biology and life sciences forum

Proceeding Paper

Agroecological Fertilisation Practices to Improve Sustainability and Circularity in Maize Crop Systems †

Martha Elena Domínguez-Hernández [1,*], Elisa Domínguez-Hernández [1], Arnulfo Domínguez-Hernández [2], María del Carmen Valderrama-Bravo [3] and Rosalba Zepeda-Bautista [2]

[1] Department of Agricultural Sciences, Faculty of Higher Studies Cuautitlan, National Autonomous University of Mexico, Cuautitlan Izcalli 54714, Mexico; elisadohe@gmail.com

[2] Sustainable Biophysical Systems for Food, Agriculture and Medicine, Department of Research and Graduate Education, School of Mechanical and Electrical Engineering (Zacatenco), National Polytechnic Institute, Mexico City 07738, Mexico; adhmec@gmail.com (A.D.-H.); rzepedab@ipn.mx (R.Z.-B.)

[3] Department of Engineering and Technology, Department of Mathematics, Research Unit for Grains and Seeds, Faculty of Higher Studies Cuautitlan, National Autonomous University of Mexico, Cuautitlan Izcalli 54714, Mexico; valderramabravom@gmail.com

* Correspondence: marthaedohe@gmail.com or marthadominguez@comunidad.unam.mx; Tel.: +52-5556231841

† Presented at the 3rd International Electronic Conference on Agronomy, 15–30 October 2023; Available online: https://iecag2023.sciforum.net/.

Abstract: Agroecological practices such as organic fertilisation offer a sustainable approach to crop systems. In this research, organic fertilisers made from a mixture of *nejayote* (lime water) and ovine manure were evaluated in maize. Several indexes and indicators were calculated based on field data. The results demonstrated that *nejayote*-manure fertilisers improve soil quality (SQI = 14.1), enhance efficiency in nutrient utilisation (increased yield, IY = 4.2 Mg ha^{-1}), and promote greater production biomass compared to chemical fertilisation. Organic fertilisation reduced dependency on external inputs and non-renewable energy, increased sustainability in maize, and facilitated the closure of nutrient cycles by integrating livestock, crop, and agro-industrial systems.

Keywords: *Zea mays* L.; sustainability; circularity; soil quality; waste management

Citation: Domínguez-Hernández, M.E.; Domínguez-Hernández, E.; Domínguez-Hernández, A.; Valderrama-Bravo, M.d.C.; Zepeda-Bautista, R. Agroecological Fertilisation Practices to Improve Sustainability and Circularity in Maize Crop Systems. *Biol. Life Sci. Forum* **2023**, *27*, 1. https://doi.org/10.3390/IECAG2023-15226

Academic Editor: Daniel Real

Published: 26 October 2023

1. Introduction

Agroecosystems sustainability is affected by their biological, agronomic, and economic productivity [1]. Productivity depends on soil quality, and because of that, management practices should be directed towards reducing or preventing soil degradation [2,3]. Soil is crucial for human development, especially for rural populations that rely on agriculture for subsistence and poverty alleviation [4]. Small-scale farmers face various challenges in production, including limited economic resources and poor soil fertility. For the maize agroecosystem, macronutrient deficiency is one of the major yield limitations [5]. Therefore, soil management is critical to maximising nutrient use efficiency [6] and is essential for improving the sustainability of agroecosystems [4,7].

Intensive agriculture systems have moved away from circularity due to factors such as the specialization of production units and the substitution of organic sources of fertilization with chemical ones [8]. These systems demand a significant amount of energy from non-renewable sources and generate considerable amounts of waste. One option for achieving the transition towards circular and sustainable systems is the recycling of agricultural, livestock, and agro-industrial waste. In Mexico, the agro-industrial process of using maize to produce tortillas and nixtamalized flour generates a contaminating waste called *nejayote*. This residue can be mixed with manure to produce organic fertilisers that offer several benefits in the maize agroecosystem, such as cost reduction and increased yield [9]. In this research, two organic fertilisers derived from mixtures of *nejayote* and ovine manure were tested to determine their impact on soil quality, sustainability, and circularity in the maize agroecosystem. The study aimed to assess whether the application of *nejayote*-manure organic fertilisers result in differences in soil quality and the sustainability of yield, and to evaluate the differences generated by the treatments in the circularity of the system through biomass production, nutrient use efficiency, and the distribution of the energy utilised in the production process.

2. Materials and Methods

Research was conducted in Ahuazotepec, Mexico, during two cropping cycles (Spring–Summer 2015 and 2016). The experimental plot was located at 2268 masl with coordinates of 20°01′51.6″ N and 98°07′15.6″ W. The climate was temperate and humid C(m). Two organic fertilisation treatments were evaluated for two maize production cycles. Organic fertiliser combinations of *nejayote* (lime water) and ovine manure were prepared (OF1 = 75 m^3 ha^{-1} *nejayote* + 50 t ha^{-1} ovine manure, OF2 = 150 m^3 ha^{-1} *nejayote* + 50 t ha^{-1} ovine manure). Additionally, an unfertilised treatment (C) and a chemical fertilisation treatment (CF = 120N-60P-30K) were established for comparison. Treatments were arranged in randomised blocks with three replicates per treatment. Each experimental unit consisted of six rows with a net plot area of 48 m^2. The maize hybrid AS-722 (Aspros™) was planted on each unit using a sowing density of 75,000 plants per ha. Fertilisation was applied manually on days 20, 40, and 60 after sowing on each cycle. Soil samples were taken before the start of the trial (baseline: 20 April 2015) and after the first and second harvests (Cycle 1: 10 November 2015, and Cycle 2: 10 December 2016). A grid sampling method was used, and soil samples (depth of 30 cm) were collected from the centre of each grid. For each sample, different physical and chemical properties were measured, as mentioned in [10].

2.1. Sustainability and Circularity Assessment

2.1.1. Soil Quality Index (SQI)

This index was calculated using the weighted additive model [11] showed in (1).

$$\mathrm{SQI} = \Sigma_{i=1}^{n} w_i s_i, \tag{1}$$

where w_i = weight of the indicator and s_i = indicator score. An analysis of variance was performed for the total soil parameters available in the dataset to select those that generated statistical differences in maize yield ($p < 0.05$). The selected indicators were loam content, OM, pH, cationic exchange capacity (CEC), EC, AN, AP, and AK. A principal component analysis (PCA) for the selected indicators was used. In each PC, the soil indicators with the largest absolute value were included in the soil quality index (SQI). The weights of the indicators were obtained by dividing the proportion of the variability explained using the PC by the total variability of the selected components. Each selected indicator was scored.

2.1.2. Yield and Biomass

The Sustainable Yield Index (SYI) [12] was estimated using (2):

$$\mathrm{SYI} = [(\overline{y} - \sigma)/y_{max}] * 10 \tag{2}$$

where $\overline{y}$ = mean yield of treatment, y_{max} = maximum yield obtained in the experiment (15.1 Mg ha^{-1}), and σ is the standard deviation of the experiment (σ = 2.7). The obtained values were multiplied by 10 to have a simpler scale. BP_{Food} and BP_{Feed} reflect food and feed production and were estimated using biomass production data. For BP_{Food}, grain production was converted to nixtamalized flour yield, since this is the basis for many foods in the study area, and then the production of protein was estimated using the chemical composition of flours reported by [13]. For BP_{Feed}, the production of maize stover was estimated from field data, and protein production was calculated using a reference value of 3.9% DM [14].

2.1.3. Nutrient Cycling Efficiency

To assess the nutrient cycling efficiency of the system, the increased yield (IY) due to the applied fertiliser [15] was calculated as the difference between each treatment yield and the control yield.

2.1.4. Energy Consumption in Maize Production

Energy consumption used in maize production was estimated using energetic equivalents of the inputs and outputs as described in [9]. Inputs were grouped as direct energy (DE—human labour and fuel), indirect energy (IDE—machinery, seed, chemical fertiliser, manure, and *nejayote*), renewable energy (RE—seed, human labour, manure, and *nejayote*), and non-renewable energy (NRE—fuel, chemical fertiliser, machinery, and herbicide) [16–18].

2.2. Statistical Analysis

Statistical treatment of indicators and indices was performed using ANOVA and a Tukey test to compare means, and effects were considered significant at $p < 0.05$. All procedures were conducted using Minitab 17 (Minitab Inc., State College, PA, USA).

3. Results

3.1. Sustainability and Circularity Assessment

3.1.1. Soil Quality Index (SQI)

SQI was then calculated substituting, the scored means in (3). The weights for each principal component were PC1 = 0.421, PC2 = 0.343, and PC3 = 0.236, and those values were assigned to the selected soil indicator in each PC.

$$\mathrm{SQI} = 0.421(\mathrm{pH} + \mathrm{CEC} + \mathrm{EC} + \mathrm{AP}) + 0.343(\mathrm{AN} + \mathrm{AK}) + 0.236(\mathrm{OM}) \quad (3)$$

Results for SQI can be seen in Figure 1. Baseline values for SQI showed no differences ($p = 0.944$). After Cycle 1, SQI increases in all treatments between 1.3 and 12.7% with respect to the baseline ($p = 0.926$). For Cycle 2, the fertilization with OF2 increases SQI by 12.9% with respect to CF and 19.2% with respect to C ($p = 0.03$). After two cropping cycles, soil quality decreases by 3.2 and 11.5% with CF and no C, respectively. On the other hand, OF2 and OF1 increased soil quality between 5.4 and 10.9% in the same period.

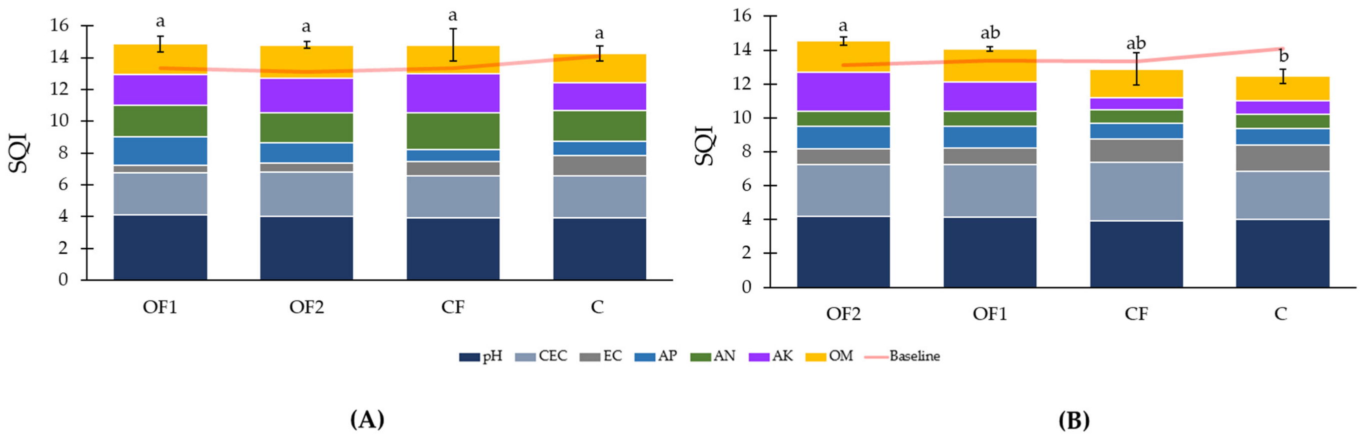

Figure 1. Soil quality indexes (SQI) of different fertilisation treatments applied to maize in Mexico. (**A**) Cycle 1. (**B**) Cycle 2, the red line is the baseline value. Stacked bars showed the scored and weighed parameters used for SQI. Different letters above the bars indicate significant differences with the Tukey method and a significance level of $\alpha = 0.05$. CEC, cation exchange capacity; CE, electrical conductivity; AP, available phosphorus; AN, available nitrogen; AK, available potassium; and OM, soil organic matter.

3.1.2. Yield and Biomass

The Sustainable Yield Index (SYI) had significant differences in both cycles ($p < 0.05$). In cycle 1, SYI with OF1 and OF2 was 31.9% higher than C (Figure 2). For cycle 2, a generalised decrease in yield caused by Hurricane Earl affected SYI values (Figure 2). Even in those adverse climatic conditions, the yield of treatment OF1 was 58.9% more sustainable than that obtained with CF. It could be explained by a positive effect on soil quality due to the organic fertilisation (Figure 1).

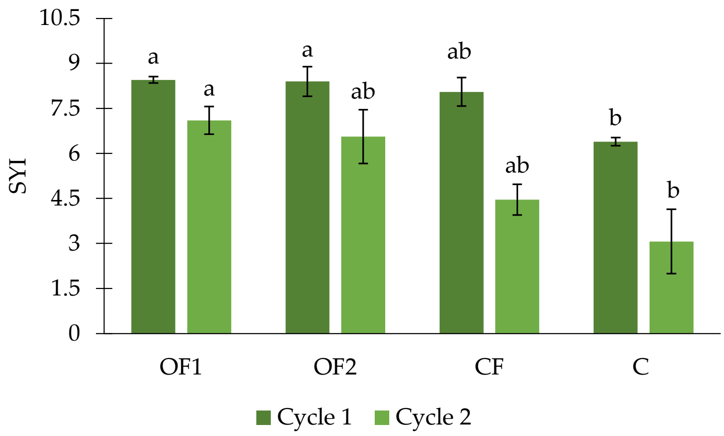

Figure 2. Sustainable Yield Index (SYI) for two maize production cycles under different fertilisation treatments in Mexico. Different letters indicate significant differences with the Tukey method and a significance level of $\alpha = 0.05$.

An important ecosystem service for the soil is the production of edible biomass. BP_{Food} showed significant differences caused by the fertilisation treatment in both production cycles ($p < 0.05$). CF and OF1 produced the highest protein yield in nixtamalized flour per hectare, 41.7 and 39.7% higher than control, respectively (Table 1). In cycle 2, OF1 and OF2 produced 34.9 and 23.5% more protein than CF (Table 1). Protein production for feed in the form of stover biomass had significant differences in both cycles ($p < 0.05$). For Cycle 1, the largest BP_{Feed} was obtained with the OF1, with a protein production 23.4 kg ha^{-1} higher than CF and 120.8 kg ha^{-1} higher than C. On Cycle 2, this treatment produced 42.9% more protein than CF (Table 1).

Table 1. Biomass production for food and feed in maize cultivated under different fertilisation treatments in Ahuazotepec, Mexico.

Fertilisation Treatment	BP_{Food} Cycle 1 (kg ha^{-1})	BP_{Feed} Cycle 1 (kg ha^{-1})	BP_{Food} Cycle 2 (kg ha^{-1})	BP_{Feed} Cycle 2 (kg ha^{-1})
OF1	1076.4 ^{a}	550.2 ^{a}	945.9 ^{a}	483.5 ^{a}
OF2	1043.4 ^{a}	547.1 ^{a}	865.9 ^{a}	454.1 ^{ab}
CF	1091.4 ^{a}	526.8 ^{ab}	700.9 ^{ab}	338.3 ^{ab}
C	770.2 ^{b}	429.4 ^{b}	468.2 ^{b}	261.0 ^{b}

Letters indicate differences between treatments ($p < 0.05$); means that do not share a letter are significantly different (Tukey method, $\alpha = 0.05$).

3.1.3. Nutrient Cycling Efficiency

The application of the fertilisation treatments changed the yield of maize with respect to C. Organic fertilisers produced an average increase in the yield of 4.2 Mg ha^{-1} (OF1, Cycle 1 IY = 3.1, Cycle 2 IY = 5.7 Mg ha^{-1}), while the CF average IY was 0.9 Mg ha^{-1}. In the second cycle, OF1 and OF2 increased the IY value by 2.3 Mg; on the other hand, CF decreased the indicator value by 0.5 Mg.

3.1.4. Energy Consumption in Maize Production

Energy consumed in maize production was similar in both cycles (Table 2). C had the minimal energy consumption (3459.8 MJ ha^{-1}), while the maximum value was obtained with OF2 (21,517.9 MJ ha^{-1}). In C and CF, between 84.4 and 96.8% of the energy used is non-renewable; on the other hand, with *nejayote*-manure fertilisers, between 79.6 and 80.4% of the energy is renewable (Table 2). Direct and indirect energy distribution is similar in organic and inorganic fertilisation (Table 2).

Table 2. Average energy consumption for maize production with organic *nejayote*-manure fertilisers in Ahuazotepec, Mexico.

Fertilisation	Direct Energy (MJ ha^{-1})	Indirect Energy (MJ ha^{-1})	Renewable Energy (MJ ha^{-1})	Non-Renewable Energy (MJ ha^{-1})
OF1	2801.1	17,841.8	16,434.7	4208.2
OF2	2801.1	18,716.8	17,309.7	4208.2
CF	1781.8	15,369.7	546.3	16,605.2
C	1775.1	1684.7	539.6	2920.2

OF1 = 75 m^3 ha^{-1} Nejayote + 50 t ha^{-1} ovine manure, OF2 = 150 m^3 ha^{-1} Nejayote + 50 t ha^{-1} ovine manure, CF = chemical fertilisation 120N-60P-30K, and C = unfertilised treatment.

4. Discussion

4.1. Sustainability and Circularity Assessment

4.1.1. Soil Quality Index (SQI)

Obtained SQI to evaluate changes derived from agroecological fertilisation practices like *nejayote*-manure fertilisation includes soil indicators such as organic matter and nutrient content. All these properties were reported in soil quality evaluations [19–22] because of their contribution to improving soil sustainability and quality [7]. Manure addition increases soil quality by at least 40% with respect to chemical fertilisation [12]. This trend was observed in *nejayote*-manure fertilisers, which had a high SQI, even with adverse climatic conditions. Conversely, CF had a negative trend in SQI, like values reported by [12,23]. An intensive conventional management leads to soil compaction, erosion, and degradation. Although soil fertility improves in a short term because of the chemical fertiliser applied, in the long-term organic matter and nutrient content decrease, affecting soil quality in a negative way [23].

4.1.2. Yield and Biomass

Manure application increases SYI, with respect to the CF [12,24]. This trend was also reported with organic amendments such as biochar and vermicompost [25], which indicates productivity and sustainability improvements. Although some organic fertiliser evaluations did not find significant differences in grain yield due to the application of manure [6] or compost [26], an added benefit of combining organic and chemical fertilisation was reported. In this evaluation, the SYI of the OF1 shows the highest value of the treatments, like single-manure applications [27]. Organic amendments increase nutrient availability, organic matter content, and crop yield [25]. The use of organic manure contributes to the prolongated availability of nutrients due to its slow-release action compared to the rapid solubility of chemical fertilisers [27].

In an agroecosystem, available nitrogen affects yield and protein content [28,29]. In this two-cycle experiment, biomass for food and feed was increased due to the organic fertiliser applications, and those results were consistent with increases of 18 and 37% in crude protein reported due to the biochar and vermicompost applications [25]. Calcium content improves the amount of nitrogen used by the plant for biomass production; this could explain the higher protein content obtained with organic fertilisation, which coincides with those reported by [29] in corn grain fertilised with calcium nitrate and with [13], who report higher protein in flours obtained from corn organically fertilised.

4.1.3. Nutrient Cycling Efficiency

Recycling nutrients contained in waste from livestock or agroindustry contributes to closing the nutrient cycle and reducing their pollution potential [8,9], improves soil properties [6], and could increase crop yield in a sustainable way. The organic fertiliser *nejayote*-manure increases agronomic efficiency compared with CF. This finding coincides with [15,30] and could be explained by the soil quality improvement, enhanced efficiency in nutrient use, and mineralization processes [24,31]. Also, in acidic soils, maize nutrient use and yield have a better response to the manure application [32]. The yield increase due to the *nejayote*-manure fertiliser application was maintained even under adverse climatic conditions, and this behaviour has been observed with other organic amendments [30].

4.1.4. Energy Consumption in Maize Production

In conventional maize production systems, the greatest amount of energy used comes from non-renewable sources such as nitrogen fertilisers and fuel [18]. In CF, urea represented 54.2% of the non-renewable energy consumed, and this value coincides with [17]. Conversely, production systems where residues are used as organic fertilisers are less dependent on fossil fuels and non-renewable mineral resources [33], reducing the effect of price variations in production costs and the chemical fertiliser dependence [34,35]. Chemical fertilisers and fuels in maize production could increase emissions of carbon dioxide and greenhouse gases, contributing to global warming and its negative environmental implications [18,36]. Thus, a transition to circular agro-food systems integrating crop, livestock, and agro-industrial production could reduce production costs and allow nutrients to return to the field [8].

5. Conclusions

Agroecological practices, such as organic fertilisation, lead to improvements in soil quality and crop productivity. According to the results, it is possible to say that the application of organic fertilisers such as *nejayote*-manure (OF1 and OF2) improves soil quality, promoting stable yields, as the Sustainable Yield Index (SYI) obtained indicates. The recovery of nutrients contained in manure and *nejayote* can mitigate the pollution potential of livestock and agro-industrial maize processing. Recycling these residues as fertilisers for maize production contributes to closing the nutrient cycle, increasing the circularity of the agroecosystems, and improving sustainability in maize production. The use of *nejayote*-manure fertilisers could be an option to address soil fertility problems and chemical fertiliser dependence in the maize agroecosystem in Mexico. Finally, since it also reduced the non-renewable energy consumed in maize production, its adoption could help smallholders who have limited economic resources.

Author Contributions: Conceptualization, M.E.D.-H. and E.D.-H.; methodology, M.E.D.-H., M.d.C.V.-B. and R.Z.-B.; formal analysis, M.E.D.-H., E.D.-H. and A.D.-H.; investigation, M.E.D.-H., A.D.-H., E.D.-H., M.d.C.V.-B. and R.Z.-B.; resources, M.E.D.-H.; writing—original draft preparation, M.E.D.-H., E.D.-H. and A.D.-H.; writing—review and editing, M.E.D.-H., A.D.-H., E.D.-H., M.d.C.V.-B. and R.Z.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by FES Cuautitlán UNAM, Project: CI2266 and Instituto Politécnico Nacional, Project: SIP20231594.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in the article.

Acknowledgments: The authors wish to acknowledge the producers and local businesses in Ahuazotepec for their invaluable material and labour contributions to the field experiment.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Dominguez-Hernandez, M.E.; Zepeda-Bautista, R.; Valderrama-Bravo, M.C.; Dominguez-Hernandez, E.; Hernandez-Aguilar, C. Sustainability Assessment of Traditional Maize (*Zea mays* L.) Agroecosystem in Sierra Norte of Puebla, Mexico. *Agroecol. Sustain. Food Syst.* **2018**, *42*, 383–406. [CrossRef]
2. Tepes, A.; Galarraga, I.; Markandya, A.; Sánchez, M.J.S. Costs and Benefits of Soil Protection and Sustainable Land Management Practices in Selected European Countries: Towards Multidisciplinary Insights. *Sci. Total Environ.* **2021**, *756*, 143925. [CrossRef] [PubMed]
3. Chen, S.; Lin, B.; Li, Y.; Zhou, S. Spatial and Temporal Changes of Soil Properties and Soil Fertility Evaluation in a Large Grain-Production Area of Subtropical Plain, China. *Geoderma* **2020**, *357*, 113937. [CrossRef]
4. Hou, D.; Bolan, N.S.; Tsang, D.C.W.; Kirkham, M.B.; O'Connor, D. Sustainable Soil Use and Management: An Interdisciplinary and Systematic Approach. *Sci. Total Environ.* **2020**, *729*, 138961. [CrossRef]
5. Subedi, K.D.; Ma, B.L. Assessment of Some Major Yield-Limiting Factors on Maize Production in a Humid Temperate Environment. *Field Crops Res.* **2009**, *110*, 21–26. [CrossRef]
6. Arif, M.; Ali, K.; Jan, M.T.; Shah, Z.; Jones, D.L.; Quilliam, R.S. Integration of Biochar with Animal Manure and Nitrogen for Improving Maize Yields and Soil Properties in Calcareous Semi-Arid Agroecosystems. *Field Crops Res.* **2016**, *195*, 28–35. [CrossRef]
7. Bhattacharya, P.; Maity, P.P.; Mowrer, J.; Maity, A.; Ray, M.; Das, S.; Chakrabarti, B.; Ghosh, T.; Krishnan, P. Assessment of Soil Health Parameters and Application of the Sustainability Index to Fields under Conservation Agriculture for 3, 6, and 9 Years in India. *Heliyon* **2020**, *6*, e05640. [CrossRef]
8. Koppelmäki, K.; Helenius, J.; Schulte, R.P.O. Nested Circularity in Food Systems: A Nordic Case Study on Connecting Biomass, Nutrient and Energy Flows from Field Scale to Continent. *Resour. Conserv. Recycl.* **2021**, *164*, 105218. [CrossRef]
9. Dominguez-Hernandez, M.E.; Zepeda-Bautista, R.; Dominguez-Hernandez, E.; Valderrama-Bravo, M.C.; Hernández-Simón, L.M. Effect of Lime Water–Manure Organic Fertilizers on the Productivity, Energy Efficiency and Profitability of Rainfed Maize Production. *Arch. Agron. Soil Sci.* **2020**, *66*, 370–385. [CrossRef]
10. Domínguez-Hernández, E.; Hernández-Aguilar, C.; Domínguez-Hernández, M.; Domínguez-Pacheco, F. Designing a Horticultural Intervention to Improve Food Security: Evaluation of Mulching Practices Using Sustainability Indicators. *Agroecol. Sustain. Food Syst.* **2020**, *44*, 1212–1242. [CrossRef]
11. Andrews, S.; Mitchell, J.; Mancinelli, R.; Karlen, D.; Hartz, T.; Horwath, W.; Pettygrove, G.; Scow, K.; Munk, D. On-Farm Assessment of Soil Quality in California's Central Valley. *Agron. J.* **2002**, *94*, 12–23.
12. Dutta, J.; Sharma, S.P.; Sharma, S.K.; Sharma, G.D.; Sankhyan, N.K. Indexing Soil Quality under Long-Term Maize-Wheat Cropping System in an Acidic Alfisol. *Commun. Soil Sci. Plant Anal.* **2015**, *46*, 1841–1862. [CrossRef]
13. Valderrama Bravo, M.C.; Cornejo Villegas, M.A.; Zambrano Zaragoza, M.L.; Domínguez Hernández, M.E.; Zepeda-Bautista, R.; Oaxaca Luna, J.A. Physicochemical Characterization of Flours and Rheological and Textural Changes of Masa and Tortillas Obtained from Maize Fertilized with Nejayote and Ovine Manure. *Int. Agrophys.* **2020**, *34*, 241–252. [CrossRef] [PubMed]
14. AFZ; INRAE; CIRAD; FAO. Feedipedia Animal Feed Resources Information System. Available online: https://www.feedipedia.org/content/feeds?category=13593 (accessed on 14 May 2022).
15. Bedada, W.; Lemenih, M.; Karltun, E. Soil Nutrient Build-up, Input Interaction Effects and Plot Level N and P Balances under Long-Term Addition of Compost and NP Fertilizer. *Agric. Ecosyst. Environ.* **2016**, *218*, 220–231. [CrossRef]
16. Banaeian, N.; Omid, M.; Ahmadi, H. Energy and Economic Analysis of Greenhouse Strawberry Production in Tehran Province of Iran. *Energy Convers. Manag.* **2011**, *52*, 1020–1025. [CrossRef]
17. Banaeian, N.; Zangeneh, M. Study on Energy Efficiency in Corn Production of Iran. *Energy* **2011**, *36*, 5394–5402. [CrossRef]
18. Kosemani, B.S.; Bamgboye, A.I. Modelling Energy Use Pattern for Maize (*Zea mays* L.) Production in Nigeria. *Clean. Eng. Technol.* **2021**, *2*, 100051. [CrossRef]
19. Andrews, S.; Karlen, D.; Mitchell, J. A Comparison of Soil Quality Indexing Methods for Vegetable Production Systems in Northern California. *Agric. Ecosyst. Environ.* **2002**, *90*, 25–45. [CrossRef]
20. Andrews, S.; Karlen, D.; Cambardella, C. The Soil Management Assessment Framework: A Quantitative Soil Quality Evaluation Method. *Soil Sci. Soc. Am. J.* **2004**, *68*, 1945–1962. [CrossRef]
21. Thuithaisong, C.; Parkpian, P.; Shipin, O.V.; Shrestha, R.P.; Naklang, K.; Delaune, R.D.; Jugsujinda, A. Soil-Quality Indicators for Predicting Sustainable Organic Rice Production. *Commun. Soil Sci. Plant Anal.* **2011**, *42*, 548–568. [CrossRef]
22. Li, P.; Zhang, T.; Wang, X.; Yu, D. Development of Biological Soil Quality Indicator System for Subtropical China. *Soil Tillage Res.* **2013**, *126*, 112–118. [CrossRef]
23. Askari, M.S.; Holden, N.M. Indices for Quantitative Evaluation of Soil Quality under Grassland Management. *Geoderma* **2014**, *230–231*, 131–142. [CrossRef]
24. Meng, Q.F.; Li, D.W.; Zhang, J.; Zhou, L.R.; Ma, X.F.; Wang, H.Y.; Wang, G.C. Soil Properties and Corn (*Zea mays* L.) Production under Manure Application Combined with Deep Tillage Management in Solonetzic Soils of Songnen Plain, Northeast China. *J. Integr. Agric.* **2016**, *15*, 879–890. [CrossRef]

25. Dubey, R.K.; Dubey, P.K.; Chaurasia, R.; Singh, H.B.; Abhilash, P.C. Sustainable Agronomic Practices for Enhancing the Soil Quality and Yield of *Cicer arietinum* L. under Diverse Agroecosystems. *J. Environ. Manag.* **2020**, *262*, 110284. [CrossRef] [PubMed]
26. Ejigu, W.; Selassie, Y.G.; Elias, E.; Damte, M. Integrated Fertilizer Application Improves Soil Properties and Maize (*Zea mays* L.) Yield on Nitisols in Northwestern Ethiopia. *Heliyon* **2021**, *7*, e06074. [CrossRef]
27. Mahanta, D.; Bhattacharyya, R.; Gopinath, K.A.; Tuti, M.D.; Jeevanandan, K.; Chandrashekara, C.; Arunkumar, R.; Mina, B.L.; Pandey, B.M.; Mishra, P.K.; et al. Influence of Farmyard Manure Application and Mineral Fertilization on Yield Sustainability, Carbon Sequestration Potential and Soil Property of Gardenpea-French Bean Cropping System in the Indian Himalayas. *Sci. Hortic.* **2013**, *164*, 414–427. [CrossRef]
28. Hernandez-Ramirez, G.; Brouder, S.; Smith, D.; Van Scoyoc, G. Nitrogen Partitioning and Utilization in Corn Cropping Systems: Rotation, N Source, and N Timing. *Eur. J. Agron.* **2011**, *34*, 190–195. [CrossRef]
29. Ochieng', I.O.; Gitari, H.I.; Mochoge, B.; Rezaei-Chiyaneh, E.; Gweyi-Onyango, J.P. Optimizing Maize Yield, Nitrogen Efficacy and Grain Protein Content under Different N Forms and Rates. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 1867–1880. [CrossRef]
30. Bedada, W.; Karltun, E.; Lemenih, M.; Tolera, M. Long-Term Addition of Compost and NP Fertilizer Increases Crop Yield and Improves Soil Quality in Experiments on Smallholder Farms. *Agric. Ecosyst. Environ.* **2014**, *195*, 193–201. [CrossRef]
31. Wang, X.; Ren, Y.; Zhang, S.; Chen, Y.; Wang, N. Applications of Organic Manure Increased Maize (*Zea mays* L.) Yield and Water Productivity in a Semi-Arid Region. *Agric. Water Manag.* **2017**, *187*, 88–98. [CrossRef]
32. Du, Y.; Cui, B.; Zhang, Q.; Wang, Z.; Sun, J.; Niu, W. Effects of Manure Fertilizer on Crop Yield and Soil Properties in China: A Meta-Analysis. *Catena* **2020**, *193*, 104617. [CrossRef]
33. Chen, W.; Oldfield, T.L.; Katsantonis, D.; Kadoglidou, K.; Wood, R.; Holden, N.M. The Socio-Economic Impacts of Introducing Circular Economy into Mediterranean Rice Production. *J. Clean. Prod.* **2019**, *218*, 273–283. [CrossRef]
34. Hasegawa, H.; Furukawa, Y.; Kimura, S.D. On-Farm Assessment of Organic Amendments Effects on Nutrient Status and Nutrient Use Efficiency of Organic Rice Fields in Northeastern Japan. *Agric. Ecosyst. Environ.* **2005**, *108*, 350–362. [CrossRef]
35. Tseng, M.L.; Chiu, A.S.F.; Chien, C.F.; Tan, R.R. Pathways and Barriers to Circularity in Food Systems. *Resour. Conserv. Recycl.* **2019**, *143*, 236–237. [CrossRef]
36. Wu, L.; Chen, X.; Cui, Z.; Zhang, W.; Zhang, F. Establishing a Regional Nitrogen Management Approach to Mitigate Greenhouse Gas Emission Intensity from Intensive Smallholder Maize Production. *PLoS ONE* **2014**, *9*, e98481. [CrossRef]