# Nutrient balances and evolution of organic matter for two vegetable farms in South Uruguay

Report of an internship (SOQ 70424, January – May 2008)

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## PREFACE

This report is the result of the work I did during my internship at the faculty of agronomy in Montevideo, Uruguay from February to May 2008. In particular, the internship was part of the EULACIAS-project, aiming at supporting farmers in their quest for a sustainable agriculture. During the internship I hoped to gain more knowledge of and experience on sustainable natural resource management for small-scale farmers.
In addition I was curious to get to know another culture and to live and work abroad a few months.
A personal reflection as well as a description of the (other) things I did during the internship can be found in the internship-report.

I could not have done this internship without the help of other people. I'd like to thank Margarita García and Santiago Dogliotti for their daily supervision during the internship. Ana Pedemonte and Sebastián Peluffo were of great help in collecting and checking all necessary data. Thanks to Jorge Corral for assisting in working with Rotsom. Thanks as well to the owners of the farms under study, Julio and Chichi Labarrere and Alberto and Lilian Cecilia. I'd like to thank Walter Rossing and Lijbert Brussaard for helping me preparing the internship and for long-distance-supervising. Finally I'd like to thank the EULACIAS-project-team and the people working at the horticultural department for their willingness to help me and for their hospitality, which made me feel welcome. It was a pleasure to work with you!

Petra Rietberg

## SUMMARY

Small-scale vegetable farmers in Southern Uruguay suffer from declining yields and a deteriorating natural resource base. Previous studies showed yields and soil organic matter content could be increased by improving crop rotations, among others by including green manure crops. The EULACIAS-project aims at bringing this into practice and at enhancing the sustainability of those farms. In the EULACIAS-project organic matter balances and nutrient balances are considered indicators of sustainability.

In this study, estimations of the soil organic matter content on the long term (40 years) were made for two fields of two farms using the Rotsom-model. This mono-component model estimates breakdown of organic substrates added to the soil and their contribution to the soil organic matter content as well as breakdown of the stable organic matter pool present in soil at the beginning of the simulation period. It was assumed the rotation in place from 2005-2008 would be repeated continuously in the future. Type and quantity of organic substrates applied would thus be repeated every four years and timing would be equal. To link the last crop to the first crop of the rotation, it was assumed an agronomical favorable substrate management was applied.

In addition, nutrient balances for nitrogen, phosphorus and potassium were made for the four fields under study. Nutrients supplied with chicken manure mixed with rice husk, artificial fertilizer, seeds and transplants were considered inputs in the balance. For nitrogen, biological fixation and atmospheric deposition were inputs as well. Outputs consisted of nutrients harvested. For nitrogen and phosphorus, storage of nutrients in or release of nutrients from organic matter could either be an input or an output, depending on the change in organic matter stock in soil. This change was estimated using the average annual change in organic matter over 40 years as calculated by the Rotsom-model. For nitrogen, phosphorus and potassium, budgets were made using the same assumptions as for the Rotsom-simulations. In addition, balances reconstructing the potassium dynamics of the past years were composed. Data were collected from 2004-2008 by farmers' interviews and soil and manure analysis, and supplemented with literature data. Balances were compared with data on phosphorus content (Bray P) and potassium content.

The fields under study were located in Canelón Grande, 50 km. North of Montevideo. Soils were Typical Agriudolls or Typical Hapluderts. Rotations consisted of vegetable and cereal crops commonly applied in the region such as tomato, sweet pepper, garlic, melon, potato and wheat. Cereal crops (wheat, barley or foxtail millet) were planted as green manure crops in all rotations considered.

In all cases soil organic matter increased, following a wavy pattern. The increase was largest in field 3 of Labarreres farm (increasing from 2.1% to 3.4%.) and smallest in field 5 of Labarreres farm (increasing from 2.3% to 2.8%). Measured soil organic matter content was larger than modeled soil organic matter content in all cases for which several possible causes are mentioned. Results indicate it is desirable that farmers carry on with the substrate management applied in the past years.

In all cases, chicken bed mixed with rice husk was the main source of nutrients, whereas nutrients harvested was the main (and in case of potassium, only) output. As an average annual *increase* of organic matter was calculated for all fields, storage of nutrients in organic matter was always an output and release of nutrients from organic matter did not appear in the balances. Usually amounts of nitrogen applied and extracted exceeded those of potassium, whereas quantities of phosphorus applied and extracted were lowest.

All fields showed positive nitrogen balances, the surplus varying from 29.3 kg N $ha^{-1}$ $year^{-1}$ (field 2, Cecilia) to 165.3 kg N $ha^{-1}$ $year^{-1}$ (field 3, Labarrere). Phosphorus balances were slightly positive: 1.2 kg P

ha$^{-1}$ year$^{-1}$ to 26.5 kg P ha$^{-1}$ year$^{-1}$. Potassium balances were negative in field 4 of Cecilias farm (-14.2 kg K ha$^{-1}$ year$^{-1}$) and in field 5 of Labarreres farm (-24.4 kg K ha$^{-1}$ year$^{-1}$).

Given the high potassium content of the soils under study, a negative potassium balance will not lead to low yields immediately. Soil fertility problems however will be caused on the long term. Fields with negative potassium balances could benefit from artificial potassium fertilization or from replacement of artificial nitrogen and/or phosphorus fertilization by application of chicken bed. Measuring soil potassium stock is desirable, to estimate the capacity of the soil to supply nutrients. In addition, measuring the degree of phosphorus saturation can reveal information on the risk of phosphorus losses by leaching.

To obtain a clear view on possible environmental losses and crop nutrient shortages more detailed balances should be made, relating nutrient availability to crop demand. Given the large amount of organic inputs used in the systems studied, these balances should include an estimation of mineralization and immobilization processes related with decomposition of organic substrates. This holds especially for nitrogen.

## RESUMEN

En el sur de Uruguay, productores de hortalizas tienen problemas de rendimientos bajos y de recursos naturales en deterioro. Investigaciones previas mostraron que los rendimientos y el contenido de la materia orgánica del suelo pueden aumentar conforme se realicen mejores rotaciones de cultivos, entre otros como incluir abonos verdes. El objetivo del proyecto EULACIAS apunta a volver estas prácticas una realidad y a mejorar la sustentabilidad de esos predios. En el proyecto EULACIAS, tanto los balances de la materia orgánica como los balances de nutrientes se consideran indicadores de la sustentabilidad.

En este estudio, se estimó el contenido de la materia orgánica del suelo en el largo plazo (40 años) para dos cuadros de dos predios, utilizando el modelo Rotsom. Este modelo mono-componente estima la descomposición de los sustratos orgánicos aplicados y su contribución a la materia orgánica del suelo, y también estima la descomposición de la materia orgánica estable que estaba en el suelo al principio de la simulación. Se asumió que la rotación realizada entre 2005 y 2008 será la misma durante los próximos 40 años. Entonces, el tipo y la cantidad de los sustratos orgánicos aplicados serán los mismos cada cuatro años, al igual que la época de aplicación. Para establecer una relación entre el último cultivo y el primer cultivo de la rotación, se asume la aplicación de un manejo de sustratos favorable.

Adicionalmente, se realizaron balances de nutrientes de nitrógeno, fósforo y potasio para los cuatro cuadros estudiados. En estos balances fueron considerados como entradas, los nutrientes proveídos por cama de pollo, fertilizantes, semillas y plantines. En relación al nitrógeno, otros elementos considerados como entradas fueron: fijación biológica y deposición atmosférica. Los nutrientes cosechados son considerados como salidas. En el caso de nitrógeno y fósforo, el almacenamiento de nutrientes y la mineralización de nutrientes de materia orgánica son considerados como entradas y salidas respectivamente, dependiendo del cambio en el contenido de materia orgánica en el suelo, el cual fue estimado en base al modelo Rotsom. En base a cálculos con el modelo Rotsom (sobre un periodo de 40 años) se estimó el cambio promedio en materia orgánica. Se calcularon balances de nitrógeno, fósforo y potasio con las mismas presuposiciones que el modelo Rotsom. Además, se hicieron balances de potasio reconstruyendo las dinámicas de potasio de los últimos años.

Se recopilo información de 2004 hasta 2008 con base en entrevistas con los productores y análisis de suelos y de cama de pollo, y además se utilizó datos bibliográficos. Se realizo una comparación de los balances con datos sobre el contenido de fósforo (Bray P) y el contenido de potasio del suelo.

Los cuadros estudiados se encuentran ubicados en Canelón Grande, 50 km. al norte de Montevideo. Los suelos son brunosols (Typical Agriudolls) o vertisols (Typical Hapluderts). Las rotaciones consistían en hortalizas y cereales comunes en la zona, como tomate, morrón, ajo, melón, papa y trigo. Se plantaron cereales (trigo, avena o moha) como abonos verdes en todas las rotaciones estudiadas.

Para Rotsom, en todos los casos el contenido de materia orgánica aumentó, con un patrón ondulante. El aumento más grande se dio en el cuadro 3 de la finca Labarrere (un aumento de 2.1% a 3.4%), y el menor en el cuadro 5 de la misma finca (un aumento de 2.3% a 2.8%). El contenido de materia orgánica medido fue más grande que el contenido de materia orgánica modelado. Algunas de las posibles causas son mencionadas. Los resultados indican que es deseable que los productores continúen con el manejo de los sustratos observado en los últimos años.

En todos los casos, la cama de pollo fue la fuente de nutrientes más importante, mientras tanto los nutrientes cosechados o almacenados en la materia orgánica del suelo fueron los únicos y mas importantes salidas. Normalmente, las cantidades aplicadas y extraídas de nitrógeno fueron mayores que las de potasio. Mientras que las cantidades aplicadas y extraídas de fósforo fueron las menores.

Todos los cuadros mostraron balances de hidrógeno positivos, con excedentes de 29.3 kg N ha$^{-1}$ año $^{-1}$ (cuadro 2, Cecilia) a 165.3 kg N ha$^{-1}$ año $^{-1}$ (cuadro 3, Labarrere). Los balances de fósforo fueron ligeramente positivos1.2 kg P ha$^{-1}$ año $^{-1}$ a 26.5 kg P ha$^{-1}$ año $^{-1}$. Los balances de potasio fueron ligeramente negativos en el cuadro 4 de la finca de Cecilia (-14.2 kg K ha$^{-1}$ año $^{-1}$) y en la cuadro 5 de Labarrere (-24.4 kg K ha$^{-1}$ año $^{-1}$).

Al observar el alto contenido de potasio de los suelos estudiados, un balance negativo de potasio no llevaría inmediatamente a rendimientos bajos. Sin embargo, esto causaría problemas con la fertilidad del suelo en el largo plazo. Es recomendable medir el contenido de potasio de los suelos, para estimar la capacidad de entregar nutrientes. Además, en el caso de fósforo, realizar una medición del contenido de nutrientes de los suelos es útil para poder estimar el grado de saturación y el riesgo de lavado.

Se recomienda hacer balances más detallados, relacionando la disponibilidad de nutrientes con las necesidades de los cultivos, para obtener una imagen clara de las pérdidas ambientales posibles y de las posibles deficiencias del cultivo. Como se utilizaron cantidades grandes de materia orgánica en los sistemas estudiados, se necesita incluir una estimación de procesos de mineralización y de inmovilización relacionados con la descomposición de materia orgánica. Esto es importante especialmente para nitrógeno.

## INTRODUCTION

Sustainable nutrient management of the farm system is of interest both from an agronomic and an environmental point of view. A farmer would like to maximize yields while at the same time minimizing costs of fertilizer inputs. Moreover excessive application of nutrients can lead to losses to the environment with the risk of causing eutrophication and acidification. Sustainable nutrient management thus requires cautious balancing of inputs and crop demands (Topp et al., 2007, Öborn et al., 2003).

In addition synchronization of nutrient availability and plant demand is important. A large availability of nutrients coinciding with low crop demand or heavy rain will lead to losses whereas shortages may occur in periods of fast plant growth (Oenema et al., 2003). This is especially important for mobile substances such as nitrate and dissolved organic compounds whereas it is less relevant for more immobile nutrients mainly associated with the soil solid phase such as phosphorus.

Nutrient balances can reveal information on the sustainability of actual nutrient management that cannot easily be seen in the field. By comparing inputs such as fertilizer, biologically fixed nitrogen and green manures with the amount extracted by harvest in a quantitative way, an estimation can be made on possible excesses or shortages of nutrients. In interpreting the results the balance should be related to the soil nutrient status. As explained the timing of nutrient availability determines whether shortages or losses occur in reality. Therefore, static nutrient balances not taking this temporal component into account can give no more than an indication of possible environmental losses (Öborn et al., 2003).

However, nutrient shortages or excesses occurring year after year are undesirable in any case. Whilst the soil can buffer short periods wherein more phosphorus or potassium is applied than extracted or vice versa, prolonged periods wherein this is the case will lead to enrichment of the environment (eutrophication) or exhaustion of the soil and subsequent yield reduction.

Soil organic matter interacts with plant available nutrients via mineralization and immobilization processes, both related to decomposition of organic substrates. Mineralization and immobilization of nutrients occur simultaneously. Whether net mineralization or immobilization occurs depends on the amount and type (composition) of organic substrates applied, on climatic conditions and on site characteristics.

Moreover, maintaining soil organic matter has been recognized as key to soil quality and productivity. Soils high in organic matter content are known to have higher water retention capacity and higher biological activity than soils lacking organic matter. In addition, soil organic matter enhances soil structure, decreasing the risk of erosion.

Many vegetable farmers in Canelón Grande in Southern Uruguay face problems of declining soil organic matter content due to intensive land use and lack of application of conservation practices (Dogliotti et al., 2003).

Within the EULACIAS-project[1], agronomic practices as crop rotations and green manure crops are promoted to maintain the natural soil resource base. In this project, evolution of organic matter as well as nutrient balances for nitrogen, phosphorus and potassium are mentioned as indicators of soil fertility (Anonymous, 2007; Anonymous, 2008). This study will focus on two farms participating in this project. For both farms, data on the history of land use, the amount of crops sold, the type of crops incorporated and

[1] The problem of declining soil organic matter content and declining soil fertility does not stand alone nor can it be solved in isolation. The Eulacias project, therefore, aims at improving the sustainability of small scale farmers considering the farm system as a whole via a cooperative learning process of farmers and researchers (Anonymous, 2007).

the type and quantity of fertilizer applied are available. In addition the organic matter content of soil was determined several times during the past years.

The farm of Alberto and Lilian Cecilia sizes 4.4 ha, of which 2.8 ha is used for vegetable production. Soils are Typical Argiudolls (brunosols) (among others field 2) and clayey Typical Hapluderts (vertisols) (among others field 4). pH-$H_2O$ varies between 5.5 – 6 (field 2), and between 7.5-7.8 (field 4). With respect to the state of conservation of the natural resources, the farm is characterized by a high risk of erosion, a low level of soil organic carbon and a considerable impact of weeds and soil-borne diseases (Anonymous, 2008). 2.5 ha out of 5.5 ha farmland is used for vegetable production by Julio and Chichi Labarrere. Typical Argiudolls (brunosol) is the main soil type, having a sandy-clayey to clayey structure. pH-$H_2O$ varies between 5.2-6.4 (field 3) and between 6.0 – 6.6 (field 5). Risk of erosion is considerable, soil organic carbon is low and impact of weeds and soil borne diseases is considerable (Anonymous, 2008). Both farmers participate in the project since the end of 2004.

The aims of this study are to quantify nutrient balances at field scale, and to evaluate current nutrient management practices of two pilot farms in the EULACIAS-project. Hereby, an estimation of net quantities of nutrients stored in or released from organic matter will be made using Rotsom. In addition, the effect of the current organic matter management on the soil organic matter status on the long term (40 years) will be evaluated. All aims apply to two fields selected in the farms of Cecilia and Labarrere.

Squash at Alberto and Lilian Cecilia’s farm,
February 2008

## MATERIALS AND METHODS

Data on history of land use, crop yield and fertilizer and organic manure applied were obtained by farmer interviews and field observation during the years 2004-2008. During this period organic matter content, soil texture, soil phosphorus content and soil potassium content were determined several times. Organic matter content was determined with a colorimeter after oxidation with dichromate and sulphuric acid as described by Walkley and Black (1934). Texture was determined following the method of Bouyoucos (1926). Available phosphorus was determined using Brays method (Bray and Kurtz, 1945) whereas exchangeable potassium content was measured through extraction with 1 M ammonium acetate and measurement of atomic emission. In three cases, the absolute value of soil phosphorus content was not given by the laboratory when this value was higher than 60 μg P $g^{-1}$ soil[2]. If applicable, this is indicated in the results section.

### *Soil organic matter*

As mentioned release of nutrients from organic sources depends on decomposition processes. Model calculations are used to estimate the development of soil organic matter and the fate of organic manure and green manure crops. For this purpose, the approaches of Kortleven (1963, mentioned in Dogliotti et al., 2003) and Yang and Janssen (2000, mentioned in Dogliotti, 2003) were combined, as done and explained by Dogliotti et al. (2003). These calculations consist of two main pillars: the development of the organic matter pool initially present in the soil, which is assumed to be composed of a degrading part and an inert part; and the contribution of organic substrates added to the soil to the soil organic matter pool. In formulas:

$$SOM_t = Y_t + \sum A_{it}$$

$$Y_t = Y_{t-1} - ((Y_{t-1} - Y_{min}) * R) * dt$$

$$A_{i\,t} = A_{i0} * \exp(-R_{9\,i} * CF * t)^{1-S_i})$$

Wherein

$SOM_t$ = soil organic matter present at time t (kg $ha^{-1}$)

$Y_t$ = amount of initially present SOM remaining at time t (kg $ha^{-1}$)

$A_{i\,t}$ = amount of substrate i present at time t (kg $ha^{-1}$)

$Y_{min}$ = minimum amount of SOM (kg $ha^{-1}$)

R = decomposition rate ($yr^{-1}$)

t = time (yr)

CF = correction factor (-)

$R_{9\,i}$ = substrate specific initial average relative mineralization rate between t=0 and t=1 ($yr^{-1}$)

$S_i$ = substrate specific measure of the rate at which the average mineralization rate decreases over time ($0 \leq S \leq 1$) ($yr^{-1}$)

It was assumed the crop rotations and intercrop management applied in the past 3-4 years were repeated continuously in the fields under study. Thus, in the case of field 2 of Alberto Cecilia's farm, it was assumed sweet potato was grown after onion. Intercrop management in the period between the last crop of the rotation and the first was assumed based on common (feasible) practice. An overview of the rotations used as input for Rotsom is shown in Tables 1-2. Detailed information on the dates of sowing and harvest

[2] Unless asked for explicitly, the laboratory does not provide the absolute value of soil phosphorus content when higher than 60 μg P $g^{-1}$ soil.

and yields as well as on quantities of animal manure applied and dates of application can be found in Appendix II Nutrient balances. An overview of the values used to describe the decomposition of crops (R9, S, yield/residue-ratios, potential yields, growing period) as well of residues and animal manure applied in the intercrop period (R9, S, amount applied, day of application) can be found in Appendix I.

Table 1. Rotation and intercrop management applied at field 2 (1a) and 4(1b) of Alberto Cecilia's farm 2004-2008, used as input for Rotsom. *Italics* indicate assumed planting of green manure and/or application of animal manure to connect the last to the first crop of the rotation. Detailed sowing, harvest and application dates can be found in Appendix I and II.

1a.

| Year | Crop | Green manure | Animal manure |
|---|---|---|---|
| 1 | Sweet potato | | |
| 1 | Pea | | |
| 2 | | Foxtail millet | Chicken Bed |
| 2 | Garlic | | |
| 3 | | Foxtail millet | Chicken Bed |
| 4 | Onion | | |
| 4 | | *Oat* | |

1b.

| Year | Crop | Green manure | Animal manure |
|---|---|---|---|
| 1 | Garlic | | |
| 1 | Sweet potato | | |
| 1 | | | Chicken Bed |
| 2 | Onion | | |
| 2 | | Oat | |
| 3 | Sweet potato | | |
| 4 | | Wheat | |
| 4 | Squash | | |
| 4 | | | *Chicken Bed* |

Table 2. Rotation and intercrop management applied at field 3 (2a) and 5 (2b) of Julio Labarrere´s farm 2004-2008, used as input for Rotsom. *Italics* indicate assumed planting of green manure and/or application of animal manure to connect the last to the first crop of the rotation. Detailed sowing, harvest and application dates can be found in Appendix I and II

2a.

| Year | Crop | Green manure | Animal manure |
|---|---|---|---|
| 1 | Onion | | |
| 1 | | Wheat | Chicken Bed (2x) |
| 2 | Melon | | |
| 3 | | Oat | Chicken Bed (2x) |
| 3 | Tomato | | |
| 3 | | | *Chicken Bed* |

2b.

| Year | Crop | Green manure | Animal manure |
|---|---|---|---|
| 1 | Tomato | | |
| 1 | | | Chicken Bed |
| 2 | Onion | | |
| 2 | | | Chicken Bed |
| 2 | Crucifers | | |
| 3 | | Foxtail millet | |
| 4 | Onion seed | | |
| 4 | | *Oat* | *Chicken Bed* |

Clay and silt content of the top 20 cm of soil were determined in April 2008 (Table 3). As no measurements on texture were done in field 2 at Cecilia's farm and in field 3 at Labarrere's farm, the average of the measurements in the fields measured were taken.

Table 3. Values of clay and silt content and organic matter content used as input in Rotsom.

| Field | Clay & silt content (%) | Organic matter content (%) |
|---|---|---|
| Labarrere3 | 67 (average) | 2.07 (March 2005) |
| Labarrere5 | 68 | 2.3 (Dec 2005) |
| Cecilia2 | 80 (average)[a] | 1.9 (April 2005) |
| Cecilia4 | 79 | 1.9 (Dec 2004) |

[a] No measurements were done in the fields under study and thus the average was taken of 3 other fields in each farm

Since the study area and climatic conditions are comparable to the ones analysed by Dogliotti et al., the same assumptions will be made with respect to the correction factor (to correct for temperature and soil texture) and decomposition rate (Table 4).

After running the model the effect of current soil organic matter management on the development of soil organic matter on the long term (40 years) was assessed.

Table 4. Values of several parameters to be used in the modelling of soil organic matter.

| Parameter | Value | Source |
|---|---|---|
| Correction Factor CF | 1.122 | Dogliotti et al. (2003) |
| Soil bulk density | 1.25 g $cm^{-3}$ | Dogliotti et al. (2003) |
| Soil volume | 2000 $m^3$ * $ha^{-1}$ | Top 20 cm is considered |
| Decomposition rate R | 0.03 $yr^{-1}$ | Dogliotti et al. (2003) |

### *Nutrient balance*

A balance was made on the basis of crop harvest, fertilizer applied, biological nitrogen fixation, atmospheric deposition, seeds or transplants and nutrients immobilized or mineralized due to changes in the soil organic matter pool. This is shown by the blue arrows in the simplified conceptual model in Fig. 1.

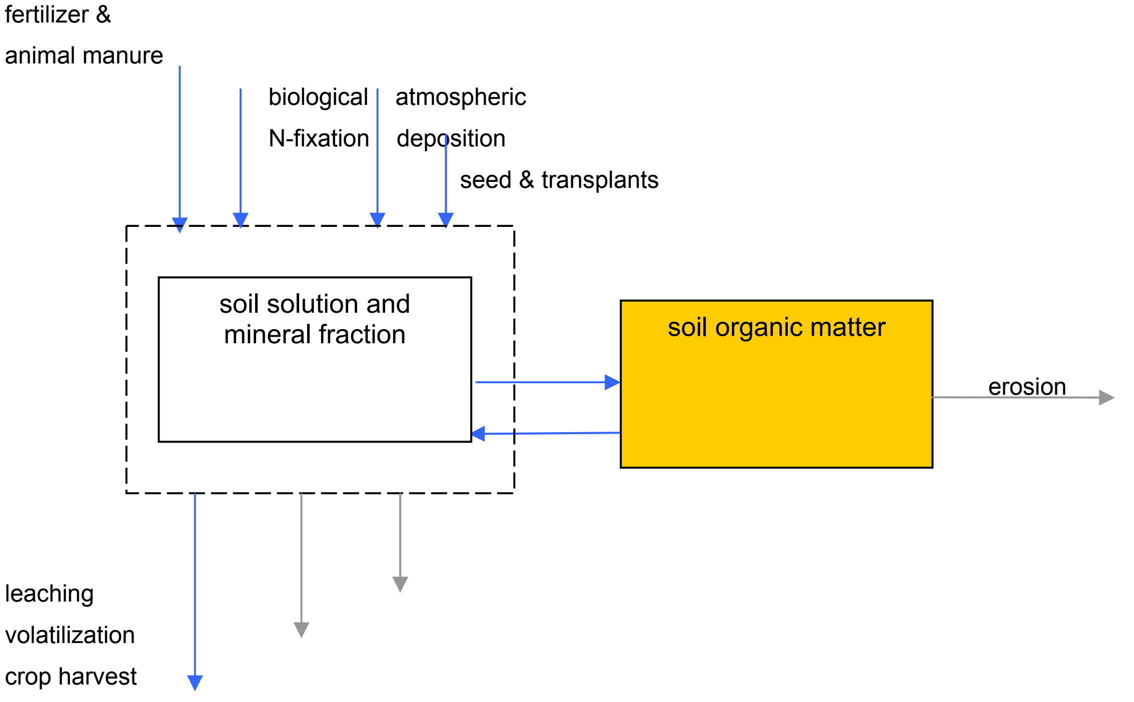


Fig. 1. Simplified soil nitrogen balance model. Measurements are done on the SOM pool indicated in yellow. Estimations were made on the flows represented by blue arrows, whereas fluxes represented by grey arrows are not taken into account. Blue arrows in the direction of the soil solution and mineral fraction are considered inputs, whereas blue arrows away from this pool are considered outputs.
- - - - - - - - system boundaries considered.

The balance can then be composed as follow:

$$\sum inputs = \sum outputs +/- excess/shortage$$

Hereby, fertilizer and animal manure, biological nitrogen fixation, atmospheric deposition, seed or transplants and release from organic matter are considered inputs whereas crop extraction and storage of nutrients in organic matter are considered outputs. Calculations were made per hectare for the top 20 cm. of soil, as most plant roots grow in this zone and the soil samples were taken in this zone. For potassium, a 'dynamic' balance for the rotation in place (Tables 1-2) for the period 2004-2007/2008 was made in this way (without making assumptions on planting of green manure or application of chicken bed directly after the period for which data where available).

For nitrogen and to a lesser extent for phosphorus, nutrient availability is partly determined by processes of mineralization and immobilization during decomposition of soil organic matter and crop residues. Crucial parameters to model this interaction during the growing season (e.g. C/N-ratio of the substrate applied) were not available. Therefore, short term interactions were disregarded and continuous application of the rotation studied was assumed, to calculate an average yearly balance. The same assumptions on the management between the last and the first crop of the rotation were used as in the Rotsom-simulations (Tables 1-2).

The effect of soil organic matter on the nutrient balance was calculated using Rotsom, following Dogliotti et al (2003).Soil organic matter contains a certain amount of nutrients and the change in soil organic matter over time indicates, therefore, whether storage of nutrients in soil organic matter or net release of nutrients from soil organic matter takes place. Eventually, an increase or decrease of soil organic matter content would thus lead to storage of nutrients in or release of nutrients from soil organic matter respectively. Thereby it was assumed composition of soil organic matter (i.e. C/N-ratio) would remain constant over the forty-year period

Long-term balances for nitrogen, phosphorus and potassium were composed in this way. These overall balances (kg $ha^{-1}$ $year^{-1}$) were calculated as

$$(\sum \text{Inputs (kg ha}^{-1}) - \sum \text{Outputs (kg ha}^{-1}))/(\text{Length of the rotation (years)})$$

The entries are calculated as follows:

### Output: harvest

The amount of nutrients removed by harvest is calculated as follows:

Nutrient harvested (kg/ha) = crop sold (kg/farm) / (total area with this crop (ha/farm)) * $10^{-3}$ *crop nutrient content (kg/ton)

In case the amount of crop sold was known on a per piece basis an estimation was made on the weight of plant material removed from the field for one broccoli (Table 5). Nutrient content of crops (harvested parts) was taken from literature (Table 6). Nutrients in residues that remained in the field were not counted as outputs. When available, data on nutrient content of crops were taken from Dogliotti (2003) as these were selected for use in the region under study. If not, the average of other values found in literature was taken. For onion and garlic, data on total absorption of nutrients were used as no residues are left on the field and thus all nutrients taken up by the crop are removed.

Table 5. Estimated weight of units in which data on harvest were available. Source: S. Peluffo, pers. comm.

| Crop | Unit | Estimated weight (kg) |
|---|---|---|
| Garlic | Head | 0.05 |
| Cauliflower | Flower | 1.25 |
| Broccoli | Flower | 0.6 |
| Melon | Tray | 18 |
| Pea | Tray | 12 |

Table 6. Values of nutrient content of crops (kg/ton fresh matter) used in the nutrient balance calculations and sources of these values.

| Crop | Nitrogen content | Source | Phosphorus content | Source | Potassium content | Source |
|---|---|---|---|---|---|---|
| Pea | **15.0** | 1a, 1b | **2.00** | 1a, 1b | **7.00** | 1a, 1b |
| Broccoli | **2.10** | 1a, 1b | **0.760** | 1a, 1c<br>3<br>4a | **2.60** | 1a, 1c<br>3 |
| Cauliflower | **3.00** | 1a, 1b | **0.620** | 1a, 1b<br>3<br>4a | **2.93** | 1a, 1b<br>3 |
| Garlic | **9.49** | 5 | **1.21** | 5 | **3.80** | 5 |
| Melon | **2.50** | 1a, 1b | **0.240** | 1a, 1b<br>3 4b | **3.40** | 1a, 1b<br>3 |
| Onion | **1.92** | 5 | **0.300** | 5 | **1.55** | 5 |
| *Sweet pepper* | ***2.39*** | *5* | ***0.300*** | *5* | ***2.90*** | *5* |
| Squash | **2.40** | 5 | **0.320** | 5 | **3.50** | 5 |
| Summer squash | **1.00** | 1b | **0.260** | 1b<br>3* | **1.85** | 1b<br>3* |
| Sweet potato | **2.40** | 5 | **0.280** | 5 | **2.04** | 5 |
| Tomato (´extracción´) | **2.10** | 1a, 1d, 1e 6 | **0.220** | 1a, 1d, 1e 3 4c 6 | **2.33** | 1a, 1d, 1e 3 6 |
| Oat | **20.0** | 2a 2b 2c 2d | **3.00** | 2a 2b 2c 2d | **3.00** | 2a 2b 2c 2d |
| Wheat | **16.3***2* | 5 | **3.70** | 5 | **4.20** | 5 |

* Value of zucchini

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1d Cristou M., Y. Dumas, A Dirmikou and Z. Vassiliou. 1999. Nutrient uptake by processing tomato in Greece. IWI. Proc 6th Int. ISHS Symp. On Processing Tomato. Acta Hort 487: 219-223. in: Archivo Agronómico #12, Ciampitti, I. and F. García, IPNI, Argentina

1e SQM. Nutritional Guides for quality crops. Consulted 24/09/2007. http://www.sqm.com/aspx/en/Default.espx. in: Archivo Agronómico #12, Ciampitti, I. and F. García, IPNI, Argentina

2ª 1 Bertsch, F. 2003, Absorbción de nutrimentos por los cultivos. San José, Costa Rica, ACCS-Universidad de Costa Rca-CIA. pp. 62-105. 10. in: Archivo Agronómico #11, Ciampitti, I. and F. García, IPNI, Argentina (=1°)

2b IFA. 1992. World Fertilizer Use Manual. international Fertilizer Industry Association. Paris, France, pp. 37-550. . in: Archivo Agronómico #11, Ciampitti, I. and F. García, IPNI, Argentina (=1b)

2c 11 INFOPOS. Informaciones agronómicas del cono sur N0 4. Archivo agronómico No 3: Requerimiento nutricionales de los cultivos. Diciembre 1999. In: Archivo Agronómico #11, Ciampitti, I. and F. García, IPNI, Argentina

2d 14 IPNI NorthCentral-S. http://www.ipni.net/ppiweb/usanc.nsf. Consulted 5/01/2007. In: Archivo Agronómico #12, Ciampitti, I. and F. García, IPNI, Argentina

3 Howard, F., J. MacCillivray and M. Yamaguchi, Boletín No. 788 de la Estación Agrícola Experimental de California. La Composición en Nutrimientos de Hortalizas Cultivadas en California, In: Mortensen, E., and E. Bullard, 1971. Horticultura tropical y subtropical, centro regional de ayuda técnica/agencia para el desarrollo internacional AID, segunda edición en español, Mexico/Buenos Aires.

4a Bingham, F.T. Phosphorus. In: H.D. Chapman, ed. *Diagnostic Criteria for Plant and Soils.* Division of Agricultural Sciences, University of California, 1966. In: Barker, A. and D. Pilbeam, 2007. Handbook of Plant Nutrition, Tayler and Francis Group, Boca Raton London/New York.

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### Input: fertilizer and organic manure

The amount of nutrients applied by fertilizer or organic manure is calculated as follows:

Fertilizer = quantity of fertilizer applied (kg/farm)/size of field under study (ha/farm) * nutrient content f fertilizer (kg/kg)

Composition of fertilizers and animal manure is shown in Table 7. Data on the chicken manure-rice husk mixture were available on a per volume basis, and assumed to consist of 150 kg dry matter per $m^3$.

Table 7. Fertilizers and organic manures used in the area under study and their nutrient content (%). Data on chicken manure on basis of dry matter.

| **Fertilizer** | **Nitrogen** | **Phosphorus** | **Potassium** |
|---|---|---|---|
| Ca super phosphate | 0 | 21 | 0 |
| Urea | 46 | 0 | 0 |
| 7-43-0 | 7 | 43 | 0 |
| 20-40-0 | 20 | 40 | 0 |
| 18-46-0 (ammonia phosphate) | 18 | 46 | 0 |
| Chicken manure mixed with rice husk | 2.8 | 1.72 | 1.77 |

### Input: biological nitrogen fixation

The only legume planted in the fields under study was pea. Nitrogen fixation of pea was estimated as 58 kg N $ha^{-1}$, based on literature data (Table 8).

In the farm under study, the growing period of pea was 104 days, sowing density 50 kg seed $m^{-1}$ and fresh matter yield of grain 2929 kg $ha^{-1}$. Based on average growing period and average fixation of nitrogen, nitrogen fixation in the field under study was estimated as 104/127 * 97.19= 79 kg $ha^{-1}$. Based on the average fixation of nitrogen per kilogram of grain produced (known for three investigations) and an estimated water content of the grain of 80%, nitrogen fixation (Dogliotti, pers. comm.) in the field under study was calculated as 2929 * 0.20 * 0.063 = 37 kg $ha^{-1}$. In the balance the average of these two values is taken: 58 kg N $ha^{-1}$.

Table 8. Overview of some data on investigations on nitrogen fixation by pea.

| Author | Publication year | Growing period (days) | Sowing density | DM yield grain (t*ha$^{-1}$) | Nitrogen fixed (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| Drew et al. | 2007 | 123 | 100 kg seed/ha | 0.13 – 0.25 | 19.75 |
| | | 147 | 100 kg seed/ha | 0.75 – 0.88 | 38.00 |
| Neumann et al. | 2007 | 115 | 40-120 seeds*m$^{-1}$ | 2.3 – 4.1 | 80.90 |
| | | 115 | 40-120 seeds*m$^{-1}$ | 3.9 – 4.3 | 83.55 |
| Evans et al. | 2003 | 155 | 90 kg seed/ha | - | 90.00 |
| | | 145 | 90 kg seed/ha | - | 90.00 |
| | | 141 | 90 kg seed/ha | - | 90.00 |
| Jensen | 1986 | 114 | 80 plants * m$^{-2}$ | 4.7 – 5.3 | 180.50 |
| | | 126 | 80 plants * m$^{-2}$ | - | 180.50 |
| | | 121 | 80 plants * m$^{-2}$ | - | 180.50 |
| Bourion et al. | 2007 | 119 | 80 plants * m$^{-2}$ | - | 216.50 |
| *Average* | | *127* | | | *97.19** |

* Calculated as the average of the average value found in the five publications.

### Input: atmospheric deposition

No data were available on atmospheric deposition in the area. Following Dogliotti (2003), it was assumed to be 5 kg N/ha/year.

### Input: seeds and transplants

As data on nutrient content of seeds were not available, it was assumed that seeds have the same nutrient content as plants. As data on foxtail millet (*Setaria italica*) were not available and amounts considered are very small the same value as for wheat was taken. Estimations of amount of seed used as input are shown in Table 9.

Table 9. Assumed mass of seeds and transplants. Values between brackets are used when half of the field is planted with this crop. Source: S. Peluffo, pers. comm.

| Crop | Number of transplants | Weight of transplant (kg) | Weight of transplant (kg/ha) | Amount of seed (kg/ha) |
|---|---|---|---|---|
| Pea | | | | 50 |
| Broccoli | 26700 | 2 * 10-2 | 534 (267) | |
| Cauliflower | 26700 | 2 * 10-2 | 534 (267) | |
| Garlic | 140000 | 4 * 10-3 | 560 | |
| Melon | 6500 | 15 * 10-3 | 97.5 | |
| Onion | 250000 | 6 * 10-3 | 1500 | |
| Squash | | | | 0.6 |
| Summer squash | | | | 1.3 (0.6) |
| Sweet potato | 33000 | 3.5 * 10-2 | 1155 | |
| Tomato | | | 300 (150) | 300 (150) |
| Oat | | | | 90 |
| Wheat | | | | 90 |
| Italian bluegrass | | | | 30 |

### Input or output: storage in or release from organic matter

Nitrogen storage in or release from organic matter is calculated as

> Storage in or release from organic matter = change in soil organic matter content (kg/ha) * carbon content of soil organic matter (%) * carbon:nitrogen-ratio in soil organic matter

Phosphorus storage in or release from organic matter is calculated as

> Storage in or release from organic matter = change in soil organic matter content (kg/ha) * phosphorus content in organic matter (%)

In both cases, the change in soil organic matter content was the average annual increase or decrease in soil organic matter (kg $ha^{-1}$ $year^{-1}$) over a period of forty years, as calculated by Rotsom. Organic matter was assumed to contain 0.58 carbon per unit organic matter. Carbon-nitrogen-ratio was assumed to be 10/1 (Dogliotti, 2003). Organic phosphorus content was assumed to be 0.035% (Hernandez, pers. comm.). Potassium is not associated with soil organic matter and therefore build-up or breakdown of organic matter is assumed not to influence the potassium balance. The annual storage in or release from organic matter thus calculated was multiplied by the length of the rotation (whole years).

## RESULTS

### *Soil organic matter*

### Farm Julio & Chichi Labarrere

*Model output*

Under the current organic matter management, soil organic matter content is likely to increase in both fields under study (Figs. 2-3). After 40 years, the average rate of increase in organic matter would be 886 kg $ha^{-1}$ $year^{-1}$ and 361 kg $ha^{-1}$ $year^{-1}$ in field 3 and 5 respectively. After 40 years with the current management, soil organic matter content would be around 3.4% and 2.8% in fields 3 and 5 respectively. In both fields decline of initially present soil organic matter is compensated by newly added substrates, mainly by organic and green manures (data not shown).

*Measurements*

In both cases field measurements show an increase in soil organic matter over time, which is slightly larger than the modelled increase (Figs. 2-3).

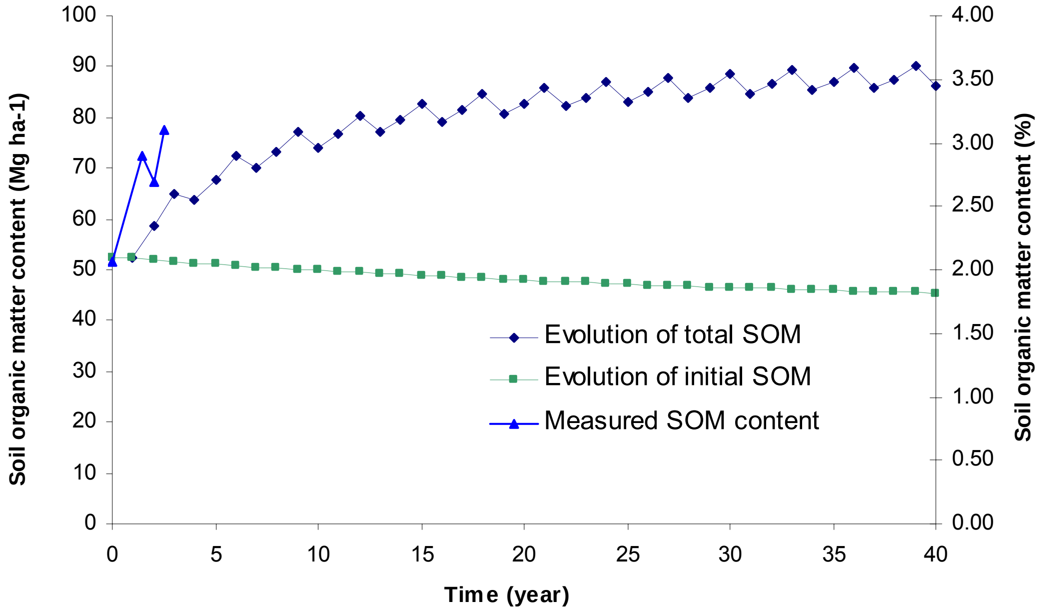


Fig. 2. Evolution of soil organic matter content as modelled with Rotsom and measured organic soil organic matter content of field 3 of Labarrere. Year 0 = 2005.

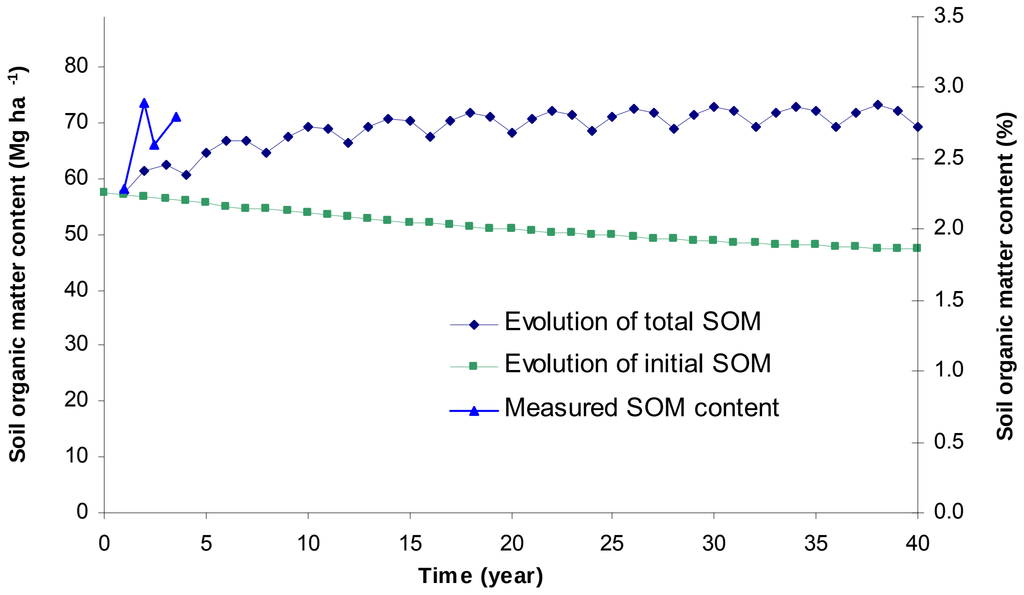


Fig. 3. Evolution of soil organic matter content as modelled with Rotsom and measured organic soil organic matter content of field 5 of Labarrere's farm. Year 0 = 2005.

## Farm Alberto & Lilian Cecilia

### *Model output*

Both fields under study show a small increase in soil organic matter content if current management is continued (Figs. 4-5). The average increase in organic matter after 40 years would be 354 kg $ha^{-1}$ $year^{-1}$ and 359 kg $ha^{-1}$ $year^{-1}$ in field 2 and 4 respectively. After 40 years with the current management, soil organic matter content would be around 2.5% in both fields. As in the farm of Julio Labarrere, decline of soil organic matter is compensated by newly added substrates and increase in soil organic matter follows a wavy pattern.

### *Measurements*

Field measurements show, on average, an increase over time. This increase is larger than predicted by the model in the first years (Figs. 4-5).

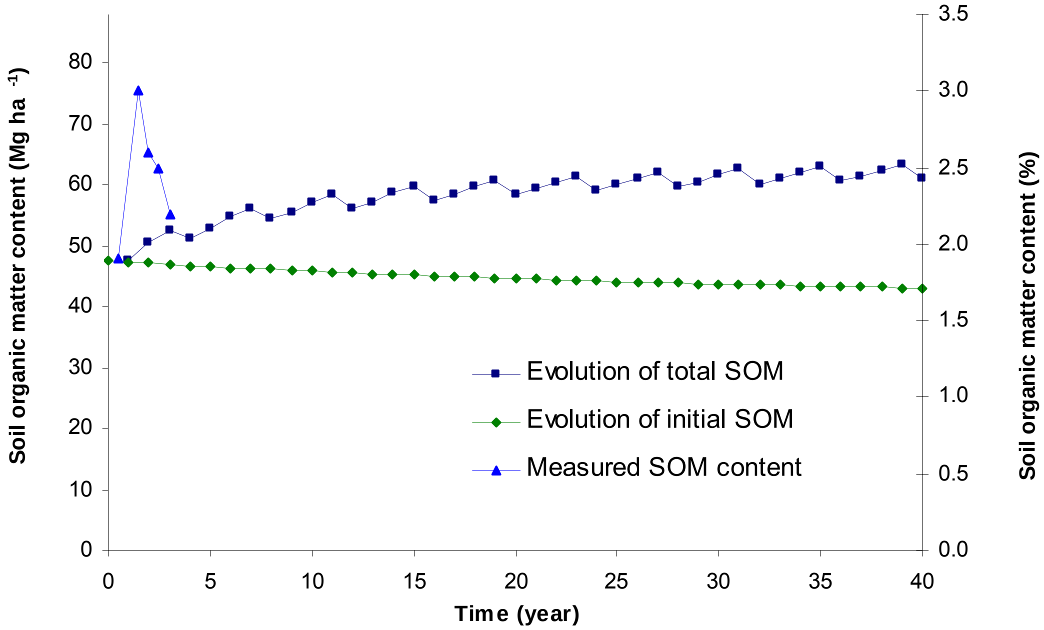


Fig. 4. Evolution of soil organic matter content as modelled with Rotsom and measured organic soil organic matter content of field 2 of Cecilia's farm. Year 0 = 2005.

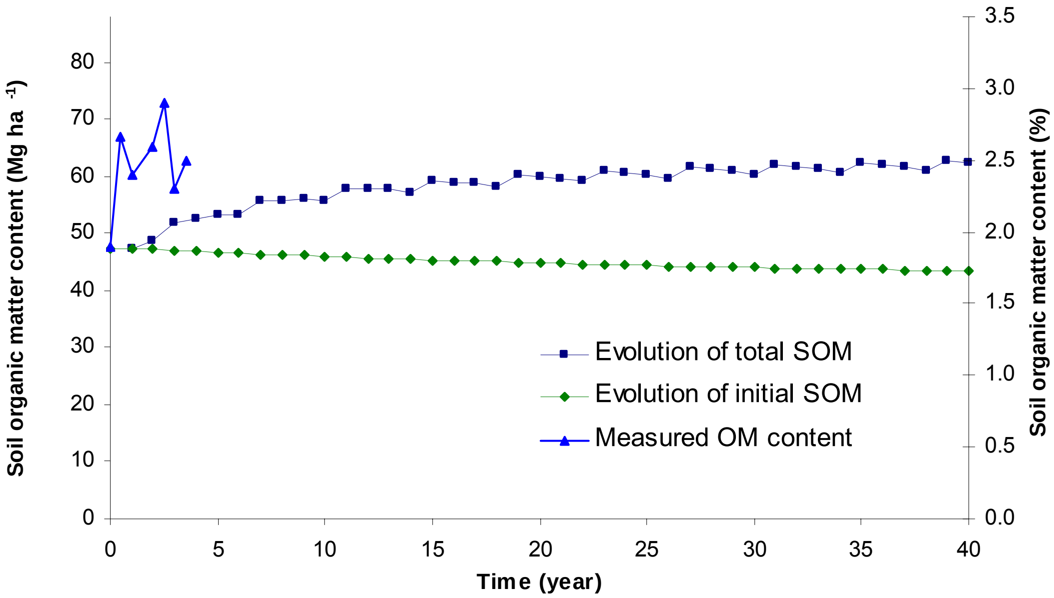


Fig. 5. Evolution of soil organic matter content as modelled with Rotsom and measured organic soil organic matter content of field 4 of Cecilia's farm. Year 0 = 2005.

### *Nutrient balances*

A detailed overview of all inputs and outputs considered from 2004-2008 as well as dates of application and extraction can be found in Appendix II. An overview of the calculation of storage of nitrogen and phosphorus in organic matter as used for the long-term balances can be found in Appendix III.

## Farm Julio & Chichi Labarrere

### *Field 3*

**Nitrogen**

*Long-term balance*

Total inputs were 787.2 kg N ha-1, mostly due to (assumed) application of chicken bed (702.9 kg $ha^{-1}$). 136.8 kg N $ha^{-1}$ was removed by harvest. Continuous application of the rotation in place from July 2004 to March 2007 would lead to an average storage of nitrogen in organic matter of 154.6 kg N in three years, and to an average yearly surplus of 165.3 kg N $ha^{-1}$ (Table 10).

Table 10. Long-term nitrogen balance of field 3 of Labarrere's farm, based on data from July 2004 – May 2007 and assumed application of chicken bed thereafter. Storage of nitrogen in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 62.5 | |
| Organic manure | 702.9 | |
| Biological fixation | 0.0 | |
| Atmospheric deposition | 15.0 | |
| Seed and transplants | 6.8 | |
| **TOTAL** | **787.2** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 136.8 |
| Storage in organic matter | | 154.5 |
| **TOTAL** | | **291.3** |
| **BALANCE** (kg N ha$^{-1}$ year$^{-1}$) | **165.3** | |

**Phosphorus**

*Long term balance*

Total inputs summed up to 106.9 kg P $ha^{-1}$, and were almost all applied in the form of organic manure and fertilizers. 18.1 kg P $ha^{-1}$ was harvested. Repetition of the rotation in place would lead to an average yearly surplus of 20.6 kg P $ha^{-1}$ (Table 11).

Table 11. Long-term phosphorus balance of field 3 of Labarrere's farm, based on data from July 2004 – May 2007 and assumed application of chicken bed thereafter. Storage of phosphorus in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 11.6 | |
| Organic manure | 94.2 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 1.1 | |
| **TOTAL** | **106.9** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 18.1 |
| Storage in organic matter | | 9.3 |
| **TOTAL** | | **27.4** |
| **BALANCE** (kg P ha$^{-1}$ year$^{-1}$) | **26.5** | |

*Soil phosphorus content*

The soil phosphorus content increased from in 29.4 µg P g$^{-1}$ soil April 2006 to 135 µg P g$^{-1}$ soil in May 2007 (Fig. 6).

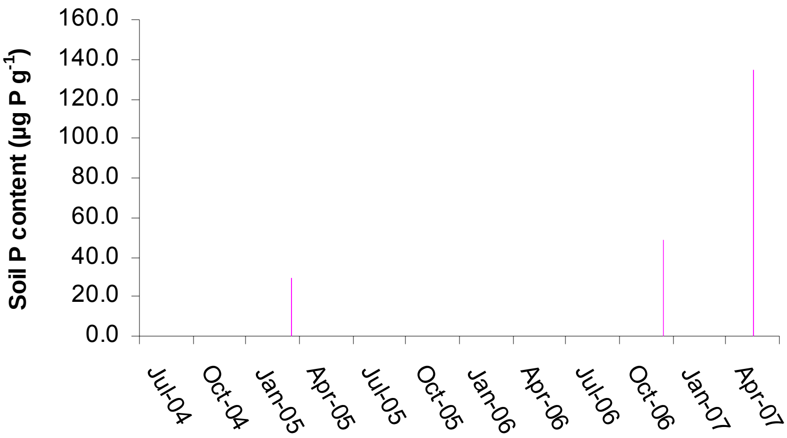


Fig. 6. Soil phosphorus content of field 3 of Labarrere's farm.

**Potassium**

*Long term balance*

Inputs summed up to 448.3 kg K ha$^{-1}$ and 185.9 kg K ha$^{-1}$ was extracted. A yearly excess of 87.5 kg potassium ha$^{-1}$ was calculated (Table 12). As for nitrogen, organic manure was by far the most important source of potassium. Harvest of nutrients was the only sink as potassium does not interact with organic matter.

Table 12. Long-term potassium balance of field 3 of Labarrere's farm, July 2004 – May 2007, based on data from July 2004 – May 2007 and assumed application of chicken bed thereafter.

| INPUTS | INPUTS (kg $ha^{-1}$) | OUPUTS (kg $ha^{-1}$) |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 444.3 | |
| Biological fixation | n.a.[1] | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 4.0 | |
| **TOTAL** | **448.3** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 185.9 |
| Storage in organic matter | | n.a. |
| **TOTAL** | | **185.9** |
| **BALANCE** (kg K $ha^{-1}$ $year^{-1}$) | **87.5** | |

[1] n.a. = not applicable

*Dynamic balance & soil potassium measurements*

Notwithstanding an overall excess of potassium (Table 13), the balance was slightly negative in the beginning of the rotation cycle, July 2004 and April 2005. In this period onion was grown. After April 2005 more potassium was applied than extracted or immobilized. In this period wheat, melon, oat, summer squash and tomatoes were grown respectively.

Table 13. Potassium balance of field 3 of Labarrere's farm, July 2004 – May 2007.

| INPUTS | INPUTS (kg $ha^{-1}$) | OUPUTS (kg $ha^{-1}$) |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 361.2 | |
| Biological fixation | n.a.[1] | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 4.0 | |
| **TOTAL** | **365.2** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 185.9 |
| Storage in organic matter | | n.a. |
| **TOTAL** | | **185.9** |
| **BALANCE** | **179.2** | |

[1] n.a. = not applicable

The soil potassium content increased from 0.7 meq 100 $g^{-1}$ in March 2005 to 1.2 meq 100 $g^{-1}$ in June 2007 (Fig. 7).

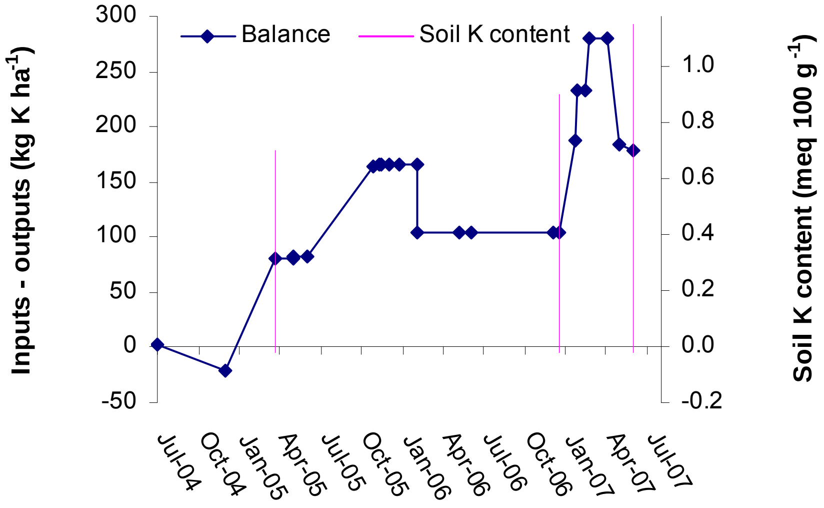


Fig. 7. Potassium balance and soil potassium content of field 3 of Labarrere's farm. Blue points indicate dates of supply or extraction of potassium.

### *Field 5*

**Nitrogen**

*Long-term balance*

Between November 2004 and December 2007, 445.0 kg N $ha^{-1}$ was applied to field 5. Organic manure was the most important source of nitrogen. Nutrients harvested (288 kg $ha^{-1}$) was the most important output. Continuous application of the rotation in place would lead to an average yearly surplus of 50.8 kg N $ha^{-1}$ (Table 14).

Table 14. Long-term nitrogen balance of field 5 of Labarrere's farm, based on data from November 2004 – January 2008, and on assumed planting of oat as green manure and application of chicken bed thereafter. Storage of nitrogen in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg $ha^{-1}$)** | **OUPUTS (kg $ha^{-1}$)** |
|---|---|---|
| Fertilizers | 136.3 | |
| Organic manure | 412.2 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | 20.0 | |
| Seed and transplants | 7.0 | |
| **TOTAL** | **575.5** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 288.4 |
| Storage in organic matter | | 84.0 |
| **TOTAL** | | **372.4** |
| **BALANCE** (kg N $ha^{-1}$ $year^{-1}$) | **50.8** | |

**Phosphorus**

*Long-term balance*

Organic manure was the main source of phosphorus whereas nutrients removed by harvest were the most important sink. After continuous repetition of the rotation considered outputs almost equal inputs and the overall balance is close to zero (Table 15).

Table 15. Long-term phosphorus balance of field 5 of Labarrere's farm, based on data from November 2004 – January 2008, and on assumed planting of oat as green manure and application of chicken bed thereafter. Storage of phosphorus in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 2.6 | |
| Organic manure | 55.2 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 1.3 | |
| **TOTAL** | **59.1** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 49.4 |
| Storage in organic matter | | 5.1 |
| **TOTAL** | | **54.5** |
| **BALANCE** (kg P ha$^{-1}$ year$^{-1}$) | | **1.2** |

*Soil phosphorus content*

The soil phosphorus content seemed to increase and was higher than 60 µg P g$^{-1}$ soil in all measurements (Fig. 8).

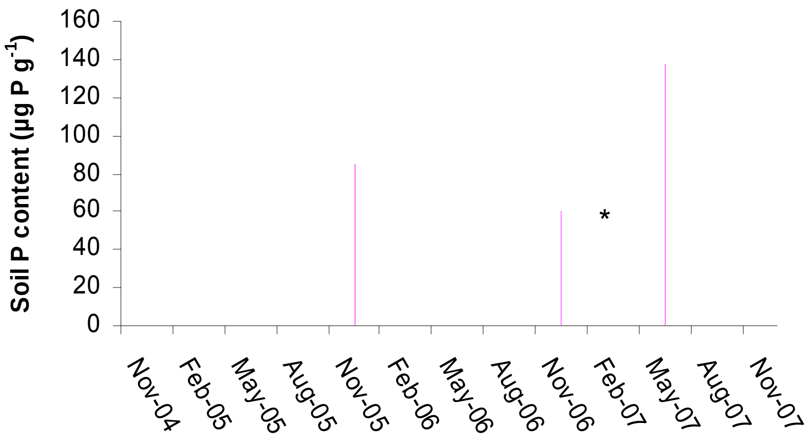


Fig.8. Soil phosphorus content of field 5 of Labarrere's farm * Soil phosphorus content > 60 µg P g$^{-1}$ soil.

**Potassium**

*Long-term balance*

The potassium balance is mainly determined by inputs from organic manure (260.6 kg K $ha^{-1}$) and outputs from harvest (361.3 kg K $ha^{-1}$). This leads to an average yearly shortage of 24 kg K $ha^{-1}$ (Table 16).

Table 16. Long-term potassium balance of field 5 of Labarrere's farm, based on data from November 2004 – January 2008, and on assumed planting of oat as green manure and application of chicken bed thereafter.

| **INPUTS** | **INPUTS (kg $ha^{-1}$)** | **OUPUTS (kg $ha^{-1}$)** |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 260.6 | |
| Biological fixation | n.a.[1] | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 4.9 | |
| **TOTAL** | **265.5** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 361.3 |
| Storage in organic matter | | n.a. |
| **TOTAL** | | **361.3** |
| **BALANCE** | **-24.0** | |

[1] n.a. = not applicable

*Dynamic balance & soil potassium measurements*

Between November 2004 and December 2007, 181.6 kg of potassium was applied, almost all with animal manure, and 361.3 kg K was extracted by harvest. Almost half of this amount (141 kg K $ha^{-1}$) was extracted by tomato. More potassium was extracted than applied during the whole period considered, leading to an overall shortage of 179.7 kg K $ha^{-1}$ (Table 17, Fig. 9). The balance was most negative between May 2005 and November 2005, when tomato and onion where grown respectively.

Soil potassium content varied between 1.3 and 1.9 meq 100 $g^{-1}$ (Fig. 10).

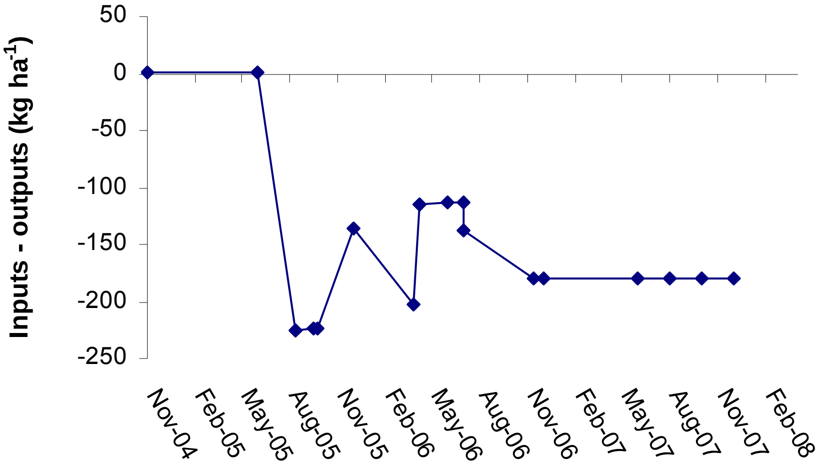


Fig. 9. Potassium balance of field 5 of Labarrere's farm. Points indicate dates of supply or extraction of potassium.

Table 17. Potassium balance of field 5 of Labarreres farm, for November 2004-January 2008.

| INPUTS | INPUTS (kg ha$^{-1}$) | OUPUTS (kg ha$^{-1}$) |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 177.0 | |
| Biological fixation | n.a.[1] | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 4.6 | |
| **TOTAL** | **181.6** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 361.3 |
| Storage in organic matter | | n.a. |
| **TOTAL** | | **361.3** |
| **BALANCE** | **-179.7** | |

[1] n.a. = not applicable

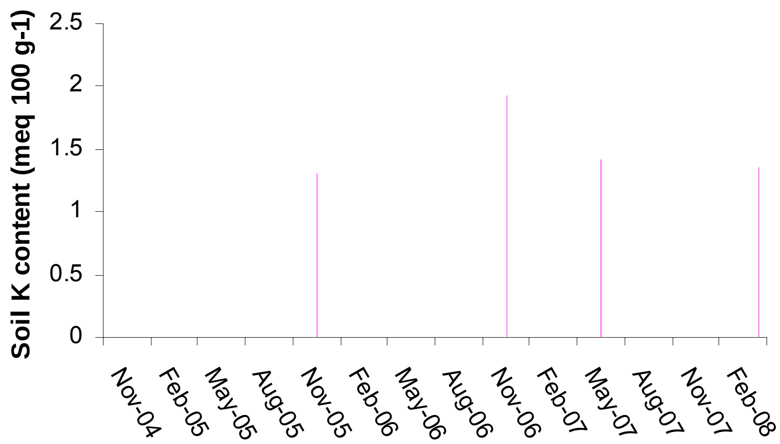


Fig. 10. Soil potassium content of field 5 of Labarrere's farm.

## Farm Alberto & Lilian Cecilia

*Field 2*

**Nitrogen**

*Long-term balance*

Fertilizers and organic manure were the main source of nitrogen. In addition, nitrogen fixated by pea accounted for 60 kg of nitrogen. Nutrients removed by harvest were the main output and accounted for 115.4 kg N ha$^{-1}$. On average the balance would be +48.5 kg N ha$^{-1}$ year$^{-1}$ (Table 18).

Table 18. Long-term nitrogen balance of field 2 of Cecilia's farm, based on data from July 2004 – December 2007, and on assumed planting of oat as green manure thereafter. Storage of nitrogen in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 147.5 | |
| Organic manure | 151.0 | |
| Biological fixation | 58.0 | |
| Atmospheric deposition | 20.0 | |
| Seed and transplants | 15.2 | |
| **TOTAL** | **391.7** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 115.4 |
| Storage in organic matter | | 82.3 |
| **TOTAL** | | **197.7** |
| **BALANCE** (kg N ha$^{-1}$ year$^{-1}$) | **48.5** | |

**Phosphorus**

*Long-term balance*

Between July 2004 and December 2007, main inputs were fertilizers (19.2 kg P ha$^{-1}$) and organic manure (20.3 kg P ha$^{-1}$). Nutrients removed by harvest was the main output. A small yearly average surplus of 5.2 kg P ha$^{-1}$ was calculated (Table 19).

Table 19. Long-term phosphorus balance of field 2 of Cecilia's farm, based on data from July 2004 – December 2007, and on assumed planting of oat as green manure thereafter. Storage of phosphorus in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 19.2 | |
| Organic manure | 20.3 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 4.1 | |
| **TOTAL** | **43.6** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 15.6 |
| Storage in organic matter | | 5.0 |
| **TOTAL** | | **20.6** |
| **BALANCE** (kg P ha$^{-1}$ year$^{-1}$) | **5.8** | |

*Soil phosphorus content*

Measurements on soil phosphorus content showed an increase from 45.9 to 65.2 µg P g$^{-1}$ soil (Fig. 11).

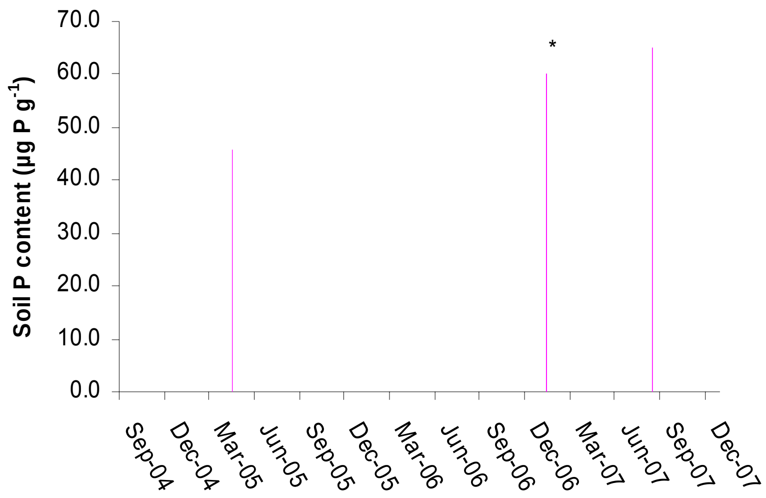


Fig. 11. Soil phosphorus content of field 2 of Cecilia's farm. *Soil phosphorus content > 60 µg P $g^{-1}$ soil.

**Potassium**

*Long-term balance*

In field 2, the lion's share of potassium was applied as green manure. On average, 9.3 kg K $ha^{-1}$ $year^{-1}$ was applied more than extracted (Table 20).

Table 20. Long-term potassium balance of field 2 of Cecilia's farm, based on data from July 2004 – December 2007, and on assumed planting of oat as green manure thereafter.

| **INPUTS** | **INPUTS (kg $ha^{-1}$)** | **OUPUTS (kg $ha^{-1}$)** |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 95.5 | |
| Biological fixation | n.a | |
| Atmospheric deposition | n.a | |
| Seed and transplants | 8.3 | |
| **TOTAL** | **103.8** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 66.7 |
| Storage in organic matter | | n.a |
| **TOTAL** | | **66.7** |
| **BALANCE** (kg K $ha^{-1}$ $year^{-1}$) | | **9.3** |

*Dynamic balance and soil potassium content*

Between July 2004 and December 2007, 36.8 kg K $ha^{-1}$ was applied more than extracted. Despite the overall positive balance, between May 2005 and April 2006 the balance was negative (Fig. 12). In this period sweet potato was grown. Soil potassium content increased from 0.31 meq 100 $g^{-1}$ in April 2005 to 0.49 meq 100 $g^{-1}$ in August 2007.

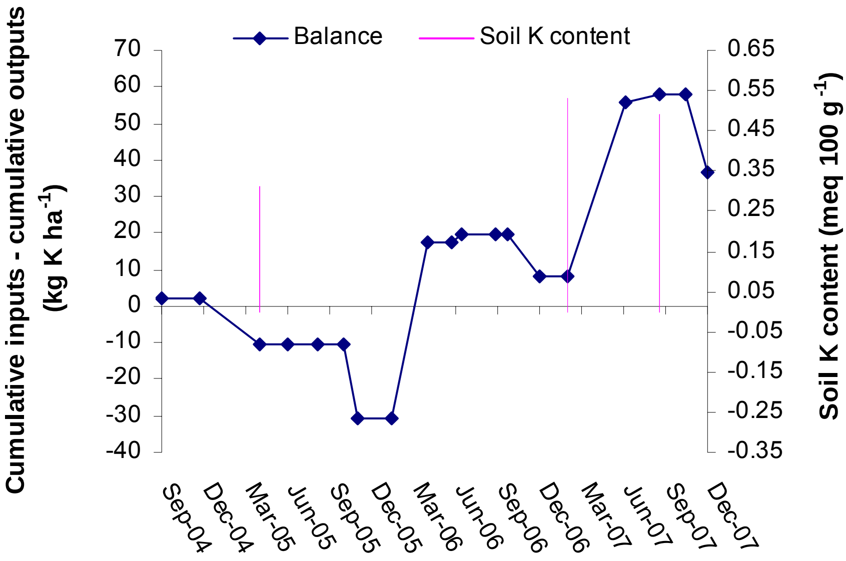


Fig. 12. Potassium balance and soil potassium content of field 2 of Cecilia's farm. Blue points indicate dates of supply or extraction of potassium.

*Field 4*

**Nitrogen**

***Long-term balance***

Fertilizers were the main source of nitrogen applied (174.6 kg N ha$^{-1}$), and harvest was the main nitrogen sink (159.5 kg N ha$^{-1}$). Continuous application of the rotation studied would lead to an average yearly surplus of 29.3 kg N ha$^{-1}$ (Table 21).

Table 21. Long-term nitrogen balance of field 4 of Cecilia's farm, based on data from June 2004 – March 2007, and on assumed application of chicken bed thereafter. Storage of nitrogen in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 174.6 | |
| Organic manure | 151.2 | |
| Biological fixation | 0.0 | |
| Atmospheric deposition | 20.0 | |
| Seed and transplants | 14.5 | |
| **TOTAL** | **360.3** | |
| **OUTPUTS** | | |
| Harvest | | 159.5 |
| Storage in organic matter | | 83.5 |
| **TOTAL** | | **243.0** |
| **BALANCE** (kg N ha$^{-1}$ year$^{-1}$) | | **29.3** |

**Phosphorus**

***Long-term balance***

Artificial fertilizers were the main source of phosphorus, providing 56.2 of the 79.5 kg P $ha^{-1}$ (Table 22) Nutrients harvested caused an output of 21.7 kg P $ha^{-1}$. An average yearly positive balance of 13.2 kg P $ha^{-1}$ was calculated.

Table 22. Long-term phosphorus balance of field 4 of Cecilia's farm, based on data from Juny 2004 – March 2007, and on assumed application of chicken bed thereafter. Storage of phosphorus in soil organic matter was calculated using Rotsom, for explanation see text.

| **INPUTS** | **INPUTS (kg $ha^{-1}$)** | **OUPUTS (kg $ha^{-1}$)** |
|---|---|---|
| Fertilizers | 56.2 | |
| Organic manure | 20.2 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 3.1 | |
| **TOTAL** | **79.5** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 21.7 |
| Storage in organic matter | | 5.0 |
| **TOTAL** | | **26.7** |
| **BALANCE** (kg P $ha^{-1}$ $year^{-1}$) | | **13.2** |

*Soil phosphorus content*

Soil phosphorus content fluctuated between 40.7 and 71 µg P $g^{-1}$ soil (Fig. 13).

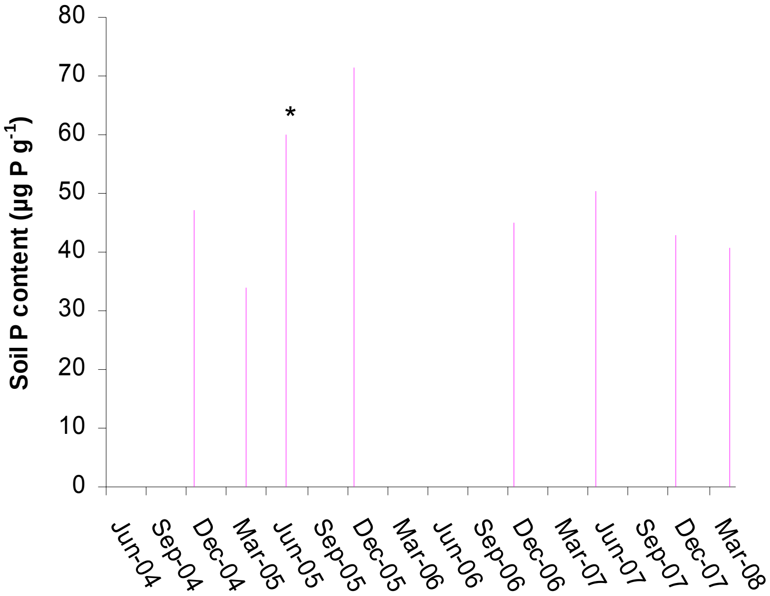


Fig. 13. Soil phosphorus content of field 4 of Cecilia's farm. *Soil phosphorus content > 60 µg P $g^{-1}$ soil.

**Potassium**

*Long-term balance*

In field 2, nutrients removed by harvest exceeded those applied with chicken bed and as seeds and transplants, leading to an average yearly balance of -14.2 kg K ha$^{-1}$ (Table 23).

Table 23. Long-term potassium balance of field 4 of Cecilia's farm, based on data from June 2004 – March 2007, and on assumed application of chicken bed thereafter.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 95.6 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 9.0 | |
| **TOTAL** | **104.6** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 161.4 |
| Storage in organic matter | | n.a. |
| **TOTAL** | | **161.4** |
| **BALANCE (kg K ha$^{-1}$ year$^{-1}$)** | | **-14.2** |

***Dynamic balance and soil potassium content***

Between June 2004 and March 2008 56.8 kg K ha$^{-1}$ was applied whereas 161.4 kg of potassium was extracted (Table 24). This lead to an overall negative balance of 104.5 kg K ha$^{-1}$. The negative balance is mainly caused by a large extraction of potassium by squash (87.5 kg K ha$^{-1}$) at the end of the rotation period. Until May 2007, the balance was positive or close to zero (Fig. 14).

The soil potassium content fluctuates between 0.5 and 1 meq 100 g$^{-1}$, and is higher (0.8) at the end of the rotation period than at the beginning (0.6).

Table 24. Potassium balance of field 4 of Cecilia's farm, June 2004 – March 2008.

| **INPUTS** | **INPUTS (kg ha$^{-1}$)** | **OUPUTS (kg ha$^{-1}$)** |
|---|---|---|
| Fertilizers | 0.0 | |
| Organic manure | 47.0 | |
| Biological fixation | n.a. | |
| Atmospheric deposition | n.a. | |
| Seed and transplants | 9.0 | |
| **TOTAL** | **56.8** | |
| **OUTPUTS** | | |
| Nutrient harvested | | 161.4 |
| Storage in organic matter | | n.a. |
| **TOTAL** | | **161.4** |
| **BALANCE** | | **-104.5** |

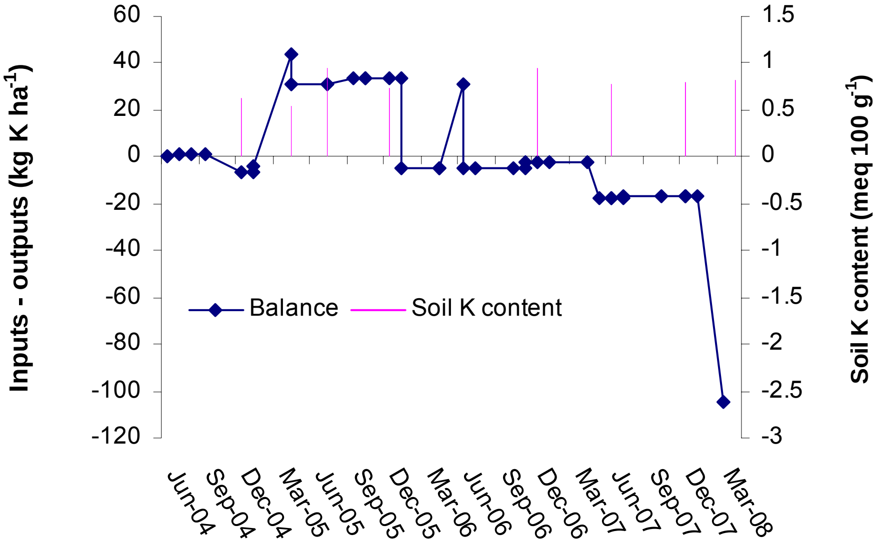


Fig. 14. Potassium balance and soil potassium content of field 4 of Cecilia's farm. Blue points indicate dates of supply or extraction of potassium.

## DISCUSSION

### *Soil organic matter*

#### Calculations

In all fields, soil organic matter content is likely to increase if the management of the past three years will be applied continuously. The increase in soil organic matter follows a wavy pattern, caused by differences in application in the different years of the rotation. In all cases green manure and application of chicken manure are main inputs of organic substrates (data not shown). For example, in the field 3 of Labarrere's farm, in the first year only residues of onion and chicken manure are applied, causing an overall decrease in the soil organic matter content. This decrease is compensated by applications of green manures (wheat and oat) and organic manures (chicken bed) in the subsequent two years.

In the farm of Julio Labarrere, soil organic matter content is likely to increase from 2.1 to 3.4 % in field 3 and from 2.3 to 2.8 % in field 5 if the soil organic matter management applied in the past three years would continue (Figs 2-3). If the same quantity of organic substrates is applied as in the past three (field 2) or four (field 4) years, soil organic matter is likely to increase from 1.9 to 2.5% in both fields of the farm of Alberta Cecilia (Figs. 4-5).

#### Assumed application of substrates and modelled results

As the rotations were not complete (normally, the last crop would not be followed by the first crop), a management between the last crop and the first crop of the rotation had to be assumed. A favourable management was assumed, that consisted of application of organic manure and/or a green manure crop. Obviously, if these substrates would not be applied the annual increase in organic matter would be less.
In addition, it was assumed the management of the past three years was repeated. However, the rotations proposed to the farmers in the EULACIAS project last longer than three years. What is modelled is thus only part of a rotation applied. However there are no reasons to assume less organic manure and green manure crops would be applied in a longer rotation.

#### Differences between modelled and measured results

An overall increase in organic matter content as measured in the field during the rotation was observed in all cases. The organic matter content measured in the field is larger than modelled. This could have several causes. First, Rotsom was designed for modelling evolution of soil organic matter on the long term. On a large timescale yearly variations, for example in climatic conditions, are assumed to level out (Dogliotti, 2003). These variations however can have a considerable influence in a shorter period. In addition, values of R9 and S, the parameters that determine the pattern of decomposition of a substrate modelled, were taken from literature and not adapted to the residues under study. Thereby, the model has a time step of one year – this means that an application in May is the same as an application in November for the model. Half a year may be little time compared to forty years, but is considerable compared to a three year period. To make more accurate estimation of evolution of organic matter on time scales as used in this study, it is desirable that a model will be developed that has a shorter time-step.

Possibly, recent additions of organic materials were included in the field measurements, leading to too high estimations of soil organic matter (Brussaard, pers. comm.). In addition, the methodology of measurements in the field would be more accurate when based on a higher number of samples taken. Due to limited resources this was however not possible.

**Recommendation**

Rapid increase of organic matter content of soils after applications of organic substrates are well-known (Garcia and Reyes, 2001). This is in line with the findings in the farms of Julio Labarrere and Alberto Cecilia, were applications of organic substrates were not common before the start of the study period. To maintain the observed increase in soil organic matter, it is necessary that sufficient quantities of organic substrates are added to the soil continuously (Garcia and Reyes, 2001). Considering the importance of a sufficiently high soil organic matter level to maintain soil quality and soil productivity, it is desirable that practices applied in the past three years will be continued.

## Nutrient balances

### Storage of nutrients in organic matter

As discussed above Rotsom simulations showed a net average yearly increase in organic matter in all cases. Consequently, in all nutrient balances storage of nutrients (nitrogen and phosphorus) in organic matter was an output. Mineralization due to breakdown of stable organic matter (the lower line in Figs X-X) is thus, supposedly, counteracted by storage of nutrients due to build-up of newly formed organic matter.
The increase in soil organic matter indicates enrichment of the soil with nitrogen and potassium in the coming years when the current management will be continuously applied in the future.

## General uncertainties in composing the balances

In almost all cases organic manure was the main source of nutrients, be it nitrogen, phosphorus or potassium. The method of estimating quantities of chicken bed applied however was quite rough. Farmers do not measure chicken beds dry weight but rather estimate the volume or fresh weight applied. The quantity of chicken bed applied could thus be underestimated. In addition the nutrient content of the chicken bed applied could be underestimated, in particular in the farm of Julio Labarrere. Here, data on quantities of chicken bed applied were available on a fresh weight basis. However the water content of chicken bed applied shows large variations, making it more difficult to estimate the nutrient content of this manure accurately.

In the case of nitrogen, nitrate and ammonium present in soil at the beginning of the rotation were not measured and not taken into account in the balance. However it is not likely that this was more than 20-40 kg ha$^{-1}$ (Dogliotti, pers. comm.). Moreover, when composing the balance it was assumed the nitrate content of the soil did not change during the period considered.

Values for nutrient content were taken from literature, although crop nutrient content is known to vary within broad ranges. In addition, if nutrient availability is limiting crop growth, crop nutrient content of nutrients that are not growth-limiting will increase (the Sprenger-Liebig Law of the minimum). The values used could be higher or lower than the actual values, leading to an under- or overestimation of outputs.

The data on outputs are, in most cases, based on crop sales. In the case of post-harvest problems due to which part of the crop couldn’t be sold this could lead to an underestimation of the outputs. In the future, it is desirable to base estimations of nutrients harvested on amounts of nutrients harvested.

## Farm Julio Labarrere

### *Field 3*

The long-term balance of all three nutrients considered was positive, the surplus ranging from 26.5 kg ha$^{-1}$ (for phosphorus) to 165.3 kg ha$^{-1}$ (for nitrogen). For phosphorus, this indicates structural enrichment of the soil, for nitrogen, this indicates structural losses to the environment. Especially the latter is undesirable, and decreasing nitrogen applications may be required. However, this should be done with care as nutrient dynamics during the growing season is not taken into account in the approach used. A more detailed analysis should reveal when losses are likely to occur.

The increasing soil phosphorus content indicates the system gained in phosphorus, and that it is unlikely the crop suffered phosphorus shortages. This is in line with the long-term positive phosphorus balance. With respect to potassium, 179 kg K ha$^{-1}$ was applied more than extracted due to the regular applications of animal manure (Table 13, Fig. 7). During the three year period, the system gained in potassium. This is reflected in the increasing soil potassium content (Fig. 7).

### *Field 5*

The long-term nitrogen balance was positive (50.8 kg N ha$^{-1}$ year$^{-1}$ on average, Table 14) indicating possible environmental losses. The potassium balance was negative (-24.0 kg K ha$^{-1}$ year$^{-1}$ on average, Table 16), indicating mining of the soil on the long term and crop shortages. The phosphorus balance was nearly neutral (1.2 kg P ha$^{-1}$ year$^{-1}$ on average). The ratio of nutrients in fertilizers (N:P:K) applied and in crops extracted was not similar. In high-potassium-demanding crops such as tomato, applying potassium-fertilizers like potassium-sulphate or potassium-chloride could be considered. These fertilizers will cause a less negative (or positive) potassium balance, whilst maintaining the amount of nitrogen (and phosphorus) applied.

The soil phosphorus content was higher than 60 µg P g$^{-1}$ soil in all measurements (Fig. 8). This indicates phosphorus was abundantly available for plant uptake, and that phosphorus was supplied from the mineral fraction of soil.

This field showed a negative potassium balance over the whole rotational period (Table 17, Fig. 9). Although potassium was applied twice with animal manure these applications were less than the amounts extracted by the crops. However it is unlikely that potassium shortages occurred as the soil potassium content did not become lower than 1.3 meq 100 g$^{-1}$. Despite the negative potassium balance, the soil potassium content did not decrease significantly between November 2005 and February 2008, indicating that potassium was released from the soil mineral fraction.

## Farm Alberto & Lilian Cecilia

### *Field 2*

On average 48.5 kg N ha$^{-1}$ was applied more than extracted (Table 18). Phosphorus and potassium balances were slightly positive as well (5.8 and 9.3 kg ha$^{-1}$ year $^{-1}$ on average respectively, Tables 19 and 20). These numbers do neither indicate large shortages nor excesses. More detailed analysis is needed to verify whether application of nutrients and crop demands are well-synchronized.

The increase in soil phosphorus content observed the field can be explained by phosphorus supply from soil. In addition spatial variation and measurement errors may have had an effect.

The balance of potassium was 36.8 kg K ha$^{-1}$ positive due to applications of animal manure and modest extraction by crops (Table 21, Fig. 12) in field 2. However a negative balance coincided with a soil potassium content close to 0.30 meq 100 gram$^{-1}$, a value below which potassium can be growth limiting. Sweet potato grown in this period thus may have suffered lack of potassium[3].

[3] It should be noted that this cannot be read immediately from Fig. 12: nutrient uptake is taking place during the whole period of crop growth, whereas the output of nutrients is taking place at harvest. In the figure, the date of harvest is used to depict the output of nutrients.

*Field 4*

Long-term nitrogen and phosphorus balances were positive (29.3 and 13.2 kg $ha^{-1}$ $year^{-1}$ on average, respectively, Tables 22 and 23) whereas the long-term potassium balance was negative (-14.2 kg $ha^{-1}$ $year^{-1}$ on average, Table 24). As in field 5 of Labarrere's farm, potassium fertilization in potassium demanding crops (like squash) could be considered, as to prevent soil potassium mining on the long term.

Soil phosphorus measurements did not show a large increase in soil phosphorus content. Possibly, the absolute phosphorus surplus was too small to induce a noticeable increase in soil phosphorus content. In addition the surplus could be stored in the soil profile.

The potassium balance of field 4 was 104.5 kg $ha^{-1}$ negative, due to considerable extraction of potassium by onion and squash. Despite these extractions soil potassium content did not decrease significantly – at the end of the rotation soil potassium content was even higher than at the beginning. This could be explained release of potassium that was associated with the mineral fraction. Taking the soil potassium content into account it is unlikely that potassium shortages occurred.

## Recommendations

As explained the period studied does not include a full rotation period. In a rotation, nutrient-demanding crops are alternated with less-demanding crops and green manure crops. Therefore it is desirable to consider a full rotational cycle when making a balance. This holds to a lesser extent to nitrogen as nitrogen surpluses are easily lost from the plant root zone. To the contrary phosphorus is stored in the soil profile. In the coming years the current balances could be extended with new data obtained.

The assumption was made that the composition of newly formed organic matter will eventually (within forty years) be similar to the soil organic matter. Thereby, a fixed nitrogen and phosphorus content of organic matter was assumed of respectively 5.8% and 0.35%, determining the amount of nutrients stored in organic matter. It will be difficult to test these assumptions in the field, as they are related to long periods of time. It is clear however that mineralization and immobilization processes on shorter timescales depend on other factors. The carbon:nitrogen-ratio of the substrate decomposed and the composition and the efficiency of the microbial community are the most important factors determining the amount of nitrogen that will be mineralized or immobilized during decomposition (Kuyper, 2002). The carbon:nitrogen-ratio of the substrate that is being decomposed changes during the process of decomposition (Kuyper 2002), and becomes less suitable as indicator of mineralization (Brussaard, pers. comm.). This complicates estimating immobilization and mineralization on the basis of substrate characteristics.

When a more detailed balance is made, it should be taken into account that estimating mineralization on the basis of organic substrates applied would imply some nutrients would be counted twice in the balance. The nutrients mineralized from decomposition of green manure crops, for example, were taken up earlier from the soil profile and thus cannot be counted as input. Possibly the soil balance model used (Fig. 1) could be adapted to solve this problem.

During this study several other assumptions were made, and for a considerable number of parameters literature data were taken. The influence of these assumptions on the results found could be tested in a sensitivity study, as to find out which parameters should be determined more accurately.

As mentioned before, for the long-term balances, fluctuations in nutrient availability and nutrient demand during the year are not taken into account. Thus, nutrient losses could occur after application of a large amount of chicken bed early in the growing season whereas a crop suffers nutrient shortage later in the growing season. Composing a more detailed balance, relating bio-availability of nutrients to plant demands is thus recommended. In doing so, decomposition processes and the associated release of nutrients should be taken into account., as these are especially important in agro-ecosystems with large amounts of organic inputs like the systems under study. Ndicea, a model to simulate carbon and nitrogen dynamics in ecological farming systems (Van der Burgt et. al., 2006), could be a helpful tool in this.

Given the annual average surpluses of nitrogen, monitoring nitrogen losses through leaching would be interesting. In case of nitrogen (small) losses to the environment are inevitable and occur in natural ecosystems as well (Kuyper, 2002). Quantifying these losses for the systems under study can indicate whether making efforts to reduce these losses is worthwhile.

The soils considered have a phosphorus content around 5 µg P $g^{-1}$ soil when they are not fertilized (García pers. comm.). Chicken bed, the predominant type of animal manure used, has a relatively high phosphorus content and is applied in large amounts. Probably this had led to an increase in soil phosphorus content making the initial phosphorus status of the soils at the beginning of the rotation under study relatively high. The soils thus are able to supply phosphorus, and a negative phosphorus balance is not immediately followed by a decrease in available phosphorus.

Soils in Canelón Grande are naturally rich in potassium through the presence of 2:1 clays like illite and montmorillonite (García pers comm.). Consequently, crops show little response to fertilization with potassium. Therefore, many farmers in the region do not fertilize with potassium, but use artificial fertilizers that do not contain potassium. However, continuous cultivation of soils without fertilization brings along risks of exhaustion of soils and declining yields. This was one of the reasons to advise the farmers to use organic manure that does contain potassium. Indeed, a positive potassium balance was found in field 2 of Cecilia's farm and in field 3 of Labarrere's farm. In field 4 of Cecilia's farm and field 5 of Labarrere's farm however, negative potassium balances were found. In these cases, application of potassium fertilizers could be considered, as well as replacement of artificial nitrogen and phosphorus fertilizers by chicken bed. The latter option however should be applied with care: nitrogen and phosphorus balances are positive and thus more nitrogen and phosphorus inputs are undesirable.

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## APPENDIX I INPUT PARAMETERS USED IN ROTSOM

Table 25. Input parameters for different crops used in the Rotsom model.

| | | | | | | First application | | | | Second application | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crop | Growing period (d) | Potential yield (kg/ha) | R/Y ratio CF | Yearly ageing factor | no. of appl. | R/Y ratio | Day nr. | R9 | S | R/Y ratio | Day nr. | R9 | S |
| Sweet potato | 121 | 23800 | 0.75 | 1 | 2 | 0.067 | 121 | 1.43 | 0.64 | 0.0567 | 121 | 0.916 | 0.66 |
| Garlic | 188 | 10800 | 1 | 1 | 2 | 0.04 | 188 | 1.609 | 0.64 | 0.0395 | 188 | 0.916 | 0.66 |
| Onion | 139 | 46350 | 1 | 1 | 2 | 0.04 | 139 | 1.609 | 0.64 | 0.0065 | 139 | 0.916 | 0.66 |
| Onion Seed | 136 | 222 | 1 | 1 | 2 | 1.91 | 136 | 1.609 | 0.64 | 0.2702 | 136 | 0.916 | 0.66 |
| Squash | 196 | 25500 | 0.75 | 1 | 2 | 0.12 | 196 | 1.609 | 0.64 | 0.0371 | 196 | 0.916 | 0.66 |
| Melon | 105 | 25500 | 0.75 | 1 | 2 | 0.12 | 105 | 1.609 | 0.64 | 0.0371 | 105 | 0.916 | 0.66 |
| Crucifers | 106 | 25500 | 0.75 | 1 | 2 | 0.12 | 106 | 1.609 | 0.64 | 0.0371 | 106 | 0.916 | 0.66 |
| Tomato (L3) | 130 | 40800 | 0.75 | 1 | 1 | 0.0154 | 130 | 0.916 | 0.66 | - | - | - | - |
| Tomato (L5) | 167 | 50336 | 0.75 | 1 | 1 | 0.0154 | 167 | 0.916 | 0.66 | - | - | - | - |
| Pea | 105 | 2929 | 1. | 1 | 2 | 0.2 | 105 | 1.39 | 0.65 | 0.06 | 105 | 0.8 | 0.67 |

L3, L5 = tomato planted in field 3 and 5 of Labarrere, respectively. See text for explanation.

For sweet potato, garlic, onion and squash values on growing period, potential yield, residue/yield-ratio ware taken from Dogliotti (2003). For pea and tomato actual yield was used in stead of a standard value and potential yield. As all above ground residues were removed from the field at harvest in Labarrere´s farm, only one application for tomato was used. For the belowground parts the same values of residue/yield-ratio, R9 and S were used as Dogliotti used for sweet pepper. For the aboveground parts of pea the same values of R9 and S were used as Dogliotti used for alfalfa, for the belowground parts as used for maize. The residue/yield ratios were calculated as

above ground dry matter production = (actual yield)/harvest index) * dry matter content aerial part

above ground R/Y = (aboveground dry matter production * (dry matter content aerial part))/(yield)

below ground dry matter production = (above ground dry matter production/fraction dry matter in shoots) * fraction dry matter in roots

below ground R/Y = (belowground dry matter production * roots in top 20 cm.)/(yield)

Whereby it was assumed:

harvest index pea = 0.5

dry matter content aerial part = 20%

fraction dry matter in roots = .15

fraction roots in topsoil (0-20 cm.) = .85

The residue/yield-ratios for onion seed were calculated in the same manner, assuming a total residue of 500 kg DM ha$^{-1}$, of which 85% is located aboveground and 15% belowground. Of this 15%, 85% is located in the top 20 cm.

Table 26. Input parameters for green and chicken manure used in the Rotsom model.

| Intercrop management | First application | | Second application | |
|---|---|---|---|---|
| | R9 | S | R9 | S |
| Green manure | 1.2 | 0.65 | 0.8 | 0.67 |
| Chicken manure | 0.7 | 0.5 | - | - |

R9 and S values of green manure and chicken manure (Table 26) were taken from Dogliotti (2003). Yields of green manure and timing of application are shown in Table 27, whereas amounts of chicken manure and timing of application can be found in Table 28.

Table 27. Green manure yields and time of application used as input in the Rotsom model.

| Farm | Field | Crop | Biomass (kg DM) | | Day of application |
|---|---|---|---|---|---|
| | | | Above ground | Below ground | |
| Cecilia | 2 | Italian bluegrass | 4439 | 1332 | 131 |
| Cecilia | 2 | Italian bluegrass | 4439 | 1330 | 130 |
| Cecilia | 2 | Oat | 6764 | 2029 | 228 |
| Cecilia | 4 | Wheat | 4289 | 1287 | 171 |
| Cecilia | 4 | Oat | 5349 | 1605 | 121 |
| Labarrere | 3 | Wheat | 5743 | 1723 | 333 |
| Labarrere | 3 | Oat | 7688 | 2306 | 268 |
| Labarrere | 5 | Oat | 7688 | 2306 | 228 |
| Labarrere | 5 | Italian bluegrass | 4925 | 1478 | 179 |

Table 28. Amount of chicken manure and time of application used as input in the Rotsom model.

| Farm | Field | Previous crop | Following crop | Chicken manure (kg DM) | Day of application |
|---|---|---|---|---|---|
| Cecilia | 2 | Pea | Garlic | 2695 | 148 |
| Cecilia | 2 | Garlic | Onion | 2700 | 181 |
| Cecilia | 4 | Sweet potato | Onion | 2700 | 8 |
| Cecilia | 4 | Squash | Garlic | 2700 | 78 |
| Labarrere | 3 | Onion | Melon | 5797 | 136 |
| Labarrere | 3 | Onion | Melon | 4696 | 329 |
| Labarrere | 3 | Melon | Tomato | 4697 | 284 |
| Labarrere | 3 | Melon | Tomato | 5218 | 333 |
| Labarrere | 3 | Tomato | Onion | 4696 | 51 |
| Labarrere | 5 | Tomato | Onion | 4907 | 81 |
| Labarrere | 5 | Onion | Crucifers | 4907 | 99 |
| Labarrere | 5 | Onion seed | Tomato | 4907 | 294 |

APPENDIX II NUTRIENT BALANCES

Table 29. Details of nutrient balance for field 2 (0.334 ha) of Cecilia's farm for the period November 2004 – October 2007.

| **INPUTS** | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fertilizers** | Quantity of fertilizer (kg/field) | Date | Fertilizer nutrient content (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM NPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) |
| 7-43-0 | 4 | 23/11/2004 | 7 | 0.8 | | 43 | 1.1 | | 0 | 0.0 | |
| 18-46-0 | 5 | 05/08/2005 | 18 | 2.7 | | 46 | 1.5 | | 0 | 0.0 | |
| Urea | 11 | 30/09/2005 | 46 | 15.1 | | 0 | 0.0 | | 0 | 0.0 | |
| 18-46-0 | 55 | 24/05/2006 | 18 | 29.6 | | 46 | 16.5 | | 0 | 0.0 | |
| Urea | 24 | 26/08/2006 | 46 | 33.1 | | 0 | 0.0 | | 0 | 0.0 | |
| Urea | 28 | 23/09/2006 | 46 | 38.6 | | 0 | 0.0 | | 0 | 0.0 | |
| Urea | 20 | 15/10/2007 | 46 | 27.5 | | 0 | 0.0 | | 0 | 0.0 | |
| | | | | | 147.5 | | | 19.2 | | | 0.0 |
| **Animal manure** | Quantity of manure DM (kg/field) | Date | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | |
| Chicken bed | 901.8 | 01/04/2006 | 2.8 | 75.6 | | 1.72 | 10.1 | | 1.77 | 47.8 | |
| Chicken bed | 900 | 06/06/2007 | 2.8 | 75.4 | | 1.72 | 10.1 | | 1.77 | 47.7 | |
| | | | | | 151.0 | | | 20.3 | | | 95.5 |
| **Biological nitrogen fixation** | | Date | | | | | | | | | |
| Pea | | 01/10/2005 | | 60.0 | | | | | | | |
| | | | | | 60.0 | | n.a. | | | n.a. | |
| **Contribution of soil organic matter** | | | | | | | | | | | |
| To be determined | | | | | | | | | | | |
| **Atmospheric deposition** | | Date | Atmospheric deposition (kg/ha) | | | | | | | | |
| | | 01/07/2005 | 1.25 | 1.25 | | | n.a. | | | n.a. | |
| | | 2005 | 5 | 5.0 | | | n.a. | | | n.a. | |
| | | 2006 | 5 | 5.0 | | | n.a. | | | n.a. | |
| | | 2007 | 5 | 5.0 | | | n.a. | | | n.a. | |
| | | | | | 16.3 | | | | | | |

| Seeds and transplants | Seeds or transplants (kg/ha) | Date | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sweet potato | 1155 | 2004 | 2.4 | 2.8 | | 0.28 | 0.3 | | 2.04 | 2.4 | |
| Pea | 50 | 05/08/2005 | 15 | 0.8 | | 2 | 0.1 | | 7 | 0.4 | |
| Moha | 30 | 12/01/2006 | 21 | 0.6 | | 4 | 0.1 | | 4 | 0.1 | |
| Garlic | 560 | 16/06/2006 | | 5.7 | | | 2.7 | | | 2.7 | |
| Moha | 30 | 29/01/2007 | 21 | 0.6 | | 4 | 0.1 | | 4 | 0.1 | |
| Onion | 1500 | 20/08/2007 | 1.92 | 2.9 | | 0.3 | 0.5 | | 1.55 | 2.3 | |
| | | | | | 13.4 | | | 3.8 | | | 8.0 |
| **INPUTS TOTAL** | | | | | 388.1 | | | 43.2 | | | 103.5 |

| **OUTPUTS** | | | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Crop** | Crop sold (kg/farm) | Area with this crop (ha) | Harvest (kg/ha) | Date | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) |
| Sweet potato | 5600 | 0.884 | 6334.8 | 01/05/2005 | 2.4 | 15.2 | | 0.28 | 1.8 | | 2.04 | 12.9 | |
| Pea | 978. | 0.334 | 2928.1 | 01/11/2005 | 15 | 43.9 | | 2 | 5.9 | | 7 | 20.5 | |
| Garlic | 1339.2 | 0.531 | 2524.4 | 01/12/2006 | 9.49 | 29.9 | | 1.21 | 3.8 | | 3.8 | 12.0 | |
| Onion | 6500 | 0.474 | 13713.1 | 01/12/2007 | 1.92 | 26.3 | | 0.3 | 4.1 | | 1.55 | 21.3 | |
| | | | | | | | 115.4 | | | 15.6 | | | 66.7 |
| **Soil organic matter** | | | | | | | | | | | | | |
| To be determined | | | | | | | | | | | | | |
| **OUTPUTS TOTAL** | | | | | | | 115.4 | | | 15.6 | | | 66.7 |
| **BALANCE** | | | | | | | 272.7 | | | 27.7 | | | 36.8 |

Table 30. Details of nutrient balance for field 4 (0.444 ha) of Cecilia's farm for the period June 2004 – December 2007.

| **INPUTS** | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fertilizers** | Quantity of fertilizer (kg/field) | Date | Fertilizer nutrient content (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM NPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) |
| 20-40-0 | 25 | 08/06/2004 | 20 | 11.3 | | 40 | 4.9 | | 0 | 0.0 | |
| 20-40-0 | 25 | 17/06/2004 | 20 | 11.3 | | 40 | 4.9 | | 0 | 0.0 | |
| Urea | 168.9 | 10/08/2004 | 46 | 34.5 | | 0 | 0.0 | | 0 | 0.0 | |
| Urea | 168.9 | 02/09/2004 | 46 | 34.5 | | 0 | 0.0 | | 0 | 0.0 | |
| 18-46-0 | 90 | 10/10/2005 | 18 | 36.5 | | 46 | 20.4 | | 0 | 0.0 | |
| 18-46-0 | 90 | 04/11/2006 | 18 | 36.5 | | 46 | 20.4 | | 0 | 0.0 | |
| 18-46-0 | 25 | 05/12/2007 | 18 | 10.1 | | 46 | 5.7 | | 0 | 0.0 | |
| | | | | | 174.6 | | | 56.2 | | | 0.0 |
| **Animal manure** | Quantity of manure DM (kg/field) | Date | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | |
| Chicken bed | 1198.8 | 01/04/05 | 2.8 | 75.6 | | 1.72 | 10.1 | | 1.8 | 47.8 | |
| | | | | | 75.6 | | | 10.1 | | | 47.8 |
| **Biological nitrogen fixation** | | Date | | | | | | | | | |
| | | | | | 60.0 | | | | | | |
| **Contribution of soil organic matter** | | | | | | | | | | | |
| To be determined | | | | | | | | | | | |
| **Atmospheric deposition** | | Date | Atmospheric deposition (kg/ha) | | | | | | | | |
| | | 01/07/2005 | 1.25 | 1.3 | | | n.a | | | n.a | |
| | | 2005 | 5 | 5.0 | | | n.a | | | n.a | |
| | | 2006 | 5 | 5.0 | | | n.a | | | n.a | |
| | | 2007 | 5 | 5.0 | | | n.a | | | n.a | |
| | | 2008 | 1.25 | 1.3 | | | n.a | | | n.a | |
| | | | | | 17.5 | | | | | | |
| **Seeds and transplants** | Seeds or transplants (kg/ha) | Date | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | |
| Garlic | 372.22 | 01/07/2004 | | 2.9 | | | 1.4 | | | 1.4 | |
| Sweet potato | 1155 | 15/01/2005 | 2.4 | 2.7 | | 0.28 | 0.3 | | 2.0 | 2.4 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Onion | 1500 | 27/09/2005 | 1.9 | 2.8 | | 2 | 0.5 | | 1.6 | 2.3 | |
| Oat | 90 | 03/04/2006 | 20.0 | 1.8 | | 4 | 0.3 | | 3.0 | 0.3 | |
| Sweet potato | 1155 | 04/11/2006 | 2.4 | 2.7 | | 4 | 0.3 | | 2.0 | 2.4 | |
| Wheat | 90 | 03/07/2007 | 16.3 | 1.5 | | 0.3 | 0.3 | | 4.2 | 0.4 | |
| Squash | 0.6 | 04/12/2007 | 2.4 | 0.0 | | 0.32 | 0.0 | | 3.5 | 0.0 | |
| | | | | | 14.5 | | | 3.1 | | | 9.0 |
| **INPUTS TOTAL** | | | | | 282.3 | | | 69.4 | | | 56.8 |

| **OUTPUTS** | | | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Crop** | Crop sold (kg/farm) | Area with this crop (ha) | Harvest (kg/ha) | Date | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) |
| Garlic | 722.8 | 0.444 | 2034.9 | 01/12/2004 | 9.49 | 19.3 | | 1.2 | 2.5 | | 3.8 | 7.7 | |
| Sweet potato | 5600 | 0.884 | 6334.8 | 01/04/2005 | 2.4 | 15.2 | | 0.9 | 1.8 | | 2.0 | 12.9 | |
| Onion | | | 24718.0 | 01/12/2006 | 1.92 | 47.5 | | 0.3 | 7.4 | | 1.6 | 38.3 | |
| Sweet potato | 5020 | 0.688 | 7296.5 | 01/05/2007 | 2.4 | 17.5 | | 0.9 | 2.0 | | 2.0 | 14.9 | |
| Squash | 11100 | 0.444 | 25000.0 | 15/03/2008 | 2.4 | 60.0 | | 0.3 | 8.0 | | 3.5 | 87.5 | |
| | | | | | | | 159.5 | | | 21.7 | | | 161.4 |
| **Soil organic matter** | | | | | | | | | | | | | |
| To be determined | | | | | | | | | | | | | |
| **OUTPUTS TOTAL** | | | | | | | 159.5 | | | 21.7 | | | 161.4 |
| **BALANCE** | | | | | | | 122.8 | | | 47.7 | | | -104.5 |

Table 31. Details of nutrient balance for field 3 (0.345 ha) of Labarrere's farm for the period June 2004 – June 2007.

| **INPUTS** | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fertilizers** | Quantity of fertilizer (kg/field) | Date | Fertilizer nutrient content (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM NPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) |
| 18-46-0 | 40 | 15/11/05 | 18 | 20.9 | | 46 | 11.6 | | 0 | 0.0 | |
| Urea | 1.25 | 23/12/05 | 46 | 1.7 | | 0 | 0.0 | | 0 | 0.0 | |
| Urea | 30 | 1/2/06 | 46 | 40.0 | | 0 | 0.0 | | 0 | 0.0 | |
| | | | | | 62.5 | | | 11.6 | | | 0 |
| **Animal manure** | Quantity of manure DM (kg/field) | Date | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | |
| Chicken bed | 2000 | 30/4/05 | 2.8 | 162.3 | | 1.72 | 21.8 | | 1.77 | 102.6 | |
| Chicken bed | 1620 | 28/10/05 | 2.8 | 131.5 | | 1.72 | 17.6 | | 1.77 | 83.1 | |
| Chicken bed | 1620 | 1/12/06 | 2.8 | 131.5 | | 1.72 | 17.6 | | 1.77 | 83.1 | |
| Chicken bed | 900 | 19/1/07 | 2.8 | 73.0 | | 1.72 | 9.8 | | 1.77 | 46.2 | |
| Chicken bed | 900 | 12/2/07 | 2.8 | 73.0 | | 1.72 | 9.8 | | 1.77 | 46.2 | |
| | | | | | 571.4 | | | 76.6 | | | 361.2 |
| **Biological nitrogen fixation** | | Date | | | | | | | | | |
| | | | | 0.0 | | | n.a. | | | n.a. | |
| **Contribution of soil organic matter** | | | | | | | | | | | |
| To be determined | | | | | | | | | | | |
| **Atmospheric deposition** | | Date | Atmospheric deposition kg/ha) | | | | | | | | |
| | | 2005 | 5 | 5.0 | | n.a. | | | n.a. | | |
| | | 2006 | 5 | 5.0 | | n.a. | | | n.a. | | |
| | | 2007 | 5 | 5.0 | | n.a. | | | n.a. | | |
| | | | | | 15.0 | | | | | | |
| **Seeds and transplants** | Seeds or transplants (kg/ha) | Date | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | |
| Onion | 1500 | 01/07/04 | 1.92 | 2.9 | | 0.3 | 0.5 | | 1.55 | 2.3 | |
| Wheat | 90 | 02/05/05 | 16.32 | 1.5 | | 3.7 | 0.3 | | 4.2 | 0.4 | |
| Melon | 97.5 | 07/11/05 | 2.5 | 0.2 | | 0.24 | 0.0 | | 3.4 | 0.3 | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oat | | 90 | | 08/05/06 | 20 | 1.8 | | 3 | 0.3 | | 3 | 0.3 | |
| Tomato | | 150 | | 25/01/07 | 2.8 | 0.4 | | 0.4 | 0.1 | | 4.5 | 0.7 | |
| Summer squash | | 0.65 | | 23/02/07 | 1 | 0.0 | | 0.26 | 0.0 | | 1.85 | 0.0 | |
| | | | | | | | 6.8 | | | 1.1 | | | 4.0 |
| **INPUTS TOTAL** | | | | | | | 655.7 | | | 89.4 | | | 365.2 |

| **OUTPUTS** | | | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Crop** | Crop sold (kg/farm) | Area with this crop (ha) | Harvest (kg/ha) | Date | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) |
| Onion | 10000 | 0.655 | 15267.2 | 01/12/04 | 1.92 | 29.3 | | 0.3 | 4.6 | | 1.55 | 23.7 | |
| Melon | 6246 | 0.345 | 18104.3 | 01/02/06 | 2.5 | 45.3 | | 0.24 | 4.3 | | 3.4 | 61.6 | |
| Tomato | 10248 | 0.4825 | 21239.4 | 01/04/07 | 2.8 | 59.5 | | 0.4 | 8.5 | | 4.5 | 95.6 | |
| Summer squash | 627 | 0.2252 | 2784.2 | 01/05/07 | 1 | 2.8 | | 0.26 | 0.7 | | 1.85 | 5.2 | |
| | | | | | | | 136.8 | | | 18.1 | | | 185.9 |
| **Soil organic matter** | | | | | | | | | | | | | |
| To be determined | | | | | | | | | | | | | |
| **OUTPUTS TOTAL** | | | | | | | 136.8 | | | 18.1 | | | 185.9 |
| **BALANCE** | | | | | | | 518.9 | | | 71.3 | | | 179.2 |

Table 32. Details of nutrient balance for field 5 (0.27 ha) of Labarrere's farm for the period November 2004 – December 2007.

| **INPUTS** | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fertilizers** | Quantity of fertilizer (kg/field) | Date | Fertilizer nutrient content (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM NPUT (kg/ha) | Nutrient content of fertilizer (%) | INPUT (kg/ha) | SUM INPUT (kg/ha) |
| Super phosphate | 15 | 11/8/05 | 0 | 0.0 | | 21 | 2.5 | | 0 | 0.0 | |
| Urea | 20 | 17/9/05 | 46 | 34.1 | | 0 | 0.0 | | 0 | 0.0 | |
| Urea | 50 | Jun-06 | 46 | 85.2 | | 0 | 0.0 | | 0 | 0.0 | |
| Urea | 10 | Oct-07 | 46 | 17.0 | | 0 | 0.0 | | 0 | 0.0 | |
| | | | | | 136.3 | | | 2.5 | | | 0.0 |
| **Animal manure** | Quantity of manure DM (kg/field) | Date | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | | Nutrient content of manure (%) | | |
| Chicken bed | 1350 | 21/7/2005 | 2.8 | 140.0 | | 1.72 | 18.8 | | 1.77 | 88.5 | |
| Chicken bed | 1350 | 25/3/2006 | 2.8 | 140.0 | | 1.72 | 18.8 | | 1.77 | 88.5 | |
| | | | | | 280.0 | | | 37.5 | | | 177.0 |
| **Biological nitrogen fixation** | | Date | | | | | | | | | |
| | | | | 0.0 | | | n.a. | | | n.a. | |
| **Contribution of soil organic matter** | | | | | | | | | | | |
| To be determined | | | | | | | | | | | |
| **Atmospheric deposition** | | Date | Atmospheric deposition kg/ha) | | | | | | | | |
| | | 2005 | 5 | 5.0 | | | n.a | | | n.a | |
| | | 2006 | 5 | 5.0 | | | n.a. | | | n.a. | |
| | | 2007 | 5 | 5.0 | | | n.a. | | | n.a. | |
| | | | | | 15.0 | | | | | | |
| **Seeds and transplants** | Seeds or transplants (kg/ha) | Date | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | | Nutrient content (g/kg DM) | | |
| Tomato | 150 | Nov-04 | 2.8 | 0.4 | | 0.4 | 0.1 | | 4.5 | 0.7 | |
| Onion | 1500 | 12/08/05 | 1.92 | 2.9 | | 0.3 | 0.5 | | 1.55 | 2.3 | |
| Cruciferous (broccoli) | 267 | 05/04/06 | 2.1 | 0.6 | | 0.76 | 0.2 | | 2.6 | 0.7 | |
| Cruciferous (cauliflower) | 267 | 05/04/06 | 3 | 0.8 | | 0.62 | 0.2 | | 2.93 | 0.8 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Italian bluegrass | 30 | 13/11/06 | 16.32 | 0.5 | | 3.7 | 0.1 | | 4.2 | 0.1 | |
| Onion Seed | 2 | 01/08/07 | 1.92 | 0.0 | | 0.3 | 0.0 | | 1.55 | 0.0 | |
| | | | | | 5.2 | | | 1.0 | | | 4.6 |
| **INPUTS TOTAL** | | | | | 436.5 | | | 41.1 | | | 181.6 |

| **OUTPUTS** | | | | | NITROGEN | | | PHOSPHORUS | | | POTASSIUM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Crop** | Crop sold (kg/farm) | Area with this crop (ha) | Harvest (kg/ha) | Date | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) | Nutrient content (kg/ton FM) | OUTPUT (kg/ha) | SUM OUTPUT (kg/ha) |
| Tomato | 13599 | 0.27 | 50366.7 | 01/06/05 | 2.8 | 141.0 | | 0.4 | 20.1 | | 4.5 | 226.7 | |
| Onion | 11879 | 0.27 | 43996.3 | 01/12/05 | 1.92 | 84.5 | | 0.3 | 13.2 | | 1.55 | 68.2 | |
| Cruciferous (broccoli) | 2505.6 | 0.27 | 9280.0 | 01/07/06 | 2.1 | 19.5 | | 0.76 | 7.1 | | 2.6 | 24.1 | |
| Cruciferous (cauliflower) | 3870 | 0.27 | 14333.3 | 01/07/06 | 3 | 43.0 | | 0.62 | 8.9 | | 2.93 | 43.0 | |
| Onion Seed | 60 | 0.27 | 222.2 | 15/01/08 | 1.92 | 0.4 | | 0.3 | 0.1 | | 1.55 | 0.3 | |
| | | | | | | | 288.4 | | | 49.4 | | | 361.3 |
| **Soil organic matter** | | | | | | | | | | | | | |
| To be determined | | | | | | | | | | | | | |
| **OUTPUTS TOTAL** | | | | | | | 288.4 | | | 49.4 | | | 361.3 |
| **BALANCE** | | | | | | | 148.0 | | | -8.3 | | | -179.7 |