonnes	14.6	12.9	22	15.0	3.4	22
Price	£/tonne	80.0			80.0		
Output value	£	1,170.0			1,200.5		
LUGD 3/							
LUGD	Days	650.4	122.9	22	1,078.0	145.1	22
Price	£/day	3.0			3.0		
Output value	£	1,951.2			3,234.1		
Total output value	£	5,531.3			5,524.2		
Total output value per hectare 4/	£/ha	921.9			920.7		
Variable costs 5/	£/ha	116.0			99.0		
Gross margin	£/ha	805.9			821.7		
II. Updated results considering table swedes in the rotation							
Swedes							
Yield	Tonnes/ha	53.9	16.0	30	---		
Price	£/tonne	160.0			---		
Output value	£/ha	8,623.7			---		
Total output value per year 4/	£/ha	2,134.6			920.7		
Variable costs 5/	£/ha	388.0			99.0		
Gross margin	£/ha	1,746.6			821.7		

Source: Based on Taylor et al. (2004).

Notes:
1/ Rotation T1 considers 50 percent of fertility building crops and T2, 67 percent. Yields are 1992-2006 averages, prices and variable costs are from Taylor et al (2004).
2/ Only considers the mean of those plots with two cereal crops (i.e., C1+C2).
3/ Livestock units grazing days.
4/ Total output value divided by the number of years of the crop rotation (i.e., 6 years).
5/ Variable cost comprises seeds, fertilisers, weeding, casual labour, transport and others.

Table 5: Proportional ground cover of major weeds assessed in May/June and October at Tulloch - Means of two complete cycles of the rotations (1992-97 and 1998-2003)

Rotation T1	**Crop**							**Mean**
	G1	G2	G3		C1	R	C2	
May/June								
1st cycle	0.005				0.048	0.060	0.075	0.0470
2nd cycle	0.001				0.174	0.075	0.189	0.1100
st.dev.				0.036				0.0300
October								
1st cycle	0.010	0.001	0.002					0.0040
2nd cycle	0.001	0.000	0.000					0.0020
st.dev.				0.0049				0.0029

Rotation T2	**Crop**							**Mean**
	G1	G2	G3		G4	C1	C2	
May/June								
1st cycle	0.004		0.006			0.058	0.059	0.0320
2nd cycle	0.002		0.001			0.138	0.147	0.0720
st.dev.				0.029				0.0231
October								
1st cycle	0.005	0.002	0.000		0.001			0.0030
2nd cycle	0.002	0.000	0.001		0.001			0.0020
st.dev.				0.002				0.0009

Source: Taken from Taylor et. (2006) p. 9

Table 5 shows that the rotation with greater proportion of grass-clover (i.e., T2) had the lowest major weed content, emphasising the value of weed control (Taylor et al. 2006). However, the figures in both rotations are very close.

Similarly to the results obtained in table 5, the results in table 6 show no major differences between rotation T1 and rotation T2.

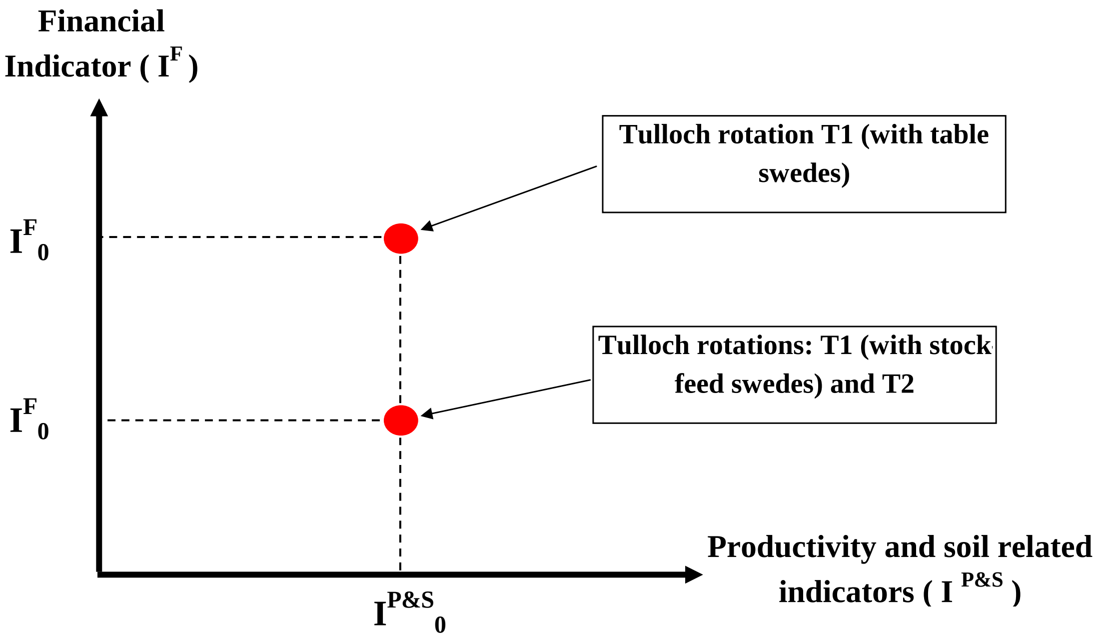
Table 6: Tulloch trials - soil organic matter, extractable soil phosphorus and potassium

Year	Soil organic matter Percentages						Extractable soil phosphorus mg/l air-dried soil < 2 mm						Extractable soil potassium mg/l air-dried soil < 2 mm					
	Rotation T1			Rotation T2			Rotation T1			Rotation T2			Rotation T1			Rotation T2		
	Mean	St. Dev.	C.V. 1/	Mean	St. Dev.	C.V. 1/	Mean	St. Dev.	C.V. 1/	Mean	St. Dev.	C.V. 1/	Mean	St. Dev.	C.V. 1/	Mean	St. Dev.	C.V. 1/
1992	9.8	1.4	14.2	8.8	1.0	11.5	14.2	5.0	34.8	14.4	3.6	24.9	60.9	19.8	32.6	65.0	19.7	30.4
1993	9.2	1.2	12.5	8.3	2.0	23.5	17.4	4.4	25.5	18.1	2.7	15.2	107.6	31.7	29.5	100.3	27.6	27.5
1994	8.7	1.9	21.7	8.7	2.2	25.3	15.4	4.1	26.3	15.9	2.6	16.2	86.6	25.3	29.2	88.2	26.3	29.8
1995	9.2	1.1	11.9	8.7	1.4	16.1	15.8	4.6	29.4	16.0	2.7	16.6	104.0	25.4	24.4	107.1	28.4	26.5
1996	8.4	1.1	13.2	8.4	1.2	14.0	16.9	5.2	30.8	17.3	3.4	19.9	137.6	44.9	32.6	138.2	38.8	28.1
1997	9.6	0.9	9.4	9.3	1.5	15.9	15.4	4.8	31.2	15.7	3.2	20.1	89.6	24.3	27.2	106.3	33.5	31.5
1998	8.6	1.5	17.5	8.4	1.4	16.4	18.6	5.3	28.6	19.3	3.7	19.4	97.1	30.6	31.5	95.1	31.5	33.2
1999	9.8	1.2	12.2	9.1	1.2	13.7	25.6	7.6	29.6	25.7	4.0	15.5	86.1	20.3	23.6	96.5	19.3	20.0
2000	10.3	1.7	17.0	10.0	1.2	11.8	13.1	3.5	26.5	13.8	2.0	14.8	79.6	21.1	26.6	95.3	21.6	22.6
2001	9.4	1.2	12.4	9.0	1.5	16.2	13.6	4.6	34.0	14.3	2.4	17.0	83.0	25.3	30.5	92.9	28.2	30.3
2002	9.0	1.0	11.1	8.8	0.9	10.6	12.3	3.5	28.3	13.3	2.3	17.2	83.8	24.2	28.8	98.3	22.4	22.7
2003	9.9	1.2	12.1	9.5	1.0	10.4	13.6	3.5	26.0	15.0	2.7	17.9	81.3	18.6	22.9	90.7	23.4	25.8
2004	9.5	1.0	10.6	9.5	1.1	11.5	16.9	4.5	26.6	18.1	3.4	18.8	111.5	24.1	21.6	118.7	25.8	21.8
2005	9.2	1.3	14.0	8.6	1.3	15.6	12.1	3.9	32.2	12.9	2.2	17.5	128.8	21.1	16.4	139.7	26.8	19.1
2006	9.2	1.1	12.3	8.8	1.1	12.3	13.6	4.6	34.3	13.7	2.1	15.3	110.0	14.8	13.4	121.8	24.7	20.3

Notes:
1/ Coefficient of variation (i.e., ratio of standard deviation to the mean) in percentage.

Based on the discussion presented in the previous section, one could represent the situation when comparing the two rotations in Tulloch by figure 3. The figure shows that in terms of its physical output (i.e., productivity) and soil related properties both rotations are quite similar (and therefore represented in the figure as reaching the same level for the productivity and soil related indicators, $I^{P\&S}_0$). On the financial side, if rotation T1 considers stock-feed swedes, then both rotations would approximately produced the same gross margin at the level I^F_0 . However, if stock-feed swedes are included in the rotation, then T1 certainly dominates T2.

Figure 3: Final comparison of Tulloch crop rotation trials



IV. Conclusions and final remarks

The purpose of this paper has been to discuss a framework for comparing crop rotations in the context of organic mixed farm systems. Whilst the selection of this specific case studied here is mainly due to data availability the same lines of the analysis can certainly be extended to other situations.

The framework seeks to integrate economic and biological perspectives with the intention of capturing a broader approach to measuring the resilience of farming systems. From the economic point of view, it considers that farmer's choice of a specific rotation is based on the expected economic return derived from the rotation. From the biological point of view, the framework considers that the crop rotation has to satisfy all the pre-requisites demanded from the organic production, and in addition, provide a sustainable farm system.

The choice of a specific crop rotation is done in terms of dominance analysis, i.e., one crop rotation dominates another if it can produce better or equal indicators than the other and at least one indicator is better. The idea is not to establish a ranking of crop rotations but to build a frontier of them where each one of the rotations of the frontier has an aspect that is better than the others. In this context the final choice is in the hands of producers that might have preferences over the different indicators. Regarding the choice of indicators, this has been based on the discussion presented in Taylor et al. (2006).

The framework was applied to two organic rotations in Tulloch, Aberdeen. The different analysis showed that the two rotations had little difference in terms of productivity and soil related indicators, but the rotation considering only 50 per cent of fertility building crops and including swedes for table dominated the other crop rotation alternatives

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VI. Annex

Figure A.1: Tulloch Rotation Trials 1991-2006
Sequences by plot

Replication	Rotation	Plot	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	T2	1	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2
1	T2	2	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3
1	T2	3	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4
1	T2	4	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1
1	T2	5	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2
1	T2	6	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1
1	T1	7	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1
1	T1	8	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2
1	T1	9	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3
1	T1	10	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1
1	T1	11	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R
1	T1	12	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2
2	T2	13	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4
2	T2	14	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1
2	T2	15	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2
2	T2	16	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1
2	T2	17	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2
2	T2	18	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3	G4	C1	C2	G1	G2	G3
2	T1	19	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1
2	T1	20	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R
2	T1	21	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2
2	T1	22	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1
2	T1	23	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2
2	T1	24	C2	G1	G2	G3	C1	R	C2	G1	G2	G3	C1	R	C2	G1	G2	G3

Notes

Rotation T1		**Rotation T2**	
G1	Grass/white clover	G1	Grass/white clover
G2	Grass/white clover	G2	Grass/white clover
G3	Grass/white clover	G3	Grass/white clover
C1	Oats	G4	Grass/white clover
R	Swedes	C1	Oats
C2	Oats u/s	C2	Oats u/s

C1 - 1st cereal respectively after the main fertility-building phase (oats).
C2 - 2nd cereal respectively after the main fertility-building phase (oats undersown).