About the theoretical possibility for the French population to have a sufficient and healthy nutrition in the absence of breeding, artificial irrigation and chemicals.

VegAu, a software to test a theoretical self-reliance with organic products

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Abstract

In the context of globalization where small farming loses ground and industrial farming destroys soils and pollutes water and air, the question of the viability of an agriculture without livestock, chemicals, and artificial irrigation becomes even more important.

The program presented in this article aims to fuel this debate by selecting crops according to the environmental conditions – climate and soil – and put them together to build rotations. It also check if the computed yields are enough to have a sufficient and healthy nutrition for the population of the concerned area.

This program, called VegAu, is here applied to France and its Little Agricultural Regions. The release presented in this work is the version 0.14, but an updated one is always available under the GNU open source licence on GitHub in the following link : https://github.com/Iscobia/VegAu

The results of the 0.14 release are consistent with the a self-sufficiency of France if agriculture banished livestock, artificial irrigation and chemicals. However, it also points out that the country could certainly not survive that way more than one year without watching over nutrient cycling. A sustainable proposition to this problem is proposed at the end of this work.

Results also highlighted some incoherences in the rotation computation and dietary assessment. The rotation computation step only used seven on the twenty permanent crops – just like fruit trees – that was edible in France. Also, dietary results invited to verify the dietary database and compare it to other sources : the only insufficient nutritive elements were copper, vitamin C and vitamin B9, and it seems like these low values come from mistakes in the database.

1. Introduction – Context

1.1. Choice of an organic agriculture

A French study recently quantified the benefits of organic agriculture by attributing them an economic value[1]. As a result, costs in water treatment would be reduced by 260 to 360 millions Euros[a], the positive impacts on climatic change are quantified to 1640€ (350€ of costs, 2000€ of benefits) and positive impacts on biodiversity to 30€ (70€ of costs, 100€ of benefits).

Medical expenses would also be reduced: in France, 1 067 intoxication due to pesticides have been registered between 1997 and 2007. Since 2002, approximately 4 or 5 new types of professional diseases due to phytosanitary chemicals are registered each year[13]. Professional exposition to pesticides is believed to cause Parkinson's disease, prostate cancer and some hematopoietic cancers[2].

Thus, organic agriculture would be more profitable than conventional one, not only concerning environmental and human health, but also economically. Concerning the yield differentiation between conventional and organic agriculture, Catherine Badgley et al. (2006)[3] showed that the yield of organic agriculture highly depends on the

a 45% of yearly pumped fresh water must be treated against pesticides (2.7 billion of m³).

quality of the soil. Hence, data from 77 published studies[4] suggest that biologically fixed nitrogen from legumes used as green manures can provide enough nitrogen to replace the entire amount of synthetic nitrogen fertilizer currently in use.

The choice of an organic agriculture for this model relies on the importance of a resilient food production to feed the population while inverting the destructive tendency of agriculture on the ecosystems. As the efficiency of organic agriculture has already been demonstrated, VegAu goes further by proposing a selection of crops according to the available water resources for each area of interest in order to promote the protection and regeneration of ground water resources.

1.2. Choice of a lifestyle without animal products

As livestock must drink and feed themselves before to feed humans, they have an important water-footprint[b]: for instance, 15 455 litres of water are needed for a single kilogram of beef meat while the same weight of soja beans only require 1 800 litres[5,6]. Actually, livestock represents 8% of world water consumption[7] and pollutes more than transports which emit 14% of greenhouse gases[8]. Main cause for this pollution are deforestation and land degradation for extensive grazing systems[9], destroying by the way one the green lung of the planet[c,10]. Another important impact of livestock on the environment is the pollution of hydrosphere with nitrates in their excreta : by dissociating livestock from the environmental resource it depends on, intensive breeding created a rupture of nutrient flow between the soil where resources are grown and animals. As a result, soil nutrient amount is in deficit at the source (where fodder are grown) and in excess at the sink, creating important pollution problems[11].

Industrial production of animal products also induces a very high promiscuity between animals, inducing a quicker propagation of diseases among them. Moreover, the intensive use of antibiotics to control diseases leads to a selection of antibiotic-resistant strains of bacteria, now threatening human health in Europe and North America[d,12]. These methods also allow these antibiotics to pass into the environment and thus harming ecosystems, in particular hydrosphere. As well, the FAO[12] draw the attention to the influence of climate change and the role of insects in importing diseases from other ecological zones.

Several studies also pointed out the link between some animal products and cancer[13], cholesterol and cardiovascular diseases[14], while a plant-based (vegan) diet has the potential for a large effect on established cardiovascular diseases[15] and even on the growth of LNCaP prostate cancer cells[16].

1.2.1. Impacts on hunger in the world

Over the world, livestock requires 80% of the total agricultural surface with 3.4 billion hectares for grazing and 0.5 billion hectares for feed crops[12]. In 1993, 40% of produced grains were used to feed livestock for their flesh, milk of eggs. Feeding industrialized livestock exhaust soil fertility and heath while the same amount of grains could feed 10 times more people than those fed by their meat[17,18]. That way, in Guatemala, 75% are undernourished in 1990 while the country exported each year 18 million of kilograms of meat to the USA[19].

Demand for meat diverts food away from poor people who are unable to afford anything but cereals: continuing to feed cereals to growing numbers of livestock will aggravate poverty and environmental degradation[20].

2. Aims

In France, the amount of farmers is always lower. From 1955 to 2010, their population decreased from 6.2 millions to 1.3 millions, while the farm number fell from 2.3 millions farms in 1955 to 590 000 farms in 2010[11]. These death of small farming and of farmers themselves (by suicide[11]) is thus explained by a financial distress [e,11] and by the transformation of farms into societies : in 2003, 23% of farms have the status of “society”[11] in order to simplify the

b A detailed table of the Water Footprint of farm animal products can be consulted in the article of Mekonnen and Hoekstra (2012)

c Cattle ranching is responsible for 91% of the deforestation of the Amazonian rain forest[10].

d Original citation from Johnson et al., 2009 (cited by the FAO[12])

e In France, the debt level of farmers increased from 57 900€ in 1980 to 159 700€ in 2010, that is 175% more[11]. From 2007 to 2009, suicides represented 15% of the deaths by men and 7% by women[11].

management of a greater surface[f].

The aim of this article is to propose a tool – called VegAu – and socio-economic alternatives to ameliorate the farmers' quality of life, encourage small farming and a sustainable agriculture. Adapting farming to environmental conditions and using natural solutions to suppress chemicals could not only protect our natural heritage, but also allow farmers to save at least 14.8% of their budget: in 2010, fertilizers and pesticides represented respectively 8% and 6.8% of their intermediate consumption[21]. Moreover, suppressing chemicals could diminish the amount of death by cancer, which represents the first cause of farmers death with 32% of deaths for men and 49% for women[11].

3. Understanding the model's mechanisms

3.1. Crop rotation

Crop rotation is defined as the sequence of crops on the same land in sequential seasons[22]. Generally, this sequence of crops follows a pre-determined crop order that have been determined according to the interactions which exist between selected crops[23,24]. Such crop successions (and associations) allow the management of soil fertility, weeds, pests and diseases[24,25]. Rotations are managed to maintain soil fertility by using the N-fixation ability of legumes and the mobilization of leaching nutrients by long-rooted crops like grains[24]. Taking care of global soil health and managing an optimal rotation is known to provide enough N resources to organic crops[1,3,16,24] and avoid soil borne pests and diseases[23,26].

VegAu's results depends on the rotations that are scheduled in its second part (see Appendix 2). These rotations only contain crops that have been selected in the model's first step as being adapted to the climate of the selected place[g] (see Appendix 1).

This model does not consider fodder crops in order to maximize space for human consumption. Only some clover and vetch varieties have been selected to ensure a sufficient nitrogen availability.

The rotation modelling continues until there is not enough nutrient any more to grow any crop that has been selected as « edible » in the first step of the program. The rotation duration then relies on nutrient availability, especially the N-gain provided by leguminous, but also all organic matters that are not used for human consumption. Such organic matter concerns for instance cabbage leaves that are not harvested, or tomato plants that remain on the field after the last harvest.

3.2. Cover crops

Cover crops are crops that are grown with the aim of enhancing soil properties over both short and long term[13]. This technique is mainly used in sustainable agriculture in order to improve soil physico-chemical properties by slowing erosion and enhancing both nutrient and moisture availability, but they also smother weeds and help control many pests[13,27]. At the same time, they can reduce costs, increase profits and even create new sources of income[13].

VegAu uses cover cropping principles in two aims : N-fertilization and protection against erosion. Cover crops like clover and vetch are used when the N-amount is too low in the soil. If water resources are sufficient, they are grown together with a cash crop in order to provide it with nitrate. The model also makes sure that the time lapse between two successive crops is as short as possible in order to keep the soil covered. As well, crops residues are supposed to stay on the field : combined with conservative tillage, it should allow a better degradation , without encouraging gaseous loss in the atmosphere or N leaching, as residues are not totally grabbed in the soil. Soil remain also protected against erosion.

4. Building a database

4.1. Environmental data

Climate data of each meteorological station of the French territory have been provided by the French national meteorological service, MétéoFrance. These average values have been calculated for 29 years, from 1981 to 2010. In the past years, standard values for scientific researches were average values for 30 years: today, climate change results in a very quick changes and these data may not be representative.

Soil data have been provided on the PRA[h]-scale by

f In 1950, agricultural surface covered 72% of the French territory with 2.3 millions farms. In 2010, agricultural surface covered 59% for 590 000 farms[11]. That means that the surface of a farm in 2010 is 3 times greater than in 1950.

g In this case, in Small Agricultural Regions called PRA (Petites Régions Agricoles)

h Stands for *"Petite Région Agricole"*, that is "Little the INRA in the BDAT[i,28] and BDETM[j,29] databases, respectively for **soil chemical elements and soil texture** (clay, sand and silt). From these data, the Available Water Capacity has been deduced according to the Ad-hoc working group (2005)[30].

The PRA[g] **agricultural surface** values come from the last agriculture census ("Recensement agricole 2010") from the French Ministry for Agriculture, Food-Processing and Forest (Agreste).

After summarizing the collected climate data on the scale of PRA[g], 17% of total climate data and 36% of total soil data were missing, that is 21% of original databases. Both missing climate and soil data have been estimated by interpolation.

4.2. Crops physiological data

Data collection for crops physiological data required the use of a lot of different sources, and sometimes estimations.

Data for **growing seasons**, seeding month have been compiled from the FAO[31,32,33], the CIRAME[34], the association of Farmers of Bretagne[35]

Crops requirements for both harvested part and residues have been provided by the american USDA[36] for nitrogen, phosphorus and potassium. For crops which are missing in this database, data proposed by the Cequal[48] for the composition of fruits and vegetables allowed to estimate macro and micro-nutrients that leave the field after harvesting. As the data from the Ciqual concerns nutritive values and widely differs from the USDA ones, it has been calibrated according to the USDA phosphorus amount, considering potassium as control value.

Concerning the **ability of legumes to fix nitrogen**, Ndfa values have been selected from Peoples et al (2009)[37] and Büchi et al.(2014)[38], with a preference for European study areas.

The amount of nutrients that are returned to the soil and the decomposition speed depends on the residues **C:N ratio**. These values have been estimated according to the classification on the Planet Natural Research Center website[39] and Zhang et al. (2013)[40] for cotton. C:N ratios for cover crops have been taken from the collective book *Managing Cover Crops Profitably*[24] as well as from Lindemann & Glover (1990)[41] and D.K. Asare et al. (2015)[42].

pH requirements come from Hudson et al. (1998)[31], the GAB/FRAG network[14] and the GreenCoverSeed professional website[46].

The **crop water requirement** (ETc) is calculated in the program thanks to the crop coefficient (Kc) values from the CIRAME[34]. Missing Kc values in the CIRAME database are based on data from the FAO[32,43]. The Kc of fennel has been assumed from the one of the carrot, because these crops both belong to the *Apiacea* family, while the jute's one has been calculated by D. Barman et al. (2014)[44] and mustard ones by Kumar et al. (2011)[45].

Data concerning **sensitivity to drought** have been compiled from the FAO[31] and from the GreenCoverSeed website[46], which mainly reworked data from the collective book *Managing Cover Crops Profitably[24]*.

The CIRAME also provided the crop's **rooting depth**, and missing values have been estimated to reach approximately 100cm depth for grains, 80cm for trees and 30cm depth for berries and 20cm for vegetables.

As VegAu considers an agriculture without chemicals, **yields** specified as coming from organic agriculture have been preferred. Average values cited in the technical factsheets provided by the French GAB/FRAB network[35] have been chosen as control value. As the data from the Destatis - German Federal Statistical Office – contains a wide range crops but certainly concerns conventional agriculture, it has been adapted to fit to an organic agriculture : average yields from the GAB/FRAB network represents in average 53.09% of the Destatis ones. For all missing data in the GAB/FRAB sheets, 53.09% of the Destatis value has been kept.

4.3. Dietary requirements for a vegan population

Canada Health provides dietary reference intake values for macronutrients[47], vitamins[48] and elements[49] for infants, children, males and females in several age brackets. Values for pregnant women and women in lactation period has not be taken into account. These details will allow to adapt the final results to the French population pyramid from the

Agricultural Region"

i INRA (Institut National des Recherches Agricoles) : French National Institute for Agricultural Research BDAT (Base de Données pour l'Analyse des Terres) : Data Base for Territories Analysis

j BD ETM (Base de Données des Éléments Traces Métalliques): Data base of Heavy Metals (in soil).

INSEE[50] and also get finer results concerning an eventual self-reliance possibility.

A great question, for vegans and also 39% of the total population[51],[52]) is the way to avoid B12 deficiency. For a full review about B12 in food for vegans, see Norris J. (2015)[53]. B12 is synthesised by microorganisms in untreated water or soil. Robbins et al. (1950)[54] sampled pond water and soil to determine their B12 level: the water contained 0.1 to 2.0 µg/L and the soil 0.002 to 0.015 µg/g of fresh soil.

Thus, protecting drinking water with an environmental-friendly agriculture could be a long-term solution to fight B12-deficiency by :

- Preventing fertilizers and pesticides would stop to pollute water. Even if it would remain polluted for many decades, once water would become potable again, it could theoretically become a natural source of B12 vitamin.
- Managing irrigation properly would avoid nutrient leaching, thereby preserving ground water.

5. Detailed explanation of the model

5.1. Overview

5.1.1. Principle

VegAu is composed of three part: the edibility assessment, the rotation simulation and the validation according to nutritional features. The output of the first step is a list of edible crops for each spatial unit from the environmental database. These crops are selected form the “plants” database according to the compatibility between the local climate and their requirements. The second step builds a rotation exploiting the resulting list of the first step as well as the environmental data, that is to say the local soil and natural water resources. It also calculates the potential yield of each crop in each rotation, taking water requirement and pests and diseases into account. Finally, the third and last step computes the average nutrient amount per person per day from the yield values that have been simulated in the preceding step. These average values are then compared to the daily recommended intake amounts (according to the thresholds from Canada Health) to see if the country could potentially live properly without importing any food resource.

5.2. First part : PRA[g] edibility for each crop

The first part of the program works at the Little Agricultural Regions scale, here called PRA[g]. It consists of testing each crop from the ‘plants’ database to pick up the ones which can grow without changing the natural environmental features. That is to say that temperatures, sunlight, rainfall and pH must be adequate while the crop’s growing season (see Figure 1). In order to cover the whole period during which the crop can grow, the growing period has been parametrized as the duration from the earliest planting date to the latest harvesting date.

This choice makes sure that the PRA’s features meet the crop’s ones even if it has a long growing period after beeing planted on the latest date.

For each compatibility assessment – except for pH –, a list is created. It allows to verify if the crop’s requirements are satisfied for a duration greater than the shortest growing season. If that is the case, the crop go on with the next tests. Else, the program switch to the next crop assessment.

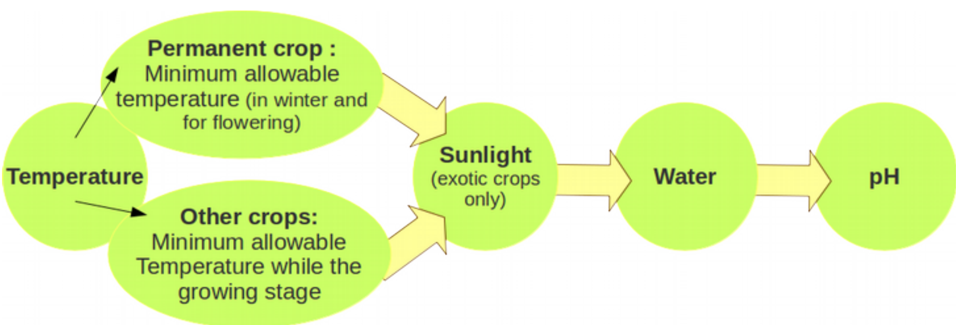

Figure 1: Schematic representation of VegAu's step 1. For each spatial unit, each crop from the 'plants' database get tested to verify if its requirements match with the local environment (climate and soil).

5.2.1. Second part : assessing a rotation for spatial unit

5.2.1.1. Sorting the edible crops according to environmental features

Once all spatial units have got an associated crops list, the rotation simulation can begin. Each crop from this list get tested according to the environmental data of the PRA[g] for which it has been selected. All soil features correspond to the median of the related database from the INRA (see 4.1). Phosphorus has three possible values that corresponds to three different extraction methods: for each spatial unit, the adequate value is selected according to its soil pH. If the pH is lower than 6.5, the method Dyer is chosen; if it is greater than 6.5, priority is given to the Olsen method, which is less aggressive than the Joret-Hébert one. It means that, if there is no data for the Olsen method, the program selects the other one.

The five first steps of the VegAu's second part result in an index calculation (Figure 2, ①, ②, ③, ④, ⑤). These indices range from 0 to 1, with 1 the better value.

The first rotation's month is set to March in order to allow the plantation in early Spring. At the beginning of the rotation, the edible crops are then the ones which can be planted in March as well as fruit trees. Afterwards, they correspond to those which can be planted between the earliest and the latest harvesting date of the preceding crop (Figure 2, ①). If the selection only contains three crops or less, the program looks for the both earliest next planting dates and adds the concerned crops to the list with a associated delay index.

The first environmental test refers to **temperature** (Figure 2, ②). It is an eliminating factor : if the temperature falls just once below the minimum temperature while its shortest growing season, the crop is deleted from the list.

Water resources (Figure 2, ③) are calculated according to the crop coefficient – Kc value – and the local evapotranspiration. If water resources are lower than the water stress threshold – the crop is deleted from the list.

If there are still crops in the selection, the program verifies if there are **enough nutrients in the soil** to grow them (Figure 2, ④). Concerned nutrients are the following : N, P, K, Na, Mg, Ca, Mn, Fe and Cu. The index is calculated in two times. First, an average value of all nutrients margin is calculated for each crop. Next, all these values are standardized according to their maximum. If there is no crop left in the list, the limiting factor is reached and the rotation is over.

If edible crops remain, their **sensibility to pests and**

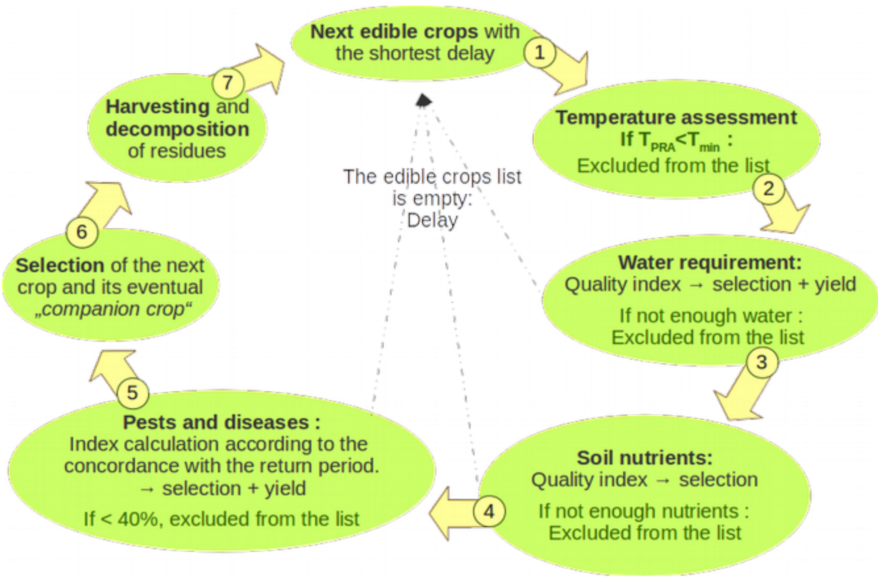

Figure 2 : Schematic representation of VegAu's 'step 2'. For each spatial unit (in this case "Petites Régions Agricoles" from France), requirements of each edible crop get tested to compare them with the local conditions. For each environmental feature (plantation date, water resource, soil nutrients and pests and diseases risks), an index is calculated. The four indices are then summarized in a single selection index to chose the crop with the better characteristics. The calculation continues until there is not enough nutrients any more in the soil.

diseases is evaluated according to the presence of crops of the same botanic family in the rotation (Figure 2, ⑤). If a crop from the same botanical family has already been grown, the duration between its the plantation and the one of the assessed crop is compared to its return period. Pests and diseases risks are considered as being proportional to the actual lapse of time between both crops : the shorter the lapse, the greater the sensibility. If the resulting percentage is lower than 40%, the crop is deleted from the list.

5.2.1.2. Selecting a crop for the rotation

Finally, **a crop can be selected** among the remaining ones (Figure 2, ⑥). If there is less than 120 kg N/ha, VegAu chooses among the edible cover crops to regenerate the soil.

Else, priority is successively given to several crops according to their representativity at the country scale and in the rotation. However, if the resulting list from the edibility tests only contains one entry, this crop is directly chosen to continue the rotation.

If the list of edible crops contains more than one entry, priority is given to crops that can be planted in times and are **unused at the local and country scale**. If all crops have already been grown at least once in the country, crops that can be **planted without any delay** and does are **not already part of the rotation** have priority. Else, **delayed crop are considered** : firstly, those which are still **not represented at the country scale**, and secondly those which have **not already been used in the rotation**.

If the list of edible crops contains more than one entry but only crops which are **all already in the rotation**, **cash crops have priority**. Else, only cover crops remain.

Once a list is selected, if it only contains one entry, the latter is selected to continue the rotation without using the indices. Else, a **final selection index** is calculated from the preceding compatibility assessments.

Once a crop is selected, the model verifies if there is enough water and nutrients to grow a companion crop with the main crop without penalizing the latter. Then the **harvesting of the selected crop is modelled** (Figure 2, ⑦).

5.2.1.3. Harvest and decomposition

The **cash crop's yield** is computed by multiplicating the cultivated surface by the expected yield in tons per hectares. Then, it is adjusted to match with the water resources and potential diseases and pests attack by multiplicating it with the water resource and pests and diseases indices.

The **harvest** is simulated by subtracting the nutrients the crop has needed for its growth to the soil stock. As the residues stay on the ground to save as much nutrients as possible, their decomposition is also computed thanks to the function from the model STICS[55].

Until the step ⑦, the changes in the soil fertility have only been tested without modifying the values. The decomposition of the previous crops is also computed to update the actual stand of the soil fertility before to continue the rotation modelling (Figure 2, back to ①).

5.2.2. Third part : assessing the feasibility of self-reliance according to the average nutritional value of harvested products.

Once all spatial unit have an associated rotation, an total average yearly yield value sums the harvested weight of each used crop in the whole country. This yield value is used to compute the daily and weekly quantities of product per person (Figure 3, ①). As nursing mothers eat more to feed their kids, infants are also counted in the total population.

Then, for each nutrient and each product, the total nutrient content is calculated and summed according to the simulated yields (Figure 3, ②).

For each nutrient and each population stratum – infant, kid, women, men –, the nutritional requirements are multiplied by the population and summed to get the total population's requirements (Figure 3, ③). The nutritional value of the yields are then divided by the needs of the total population. Each unit nutrient amount is then compared to the dietary thresholds given by Canada Heath : the Estimated Average Requirements, the Recommended Dietary Allowances, also called Adequate Intake, and the Tolerable Upper Level.

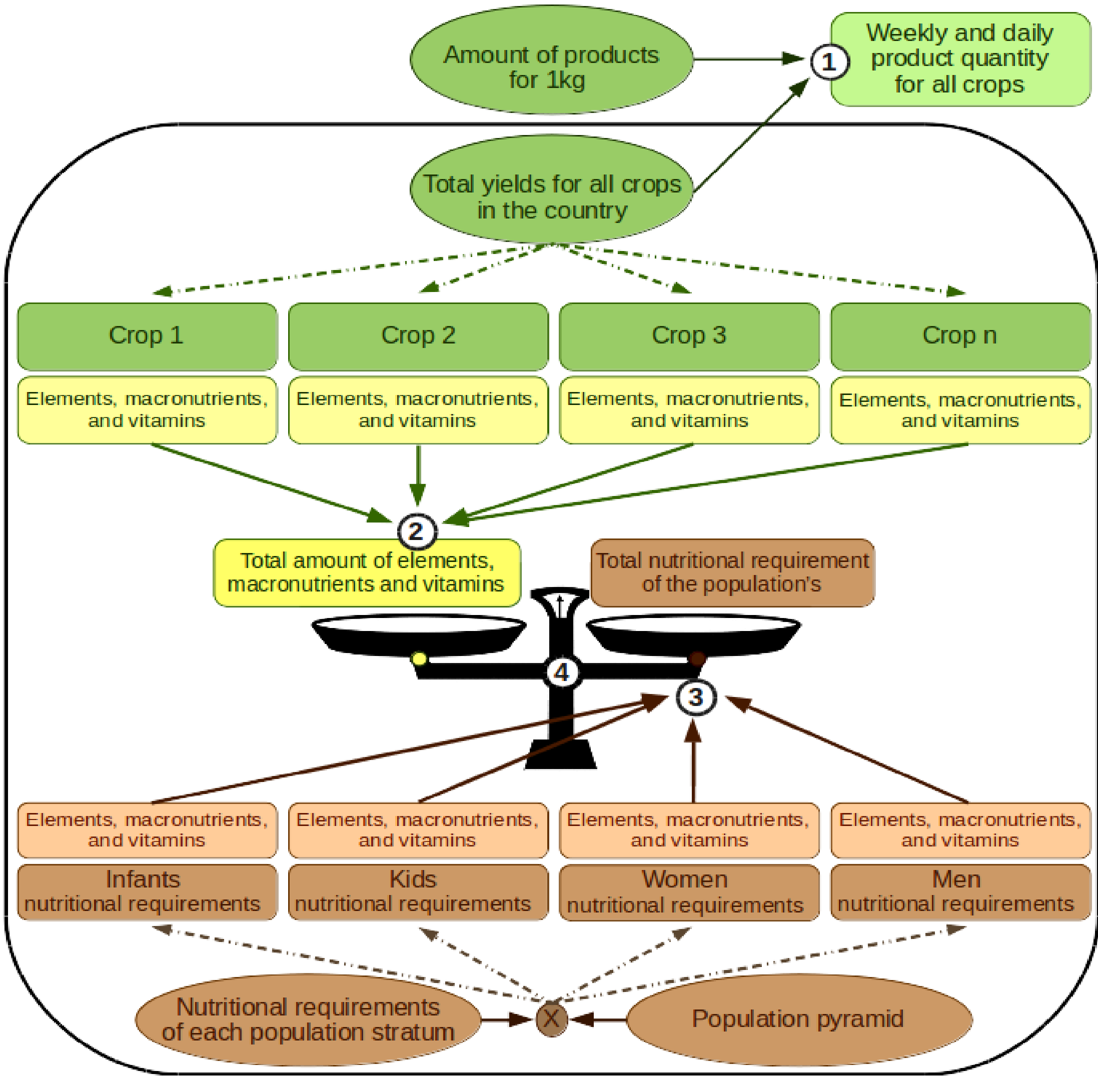

Figure 3: Schematic representation of VegAu's 'step 3' : ① Calculating the weekly and daily amount of products, ② Summing all nutritional features of the simulated yields, ③ Summarizing the total nutritional requirement of the whole population.

6. Results

6.1. First part : edibility assessment

80 crop in 120 can be grown in France without any artificial irrigation and greenhouse, among them 16 Cover Crops. In average, a PRA[g] can potentially grow 37 different crops, with a minimum of 10 in the PRA 30465[k] and a maximum of 66 crops in the PRA 79373[l].

Th eastern border of France predominantly proposes sets of 42 to 52 crops when results in the remaining space are very variable.

k “Vallée du Rhone”, in the Gard (30) department
l “Bocage”, in the Deux-Sèvres (79) department

	Estimated Average Requirements	Recommended Dietary Allowances / Adequate Intake	Tolerable Upper Level
GLOBAL AVERAGE	2858,2%	11038,4%	780,4%
Ca	2144,6%	1742,6%	788,8%
Cu	**9,9%**	**7,6%**	**0,7%**
Fe	6646,0%	4290,2%	1006,7%
I	610,2%	385,4%	56,8%
K	-	2764,7%	-
Mg	4529,9%	3776,5%	3815,1%
Mn	-	13665,3%	2906,1%
P	6249,4%	5178,6%	995,0%
Proteins	-	4019,8%	-
Se	5594,0%	4567,0%	641,1%
Zn	3570,7%	3022,7%	762,6%
Carbohydrates	8057,3%	6157,0%	-
Lipids	-	190400,4%	-
Vitamin A	**8,8%**	**6,1%**	**1,7%**
Vitamin B1	5459,5%	4492,3%	-
Vitamin B12	**1,2%**	**1,0%**	**-**
Vitamin B2	1617,8%	1349,3%	-
Vitamin B3	1898,0%	1454,0%	646,6%
Vitamin B5	-	2379,7%	-
Vitamin B6	4044,0%	3399,6%	49,8%
Vitamin B9	**1,9%**	**1,5%**	**0,6%**
Vitamin C	1004,8%	820,9%	33,6%
Vitamin D	**0,0%**	**0,0%**	**0,0%**

Table 1: Average results related to the nutritive value of the computed yields of 20 simulations.

6.2. Second part : assessing a rotation for spatial unit

In average, computed rotations last 12,85 months with a median of 10 months. These statistics have been calculated from the results of 20 sequences to get a better overview of the potential of each PRA[g].

The shorter median rotation length is referenced in the Guard (30) department, on the Mediterranean coast. It lasts only 4 month with a single crop, when the longest one lasts 44 months with a total of 9 crops, of which 5 different, on the Atlantic coast in the Vienne (86).

The shorter average rotation length is registered in Corsica (department 2A) with a duration of 5,7 months and a single crop. Just like the longest median rotation duration, the median one lasts 38,7 months with an average total amount of 8 crops and 4,8 different crops in the Vienne (86).

6.3. Third part : nutritional value of harvested products and requirements of the population

According to the Table 1, only five nutritive features do not reach the requirements : copper and the vitamins A, B3, B9 and B12 covers respectively only 9.9%, 8,8%, 1,2% and 1,9% of the Estimated Average Requirements (and 7.6%, 6.1%, 1% and 1.5% of the Adequate Intake), while vitamin D is totally absent from the nutritive resources.
Else, all other nutritive features would at least cover 6 times the Estimated Average Requirements and almost 4 times the Recommended Dietary Allowances with iodine, which is the less provided element after the five insufficient ones. The detailed amount of each product per day or week per person is in the Appendix 3.

7. Interpretation

7.1. Covering the needs for food

The contrast between sufficient resources and insufficient ones makes difficult to know if it comes from an error in the code or in the database or furthermore if it may effectively reflect the reality.

Comparing the actual database to other sources highlights that amounts of copper and vitamin A and B9 do not match together. For instance, the database used in the program seems to ignore the B9 content of all products except brown walnuts.

Vitamin D can be synthesized thanks to sun exposure and vitamin B12 should become naturally accessible once the actual environmental impacts of pesticides and excessive fertilizers are reduced (see paragraph 4.3).

That way, it seems like the eventual deficiency computed in this model is certainly caused by mistakes in the database. To test this possibility, the model should run with optimal soil fertility to (in)validate the hypothesis of a too low fertility and the impossibility to grow some crops which provide the missing nutritive resources. If the Adequate Threshold is not reached even if daily food resources are sufficient or even abundant, the problem may come from the database.

7.2. Covering the needs for textile fibres

Only fibre flax could be grown in France according to VegAu 0.14. The simulated yields predict 12591494 tons of fibre, that is 194135 grams of fibre per person in one year.

There are several cloth thickness according to the type of item of clothing, for instance 50 g/m2, 70 g/m2, 110 g/m2 and 200 g/m2. Admitting that a quarter of the computed fibre yield is used for each cloth thickness, a single person could respectively get 647, 462, 294 and 162 meters of each of this cloth quality for pieces of 1,5 meters wide.

7.3. Acting for biodiversity and alternative energy sources

Admitting that the nutritive deficiency in copper, vitamin A and B9 is only due to an input mistake, resources should be largely sufficient to feed the whole French population. Hence, agricultural surface could be reduced to promote reforestation, the growth of endangered plant species or even implementation or extension of protected area. Such steps could have a great influence on the protection of species, for animals like for plants as well as for soils. The simple abort of chemicals use would be a great point for bees protection.

Biofuel could also become a great energy source by using food waste and manure either at the individual, family scale or at a larger scale. As crops residues stays in the field to return their components to the soil and enhance its properties, they cannot be used for this purpose.

7.4. The question of nutrients cycling

The limiting factors of this model is the nutrient availability. One of the greatest problem that organic agriculture has to face is exactly this one : by adding no fertilizer in the soil, the latter may be damaged by the lack of nutrients. Nutrient cycling is though an essential point to care if the theory of this model should be applied. If all organic wastes become gathered for biofuel, the solid waste could be used to fertilize the soil and return nutrients to it. Indeed, according to the Stockholm Environment Institut[56], urine is a very N-rich fertilizer with a N:P:K ratio of 10:1:4 while faeces provide a more balanced fertilizer with a ratio of 2:1:1[56].

Thus, nutrient cycling should be managed if manure returns to the soil.

8. Discussion

8.1. A necessary data improvement

Because of the wide range of crops and retained variables, this project was a real challenge concerning plant data gathering, especially considering that lots of contacted Institutes have not been able to supply a single database with more than one variable type. The wide range of crops forced to compile data with several sources, making the final database quite heterogeneous. As a result, some values are hazardous.

Concerning the nutritive database, as the Ciqual provided a rich and homogeneous data set, it has been kept untouched. However, the actual results encourage the investigation of its accuracy by comparing it to other sources.

In the context of a doctor thesis, this project could be enhanced by creating an homogeneous database with adapted methods. Indeed, a coherent database would be absolutely required in order to improve the quality of the VegAu's results.

8.2. A too wide scale to take soil variability into account

The appropriateness between soil and crop could not sufficiently be taken into account because of the lack of data and the too wide spatial scale: the PRA[g] scale can not take variability of soil into account.

In this model, the simulation of organic matter accumulation while the rotation is supposed to compute the favourable impact of humification on the soil. This evolution in soil humus content should lead to an homogenization of soil texture at the country scale because of its improvement, but it still not solves the problem of the lack of information and precision about soil fertility.

8.3. Possible improvements

Several improvement projects are taken into account for future releases :

- Improving crops selection in the both first steps
- Computing pH evolution while the rotations
- Improving the simulation of soil texture evolution
- Taking maximum temperatures into account
- Using the amount of days below threshold temperatures instead of average temperatures
- Integrating plant association for yield improvement and a better pests and diseases management
- Improving nutrients managing by alternating legumes with grains to prevent leaching
- Handling with climate change by using several data sets
- Improving the accessibility by creating an interactive graphical user interface

9. Conclusion

As a mathematical tool, a crop rotation model only takes into account generic conditions as well as values and principles that are considered as reliable. However, predictions which are judged optimal by models can't represent the uniqueness of the farmers' frame and decisions[57].

In the VegAu's case, this is all the more true because the simulation yearn for a large-scaled approximation. The latter is essentially based on the adequacy between environmental features and plants properties. Unlike most models, the rotation computation does not take economical advantages into account. However, the program's use at the field scale remain possible and aims to decrease chemicals and water spending of farmers. In this way, even if the financial aspect is not clearly modelled, it stays one of the VegAu's underlying aims or interest.

According to the results of it's 0.14 release and considering that the very restricted amount of copper, vitamin B9 and vitamin C comes from mistakes in the database, the French population could theoretically have an healthy nutrition, abundant food resources and be autarque in cloth production if agriculture excluded livestock, artificial irrigation and chemicals.

As the code and database still present some incoherences, the results related in the present work must be considered carefully. Numerous incoming enhancements should provide more stability and accuracy to the program. After the verification of the nutritive database, the improvement of crops selection in the edibility assessment (first step) and the rotation (second step) would be the second priority. Climate is also a great point to consider by taking climate change and the maximum allowable temperature into account in the edibility tests. Integrating plant association to the program could also balance yields and encourage a better pests and diseases management, but further researches will be needed. At least, a graphical interface should allow users to interact with several options to adapt the queries and data to their needs and to take part to the database enhancement.

Appendix 1 :Results of the first VegAu's step. This table enumerates all crops which can grow in France without artificial irrigation andgreenhouse according to the results of the VegAu's first step (version 0.14)

Cover crops	Grains	Legumes	Vegetables	Fruits	
• Clover (Balansa) • Clover (Berseem) • Clover (Persian) • Clover (red) • Clover (subterranean) • Clover (yellow sweet) • Clover (white) • Orchardgrass • Vetch (common) • Hairy vetch • Woolly Pod Vetch • Mustard (brown) • Mustard (yellow) • Sunflower • Flax	• Barley (winter) • Buckwheat • Oats (summer) • Rape (Canola) • Rye • Wheat (summer) • Maize (grain) • Maize (sweet) • Sunflower • Flax	• Peas • Blackeye peas • Chickpea • Cowpea • Bean (Great Northern) • Bean (Snap dry) • Soybean • Lentils • Mustard (brown) • Mustard (yellow)	• Eggplant • Collard • Kale • Carrot • Endive • Fennel • Garlic • Leek • Lettuces • Onion • Pepper (hot, red) • Pepper (sweet) • Rhubarb • Spinach • Squashes	• Strawberry • Honeydrew • Muskmelon • Watermelon • Grapes european • Blackberry • Blueberry • Raspberry • Apple • Apricot • Cherry (sweet) • Peach • Pear (mean) • Plums • Plums (prune-type)	• Almonds • Hazelnut Filberts • Walnut (black) • Walnut (persian/english) • Olive • Lemon • Orange • Tangerine

Appendix 2: Results of the third VegAu's step – Weekly and daily products quantity per person for each crop used in the simulated rotations. The model have been run 20 times to get average and median results that can be as representative as possible.

	Average		Median	
	Weekly Product Amount per Person	Daily Product Amount per Person	Weekly Product Amount per Person	Daily Product Amount per Person
Aubergine	29,89	4,27	28,93	4,13
Flax	0,74	0,11	0,75	0,11
Apricot	1,58	0,23	1,58	0,23
Cherry	5,39	0,77	5,39	0,77
Garlic	7,38	1,06	5,52	0,79
Barley (winter)	0,43	0,06		
Oats (summer)	0,01	0,00	0,01	0,00
Rape (Oilseed)	0,22	0,03	0,22	0,03
Rye	4,97	0,71	4,88	0,70
Winter wheat	0,43	0,06	0,42	0,06
Grape	0,97	0,14	0,97	0,14
Leek	0,03	0,00	0,03	0,00
Lentils	0,15	0,02	0,15	0,02
Maize (grain, mature)	32,20	4,60	32,14	4,59
Watermelon	1,42	0,20	1,22	0,17
Mustard (brown, sommer)	0,17	0,02	0,16	0,02
Mustard (brown, winter)	4,07	0,58	4,16	0,59
Mustard green (summer)	65,55	9,36	62,35	8,91
Mustard (yellow, sommer)	0,09	0,01	0,99	0,14
Mustard (yellow, winter)	76,91	10,99	80,67	11,52
Almond	0,25	0,04	0,25	0,04
Walnut black	4,38	0,63	4,38	0,63
Olive (green)	2,26	0,32	2,64	0,38
Olive (black)	1,60	0,23	1,60	0,23
Onion (young green)	9,00	1,29	6,36	0,91
Onion (mature, dry)	44,79	6,40	48,23	6,89
Chickpea	4,85	0,69	4,88	0,70
Pepper (sweet)	1,44	0,21	1,49	0,21

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