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Plant Cultivation: A Strong and Sustainable Response to CO_2 Emissions

Arnaud Muller-Feuga

AMF Conseil, Baillargues, France
Email: arnaud.muller-feuga@wanadoo.fr

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Abstract

According to the quantities of plant and animal products placed on the world market in 2022, agriculture and forestry captured 20.1 ± 1.5 billion tonnes (Gt or Pg) of CO_2, with a weighted mean duration of the corresponding storage of 10.9 ± 3.3 years. These figures are supplemented here by the unharvested above-ground and below-ground parts of plants that are left in place and increase the soil organic carbon pool. This brings the capture by cultivated whole plants to 41.0 ± 0.6 $GtCO_2$, and the storage duration weighted mean to 26.3 ± 2.0 years in 2022. This was the largest global contribution to the reduction of atmospheric CO_2 by amplitude and duration, which bio-remediated the global anthropogenic emissions totally, cancelling their influence on climate. The enrichment of the atmosphere with CO_2 comes probably from the ocean, which could be a source and not a sink. Complementary approaches, freed from doctrinal preconceptions, should make it possible to clarify further the compensations of CO_2 emissions by plants and their environmental consequences.

Keywords

Carbon, Capture, Storage Duration, Whole Plants, Ocean

1. Introduction

Accepting the postulate that carbon dioxide emissions have a negative influence on the Earth's climate, most governments have taken binding measures to reduce them, especially those resulting from the combustion of fossil fuels. To this end, they have notably established and promoted carbon capture, utilization and storage (CCS or CUSC) systems, mainly by geological burial.

In what follows, we examine the contribution of world agriculture and forestry. To do this, we distinguish between stocks and fluxes, with only the latter, which is the variation of the former, giving rise to carbon exchanges in the form of CO_2. **Table 1** lists the main global carbon stocks and fluxes as reported in the literature.

Table 1. Main global carbon stocks (GtC or PgC) and fluxes ($GtCO_2$) averaged over the period 2010-2022 and references. The + sign of the flux indicates an increase and sign a decrease of the stock.

Stock	Carbon stocks GtC	Carbon fluxes $GtCO_2/y$	References Stock - Flux
Limestone rocks	140.000.000	$+3.2 \times 10^{-5}$	(Sorokhtin et al., 2007) - (Vinos, 2022)
Inorganic ocean	39.000	+10.3	(Friedlingstein et al., 2023) - ibid.
Soils and permafrost	3.100	0.0	(Canadell et al., 2021) - ibid.
Hydrocarbons	905	−40.0	(Canadell et al., 2021) - ibid.
Atmosphere	885	+18.7	(Canadell et al., 2021) - ibid.
Organic ocean	703	0.0	(Friedlingstein et al., 2023) - ibid.
Continental vegetation	450	+12.5	(Canadell et al., 2021) - ibid.
Geological CCS	0.07	+0.7	(Global CCS Institute. 2023)- ibid.
Total	140.045.000	+2.2	

Limestone rocks are the main carbon reservoirs on the planet. Their formation and that of hydrocarbons were to the detriment of the atmosphere, which went from 7.000 to 420 ppmv in 600 million years (Godwin, 2022). This depletion is worrying because photosynthesis no longer works at low concentrations (Dippers et al., 1995). This is why Muller-Feuga (2024) recommended preferring CCS by plants to geological CCS, which is irreversible. In this article, the statement was made of the underestimation of carbon capture and storage by plants by most of the articles cited by the Intergovernmental Panel of Climate Change (IPCC). **Table 1** illustrates this since continental vegetation is only credited with 12.5 ± 3.3 $GtCO_2$/year biofixed from atmosphere, when previous author estimated it at 21 $GtCO_2$/year based on marketed products only.

One of the arguments put forward to justify this underestimation is the rapid return of carbon to the atmosphere due to a short duration of carbon storage of agricultural products. Considering this time the contribution of the non-commercial parts of the cultivated plants left on site, the approach of their capture amount and their storage duration was attempted in what follows. Only 2022 is being considered as the disruptions caused by the COVID-19 pandemic are being resolved.

2. Material and Method

The stoichiometry of the polymerization-mineralization reaction of carbon by photosynthesis and respiration predicts that the production of one ton of dry plant biomass (dm), consisting mainly of hexoses, requires 0.40 tons of carbon (C/dm = 0.40) from 1.47 tons of CO_2 (CO_2/dm = 1.47) captured in the atmosphere. The C/dm ratio was 0.25 for animal products, 0.50 for wood, 0.52 for ethanol, and 0.96 for sunflower oil. To calculate the amount of CO_2 mobilized by a biomass, it is necessary to remove the water that enters for 0% to 94% of the fresh weight, then apply the C/dm factor to the anhydrous weight to obtain the incorporated carbon, or the CO_2/dm factor to obtain the CO_2 captured in the atmosphere.

The emerged lands are cultivated to cover the needs of humanity and its livestock in food plants (cereals, vegetables, fruits, etc.), textiles (cotton, flax, hemp, etc.), pleasure plants (tobacco, grapes, flowers, etc.), heating and construction. Here, we considered the productions of agriculture and forestry that are fully and precisely reported by FAO statistics at the global level. These plant products capture and store atmospheric carbon modulated by solar energy. The carbon is stored there during the few months to a few centuries that separate the harvest from the mineralization by digestion or combustion, marking the return of carbon to the atmosphere in the form of CO_2.

The carbon storage period in agricultural and forestry products is divided between the period of capture by photosynthesis (CP) and the period of restitution by mineralization (RM). During the former period (CP), which separates the beginning of plant growth, by sowing, planting, or previous harvest ($n - 1$) and the harvest (n), the carbon pool is gradually formed by photosynthetic capture of CO_2 from atmosphere. This period lasts between a few months for annual plants and a few decades for trees. As the growth of fruits and vegetables generally presents an S shape (e.g. Tijero et al., 2021), the quantity of carbon captured over time was assumed to be distributed according to an increasing normal distribution law.

The latter period (RM) separates the harvest from mineralization by respiration or combustion with restitution of carbon to the atmosphere under the form of CO_2. During this period, organic matter is stored on shelves, in bulk, or in the soil. This period lasts between a few days for perishable fruits and vegetables and a few centuries for lumber and soils. The quantity of carbon released is assumed to be distributed over time according to a decreasing normal distribution law.

Intermediate storage in a hopper, silo or refrigerated room, during which the product is processed and packaged, sometimes precedes marketing. This intermediate storage is as short as possible to increase the economic profitability and will not be considered. The quantities of carbon mobilized in the increase of animal populations are also approached in what follows as well as their storage duration.

Since the normal distribution laws are centered, the mean and median carbon storage durations (CSD) are equal to the sum of half the maximum growth period (CP/2) and half the maximum restitution period (RM/2) according to formula (1).

$$\text{CSD} = (\text{CP} + \text{RM})/2 \tag{1}$$

The equations of the cumulative normal distribution of carbon stock with time $S(t)$ are:

$$S(t) = Sn/2 * \left(1 \pm erf\left(\left(t - n + d/2\right)/\sigma/\sqrt{2}\right)\right) \tag{2}$$

where

- t is the time in years,
- n is the harvest year,
- Sn is the carbon stock in harvest year n,

- *erf* is the error function of the centered normal distribution,
- *d* is the duration of the considered period (mean),
- σ is the camber of the curve (standard deviation).

If $t \le n$, then d is the capture period CP and the erf function is added. If $t > n$, then d is the restitution period RM and the erf function is subtracted. Figure 1 illustrates the variations of the $S(t)$ functions in a typical case according to Equations (2).

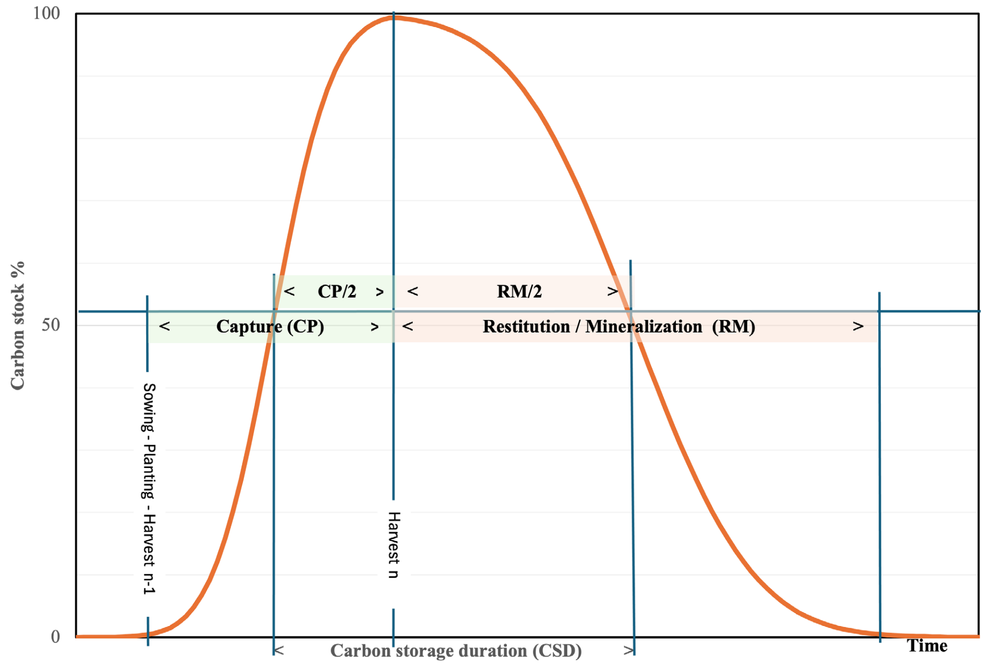

Figure 1. Theoretical variation of carbon stock expressed in % during capture by photosynthesis (CP) and restitution by mineralization (RM), and carbon storage duration (CSD).

To calculate the quantities of CO_2 stored and the duration of storage, some assumptions were made regarding water contents, protein contents, the ratio C/dm, durations of CP and RM periods, based on the most relevant data from the literature. The anhydrous weights of each biomass are determined by applying a water content to the fresh weight provided by the statistics. The CP and RM durations are assigned to each biomass, then the mean weighted by anhydrous weights are calculated for each group of biomasses. The dispersion of the results is expressed by their standard deviation. Five groups of biomasses are distinguished in a first time, then three in a second time. In each group of biomasses, our approach distinguishes the commercial products, the aerial parts and the underground parts whose sum constitutes the whole plants.

3. Results

3.1. Agricultural Plant Products

We used FAO statistics under the heading "Production", then "Crops and animal products" which specify the quantities of plant products marketed by world agriculture in 2022. To determine the carbon capture of these plant products, the anhydrous weights (dm) are obtained by multiplying the fresh weight by 1 minus the water content (dm = fresh weight * (1 - wc)). These water contents (wc) are between less than 10% for seeds and dried fruits and more than 90% for fresh fruits and vegetables.

The consumption of food products ranges from purchase on the market to the use-by date which is generally well-informed and considers storage by refrigeration and freezing which significantly extends it. For most plants, CP is in the order of a year, while RM varies with the water content of the products between a few months and a few decades. Some seeds retain their germination power for several centuries. Appendix 1 shows the global production of the 160 agricultural commodities listed by FAO. The mean CSD weighted by anhydrous products of world agricultural crops in 2022 is 9.1 ± 0.3 years, according to formula (1).

3.2. Fodder

The quantities of meat, milks and eggs consumable by humans expressed in tonnes are described in the FAO statistics "Production - Quantity" and "Primary Livestock". These products are mainly intended to supplement human food with quality proteins and a set of micronutrients and mineral salts. They result from the conversion by animals, mainly ruminants and monogastrics, of plants from meadows, foliage and crops.

According to Mottet et al. (2017), global livestock consumed 6 Gt/year of anhydrous fodder. The feed conversion rate, given the weight of anhydrous fodder per weight of animal protein, would be 80 for all species combined, according to these authors. A portion of fodder is included in the previous section of agricultural plant products. Still according to Mottet et al. (2017), 14% of the tonnage consumed by global livestock is consumable by humans, A reduction of the same amount is applied to anhydrous fodder so as not to count twice this part consumable by humans.

Appendix 2 shows the 48 global livestock products listed by the FAO. The protein levels used vary between 3.2% for milk and 32% for meat products. Anhydrous fodder is calculated by applying the conversion rate of Mottet et al. (2017). Anhydrous fodder of non-food or protein-free products such as fats, skins, waxes, honey are calculated by applying the conversion rate (dry weight of fodder/fresh weight of livestock product) obtained with protein products, i.e. 4.2.

Fodder is produced and stored for 0.8 to 3 years to await maturity and pass unproductive periods. The RM period of livestock products lasts between 40 days (eggs) and 100 years (beeswax). The mean CSD weighted by the anhydrous weights of fodder from global livestock farms is 1.2 ± 0.1 years, in accordance with formula (1), in 2022.

3.3. Forestry

Statistics on the quantities of wood produced in the world are available in the

"Forests" section of "Data" from FAO. These "Production - Quantity" of firewood, saw logs. pulpwood and industrial wood are expressed in cubic meters to be converted into anhydrous tonnes by applying a density varying between 0.49 and 0.70 depending on the nature of the wood.

Appendix 3 shows the 8 global forestry productions in 2022 and the durations of the CP and RM periods. Only the felling of standing trees was considered, excluding products made using the wood from these felling's to avoid counting them twice. The plant growth period (CP) is between 25 and 50 years. The restitution by mineralization period (RM) varies between 2 years for firewood and 3 centuries for construction timber. The mean CSD weighted by anhydrous products of global forestry calculated according to formula (1) is 31.0 ± 2.7 years in 2022.

3.4. Other Captures

Appendix 4 shows global aquaculture and fisheries products as provided for 2021 by FAO FishStatJ data. Their mean weighted CSD calculated according to formula (1) was 1.6 ± 1.0 years. These productions are an order of 10 lower than the previous ones.

A portion of the carbon in plant products does not return to the atmosphere. It remains part of the animal biomasses, livestock and humanity that feed on it and contribute to the weight increase described in Appendix 5. The mean weighted CSD is 9.5 ± 0.7 years.

4. Discussion

4.1. Commercial Products

Table 2 summarizes the calculation elements depicted in Appendix 1 to 5. Considering only the commercial products, the main global contributions to atmospheric carbon capture by photosynthesis were agriculture (forages and crops) and forestry in 2022.

Table 2. Dry weights of world commercial products of cultivated plants from agriculture and forestry, fisheries and aquaculture and mobilized by the increase in animal populations (FAO, n.d.), CO_2/dm ratios, CO_2 captures, and mean durations of carbon storage weighted by dry weights, in 2022.

Carbon capture	Dry weights (dm) Gt/y	CO_2/dm	Capture $GtCO_2$/y	CP/2 y	RM/2 y	CSD y
Fodder	5.44 ± 0.3	1.47	8.0 ± 0.4	0.8	0.4	1.2 ± 0.1
Crops	5.17 ± 0.1	1.47	7.6 ± 0.2	0.4	8.6	9.1 ± 0.3
Forestry	2.49 ± 0.4	1.83	4.6 ± 0.7	18.8	12.2	31.0 ± 0.3
Aquatic products	0.05 ± 0.02	1.10	0.1 ± 0,03	1.4	0.3	1.6 ± 1.0
Animal populations increase	0.02 ± 0.01	0.93	0.02 ± 0.01	0.0	9.5	9.5 ± 0.7
Total	13.16 ± 0.2		20.1 ± 0.3	4.0	5.9	9.9 ± 0.2

Storage durations (CSD) of commercial products are derived from the analysis of FAO statistics to which CP and RM durations were assigned, ranging from a few days for fresh vegetables to 300 years for construction timber. The mean CSD weighted by anhydrous commercial productions of agriculture and forestry was 9.9 ± 0.2 years in 2022. The minor captures (Appendix 4 and 5) were below the precision of the calculation and not considered further.

4.2. Whole Plants

The figures in **Table 2** do not include non-commercial plant biomass such as leaves and stems for the aerial part, and roots and exudates for the buried part. These non-commercial aerial and buried parts most often remain on site and enrich the soil with organic carbon.

Unlike the commercial parts, the above and below-ground parts of crops are not included in statistics, having no commercial value. The former part was subject of evaluation in what follows using the harvest index HI, which is the ratio of biomass of the commercial part harvested to the aerial part of the whole plant. This index is on average 0.42 (Hay, 1995) for the three main crops (maize, wheat, rice) which alone provide half of the world's agricultural production (see Appendix 1). The 157 other crops listed by the FAO have HIs which vary with the cultivar and the climate-edaphic conditions in such proportions that an average is difficult to determine. This other half of world production would merit an in-depth examination species by species. However, if we assume that the same average HI is applicable to this other half, the total capture of aerial parts of global crops would have been in this case 12.1 ± 0.3 $GtCO_2$/year (**Table 3**). For the products of forestry, we took an HI of 0.8.

Table 3. Means of CO_2 captures, weighted by anhydrous productions of global agricultural and forestry, by non-commercial parts, and whole plants in 2022.

Carbon capture	Above ground parts $GtCO_2$/y	Below ground parts $GtCO_2$/y	Whole plants $GtCO_2$/y
Crops	11.0 ± 0.6	2.8 ± 1.2	21.3 ± 0.4
Fodders	0.0	5.2 ± 1.7	13.2 ± 1.2
Forestry	1.2 ± 0.4	0.8 ± 0.3	6.6 ± 0.03
Total	12.1 ± 0.3	8.8 ± 0.7	41.0 ± 0.6

The below-ground parts are more difficult to assess as they are invisible and rarely quantified. According to Blume et al. (2015), the root system represents 10% to 20% of the total biomass of a tree, 10% to 50% of the biomass of cultivated plants and 50% to 80% of grassland plants. The aerial parts of fodder are counted among the commercial products. The return to the soil in the form of excrement was neglected, minimizing the estimate. Under these conditions, **Table 3** shows the distribution of CO_2 capture and storage in the two non-commercial parts of cultivated terrestrial plants, and the sum of the commercial and non-commercial parts (whole plants).

According to this calculation, capture by whole plants have reached 41.0 ± 0.6 $GtCO_2$ in 2022, which is twice that of commercial products alone. This figure is an understatement because it does not include the share of non-commercially exploited plant covers, whose contribution is still to specify. Unexploited continental vegetation is stable and plays a marginal role in capturing atmospheric carbon. Should unmanaged forests still capture carbon, they do so at levels much lower than most crops, which FAO mean double yield weighted by dry weights of the products is set at 19.5 ± 0.7 tCO_2/ha/y. For example, current logging regulations in Brazil adopt a standard post-harvesting recovery rate of 0.86 m^3/ha/y (Vidal et al., 2020), which captures 0.9 tCO_2/ha/y. It should be noted here that, contrary to popular belief, forest cutting and burning do not result in a loss of capacity to store and capture CO_2. The soil stock remains in place while spontaneous or replanted regrowth continues to capture to ensure tree growth before new cuttings 25 to 35 years later. If the forest is replaced by pastures or crops, the space it frees up captures CO_2 at much higher levels.

The capture we obtained represented 1.3% of total atmospheric CO_2, 3.2 times the continental sink of Friedlingstein et al. (2022) at 12.8 ± 3.3 $GtCO_2$/y, and 2.1 times that of Pan et al. (2024) at 19.8 $GtCO_2$/y. It also represented four times the oceanic sink estimated by Fay et al. (2023) at 10.3 ± 0.4 $GtCO_2$/y. Above all, it compensated the total anthropogenic emissions estimated at 41.46 $GtCO_2$ in 2022, including 37.15 $GtCO_2$ by energy and industrial combustion of fossil hydrocarbons (Ritchie & Roser, 2024; data from Global Carbon Budget). The difference between these last figures is attributed to non-fossil emissions by mineralization of plant products and by consumption of fossil products other than energy, especially for fertilizers. Even if we attribute all those additional emissions (4.3 $GtCO_2$, Land Use Change) to plant cultivation, its net balance will remain largely positive with 36.7 $GtCO_2$/y removed from the atmosphere.

Our figure was significantly higher than those cited by the IPCC according to which the continental sink would be between 10 and 20 GtCO2/y (Amthor & Baldocchi, 2001; Beer et al., 2010; Ciais et al., 2013; Dusenge et al., 2018; Friedlingstein et al., 2023), and we have tried to understand why such a difference. The figures cited by the IPCC are constructed from field surveys describing carbon fluxes per unit of surface area and time, then extended to the global surfaces of the different plant covers by dynamic models. These covers are forests (tropical, temperate, boreal), tundras, Mediterranean scrubs, crops, savannas, tropical pastures, temperate pastures, and deserts. The surface capture is between 3.7 (deserts) and 43.1 (tropical forest) tCO_2/ha/y (Saugier et al., 2001). The share of forests was greatly overestimated, while that of crops, credited with only 10.1 tCO_2/ha/year, was significantly less than the FAO mean crop yield seen above. The capture of old-growth unexploited forests was subject to debate revealing the difficulty of its evaluation (Luyssaert et al., 2008; Gundersen et al., 2021; Luyssaert et al., 2021).

The difference between our approach, relying on the chemical composition of the marketed products described by FAO statistics, and that of the authors cited by the IPCC, based on field measures of carbon fluxes extended to cover surfaces, resulted in a four times lower capture of the latter. It seems that this approach comes up against problems of representativeness of the sampling of each plant cover, which surface was defined by satellite remote sensing. In our case, the sampling is extended to all commercialized plants, to which should be added the share of unexploited plants if significant.

4.3. Storage Duration

The soil carbon pool is made up of the non-commercialized aerial parts remaining on site and the below-ground parts after harvest. The CSD of these necromasses correspond to the average residence time of carbon before mineralization by decomposing organisms, erosion and leaching. An annual crop cycle benefits from the carbon stocks already present in the soils which are partly consumed. The additional storage of successive annual cycles makes it possible to stabilize the carbon pool towards an equilibrium. It is this equilibrium that we have tried to render by choosing the retention times from the literature. For forests, the retention times varied between 0.9 and 152 years (Wang et al., 2017). They increased with latitude (x4) and decreased with temperature (x10) and precipitation (x4). Temperate regions achieve a compromise between high and low latitudes. Also, an average residence time of 40 years (Balesdent & Recous, 1997; Pellerin et al., 2019) for the soils of crops and meadows, and of 75 years for those of exploited forests were retained (**Table 4**). Assuming a normal distribution of mineralization over time, these durations were divided by 2, in accordance with formula (1).

Table 4. Carbon storage durations during photosynthetic capture (CP), during restitution by mineralization (RM), and total carbon storage duration (CSD) for whole plants (means weighted by anhydrous weights of products).

Carbon capture	CP/2 y	RM/2 y	CSD whole plants y
Fodders	0.8 ± 1.0	20.0 ± 1.0	20.8 ± 1.0
Crops	0.4 ± 0.6	20.0 ± 0.6	20.4 ± 0.6
Forestry	18.8 ± 4.9	37.5 ± 4.9	56.3 ± 4.9
Weighted mean	3.5 ± 1.6	22.8 ± 2.4	26.3 ± 2.0

Since the capture duration CP cannot be shorter for whole plants than for commercial products, we have taken the same duration as the latter in the following.

Figure 2 shows how were distributed over time the atmospheric CO_2 absorption and restitution by products and whole plants of agriculture and forestry harvested in 2022 according to Equation (2) and their argument values depicted in **Table 5**.

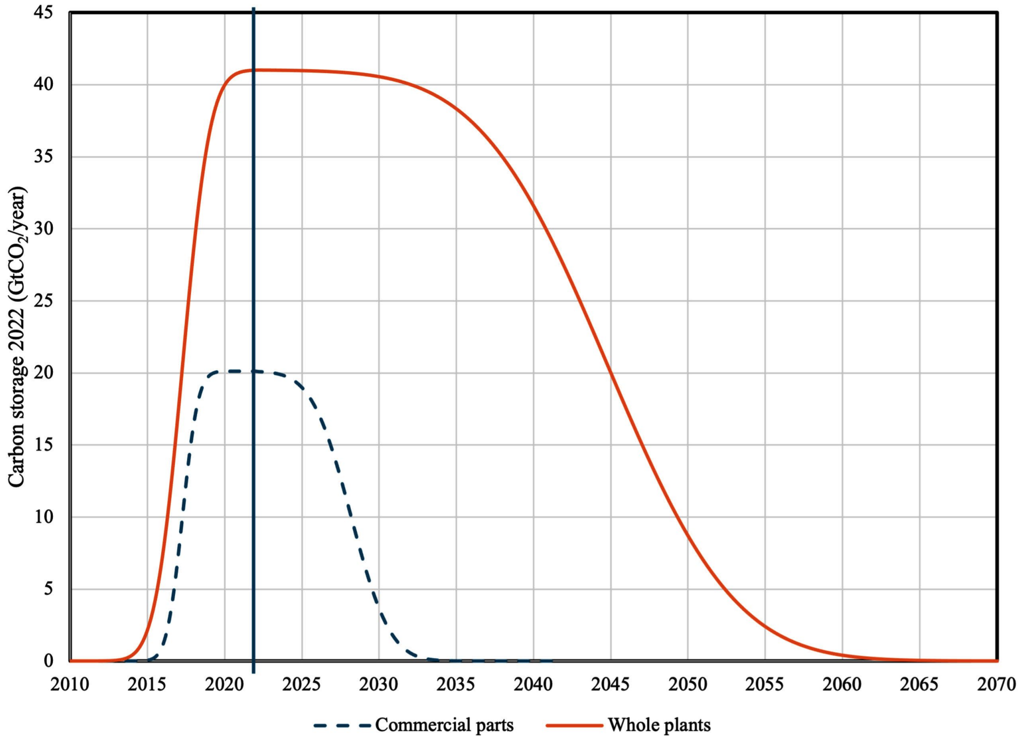

Figure 2. Variations over time of CO_2 captured and then released by cultivated whole plants (solid line, red) and their commercial products (dotted line, blue) harvested in 2022 ($GtCO_2$/year).

Table 5. Argument values of Equations (2) illustrated by **Figure 2** for harvest year 2022 (n = 2022).

Argument	Notation	Commercial parts		Whole plants	
		$t \leq n$	$t > n$	$t \leq n$	$t > n$
CO_2 captured ($GtCO_2$/y)	S_n	20.12	20.12	41.02	41.02
Cambers	σ	0.8	2.0	1.4	6.5
CP/2, RM/2 (y)	d	4.73	6.18	4,73	22.80

Should all the years after 2022 be identical to it, then successive carbon captures and storages would constitute a stock of 294 GtC by biofixation of 1.078 $GtCO_2$ from atmosphere (or CSD times the whole plant capture of 2022 harvest), in addition to the pre-existing one, after 26.3 years (or CSD years) and which remains at this level thereafter. This is of the order of magnitude of the stocks of continental vegetation alone, without those of soils and permafrosts, of Canadell et al., 2021, (see **Table 1**). By going back further into the last century, it would be possible to quantify the carbon stocks of whole cultivated plants that have been built up since then.

5. Conclusion

Here, we attempt to clarify the contribution of cultivated whole plants to the consumption of atmospheric CO_2 with a margin of uncertainty relating to both quantities stored and retention times. When some doubts arose, we retained the hypotheses minimizing both. This is a delicate exercise due to the diversity of the factors involved, which were chosen in the literature among the most relevant. Subject to the accuracy and completeness of those factors and of the FAO statistics, capture by plant and animal products placed on the market represented 20.1 ± 1.5 $GtCO_2$ in 2022. Taking into additional account the biomass left on site during these productions brings this capture to 41.0 ± 0.6 $GtCO_2$/year, which significantly increased the contribution of cultivated plants. These figures need to be refined and completed by their evolution in time and space, but they describe major trends. They reveal the outstanding contribution of agriculture and forestry, which is not considered at its fair value, their share being systematically minimized when not presented as net emitting. These activities mobilize atmospheric CO_2 at levels that make them by far the main carbon capture and storage system in the hands of Man, without him having to change his practices to achieve this result. In addition, they allow the return to the atmosphere of this gas crucial for the planetary ecosystem, unlike geological CCS.

Therefore, it is not the anthropogenic fossil emissions that are responsible for the increase in atmospheric CO_2 since they were entirely bio-remediated by the capture of cultivated plants. This calls into question their much-criticized influence on climate change and destroys the foundations of the emission reduction politics conducted by international organizations et retained by governments.

Then what are the real sources responsible for atmospheric CO_2 increase by 18.7 $GtCO_2$/year (2.5 ppm/year)? To provide such quantities, the only other possible source is the ocean, which would not be a sink, as presented in many works, but a source. We had highlighted the seasonal versatility of the ocean, and its sink-source alternation linked to oscillations in atmospheric CO_2 content as measured at Mount Mauna Loa (Muller-Feuga, 2023). Ocean degassing is reportedly underway.

It also follows from our calculation that the mean duration of carbon storage by cultivated plants, estimated at more than a quarter of a century, is substantial and greater than expected. With such large captures and such long storage times, the lack of attention paid to agriculture and forestry by international bodies and governments is not explicable. These ancestral activities that feed, warm, delight and clothe Man are based on photosynthesis to which we owe life, and which remains the simplest and most effective means of capturing and storing atmospheric CO_2.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix 1. Crops

World plant productions from agriculture in 2022 (FAO, n.d.), capture-photosynthetic period (CP) duration, restitution by mineralization period (RM) duration of crops products and share of total production, sorted by decreasing dry weight. Water contents are taken from several sources including https://feedtables.com and https://www.lanutrition.fr.

Product	Fresh weigth (tonnes)	Water content %	Dry weight (Mt)	CP (y)	RM (y)	Share%
Maize (corn)	1,163,497,383	13.7	1004.1	0.8	20	19.4
Wheat	808,441,568	13.1	702.5	0.8	20	13.6
Rice	776,461,457	12	683.3	0.8	20	13.2
Sugar cane	1,922,059,851	70	576.6	1.0	40	11.2
Oil palm fruit	424,587,460	0.1	424.2	0.8	5	8.2
Soya beans	348,856,427	10.5	312.2	0.8	10	6
Barley	154,877,140	12.8	135.1	0.8	20	2.6
Cassava. fresh	330,408,754	59.7	133.2	0.8	0.5	2.6
Potatoes	374,777,763	78.3	81.3	1.0	0.5	1.6
Rape or colza seed	87,221,221	12	76.8	0.8	20	1.5
Other vegetables. fresh n.e.c.	297,995,825	75	74.5	0.8	0	1.4
Seed cotton. unginned	69,668,143	8	64.1	0.8	20	1.2
Sorghum	57,581,943	12.2	50.6	0.8	20	1
Sunflower seed	54,285,949	7.2	50.4	0.8	20	1
Groundnuts, excluding shelled	54,238,560	12	47.7	0.8	1	0.9
Sugar beet	260,998,614	83.9	42	0.8	40	0.8
Coconuts, in shell	62,409,431	45	34.3	1.0	10	0.7
Bananas	135,112,326	75.8	32.7	0.8	0.3	0.6
Millet	30,859,664	10.4	27.7	0.8	0.5	0.5
Beans, dry	28,346,199	10.1	25.5	0.8	10	0.5
Oats	26,385,330	12.4	23.1	0.8	20	0.4
Tea leaves	29,760,668	25	22.3	0.8	5	0.4
Yams	88,257,159	75	22.1	0.8	0.1	0.4
Other beans, green	23,340,916	11.1	20.8	0.8	0	0.4
Sweet potatoes	86,410,355	78.3	18.8	0.8	1	0.4
Chillies and peppers, green (Capsicum spp. and Pimenta spp.)	36,972,494	50	18.5	0.8	0.2	0.4
Peas, green	20,945,189	12.8	18.3	0.8	0.1	0.4

Continued

Onions and shallots, dry (excluding dehydrated)	110,616,270	83.9	17.8	0.8	5	0.3
Chick peas, dry	18,095,248	12.7	15.8	0.8	20	0.3
Eggplants (aubergines)	59,312,600	75	14.8	0.8	0	0.3
Plantains and cooking bananas	44,150,813	67	14.6	0.8	1	0.3
Apples	95,835,965	85	14.4	1.0	0.5	0.3
Grapes	74,942,573	81	14.2	1.0	0	0.3
Peas, dry	14,166,030	12	12.5	0.8	20	0.2
Triticale	14,157,881	13.2	12.3	0.8	20	0.2
Natural rubber in primary forms	15,125,393	20	12.1	0.8	5	0.2
Mushrooms and truffles	48,335,996	75	12.1	1.0	0	0.2
Rye	13,143,055	12	11.6	0.8	20	0.2
Tomatoes	186,107,972	94	11.2	0.8	0	0.2
Olives	21,449,868	50	10.7	1.0	5	0.2
Carrots and turnips	42,233,350	75	10.6	0.8	0.2	0.2
Mangoes, guavas and mangosteens	59,151,823	83	10.1	1.0	0.1	0.2
Watermelons	99,957,595	90	10	0.8	0.1	0.2
Other fruits, n.e.c.	38,200,106	75	9.6	1.0	0.1	0.2
Cucumbers and gherkins	94,718,397	90	9.5	0.8	0	0.2
Coffee, green	10,782,334	20	8.6	0.8	0.2	0.2
Cow peas, dry	9,774,866	12	8.6	0.8	20	0.2
Spinach	33,116,288	75	8.3	0.8	0	0.2
Oranges	76,410,037	90	7.6	1.0	0.1	0.1
Cereals n.e.c.	8,713,290	13.2	7.6	0.8	20	0.1
Pineapples	29,361,138	75	7.3	0.8	0	0.1
Green garlic	29,149,438	75	7.3	0.8	0.1	0.1
Other tropical fruits, n.e.c.	28,359,402	75	7.1	0.8	0.1	0.1
Lettuce and chicory	27,149,446	75	6.8	0.8	0	0.1
Sesame seed	6,741,479	12	5.9	0.8	20	0.1
Lentils, dry	6,655,828	11.6	5.9	0.8	20	0.1
Broad beans and horse beans, dry	6,144,395	12	5.4	0.8	20	0.1
Cocoa beans	5,874,582	12	5.2	0.8	0.2	0.1
Cabbages	72,603,755	93	5.1	0.8	0	0.1
Dates	9,747,570	50	4.9	0.8	0.1	0.1
Pigeon peas, dry	5,326,932	12	4.7	0.8	20	0.1

Continued

Taro	17,718,129	75	4.4	0.8	0.5	0.1
Tangerines, mandarins, clementines	44,179,831	90	4.4	1.0	0	0.1
Other pulses n.e.c.	4,904,918	12	4.3	0.8	0	0.1
Pears	26,324,874	84	4.2	1.0	0.5	0.1
Chillies and peppers, dry (Capsicum spp., Pimenta spp.), raw	4,909,321	25	3.7	0.8	1	0.1
Linseed	3,973,932	8	3.7	0.8	20	0.1
Walnuts, in shell	3,874,025	12	3.4	1.0	0.5	0.1
Cashew nuts, in shell	3,852,868	12	3.4	0.8	0.5	0.1
Almonds, in shell	3,630,428	12	3.2	1.0	0.5	0.1
Jute, raw or retted	3,503,448	12	3.1	0.8	20	0.1
Cantaloupes and other melons	28,558,069	90	2.9	1.0	0	0.1
Okra	11,232,656	75	2.8	0.8	0.2	0.1
Peaches and nectarines	26,354,497	90	2.6	1.0	0.1	0.1
Plums and sloes	12,391,467	80	2.5	1.0	0	0
Green corn (maize)	9,868,461	75	2.5	1.0	0.5	0
Other stimulant, spice and aromatic crops, n.e.c.	3,172,095	25	2.4	0.8	1	0
Unmanufactured tobacco	5,780,940	60	2.3	1.0	5	0
Pumpkins, squash and gourds	22,806,321	90	2.3	0.8	0	0
Avocados	8,978,275	75	2.2	1.0	0	0
Areca nuts	2,542,072	12	2.2	0.8	1	0
Edible roots and tubers with high starch or inulin content, n.e.c., fresh	8,877,780	75	2.2	0.8	0.2	0
Asparagus	8,824,150	75	2.2	1.0	0	0
Lemons and limes	21,529,604	90	2.2	1.0	0.2	0
Anise, badian, coriander, cumin, caraway, fennel and juniper berries, raw	2,751,010	25	2.1	0.8	0.5	0
Other oil seeds, n.e.c.	2,527,518	20	2	0.8	0.5	0
Buckwheat	2,235,193	12	2	1.0	20	0
Mixed grain	2,223,144	12	2	0.8	20	0
Cauliflowers and broccoli	26,058,228	93	1.8	0.8	0	0
Coir, raw	1,939,430	12	1.7	0.8	20	0
Castor oil seeds	1,829,522	12	1.6	0.8	20	0
Chestnuts, in shell	2,131,241	25	1.6	1.0	1	0
Papayas	13,822,328	89.4	1.5	1.0	0.1	0
Other citrus fruit, n.e.c.	14,422,194	90	1.4	1.0	0.1	0

Continued

Onions and shallots, green	4,970,615	75	1.2	0.8	0.1	0
Lupins	1,644,691	25	1.2	0.8	0.1	0
Broad beans and horse beans, green	1,642,153	25	1.2	0.8	0.2	0
Ginger, raw	4,874,216	75	1.2	0.8	0.2	0
Cashewapple	1,329,862	12	1.2	0.8	20	0
Kiwi fruit	4,539,471	75	1.1	1.0	0.1	0
Pomelos and grapefruits	9,761,755	90	1	1.0	0.1	0
Strawberries	9,569,865	90	1	0.8	0	0
Pistachios, in shell	1,026,803	12	0.9	1.0	20	0
Hazelnuts, in shell	1,195,732	25	0.9	1.0	0.5	0
Persimmons	4,436,475	80	0.9	1.0	0.1	0
Other nuts (excluding wild edible nuts and groundnuts), in shell, n.e.c.	1,051,017	25	0.8	0.8	1	0
Tallowtree seeds	1,038,671	25	0.8	0.8	20	0
Apricots	3,863,180	80	0.8	1.0	0	0
Safflower seed	995,508	25	0.7	0.8	1	0
Melonseed	968,692	25	0.7	0.8	20	0
Pepper (Piper spp.), raw	812,674	12	0.7	0.8	20	0
Maté leaves	1,653,167	60	0.7	1.0	5	0
Mustard seed	852,808	25	0.6	0.8	20	0
Karite nuts (sheanuts)	815,825	25	0.6	0.8	10	0
Fonio	658,708	12	0.6	0.8	10	0
Cherries	2,765,827	80	0.6	0.8	0.1	0
Leeks and other alliaceous vegetables	2,109,066	75	0.5	1.0	0	0
Vetches	684,264	25	0.5	0.8	0.2	0
Artichokes	1,584,514	75	0.4	1.0	0	0
Yautia	396,407	12	0.3	1.0	0	0
Tung nuts	453,685	25	0.3	0.8	1	0
Sour cherries	1,593,025	80	0.3	1.0	0	0
Blueberries	1,228,596	75	0.3	1.0	0.1	0
String beans	1,375,584	80	0.3	0.8	0.1	0
Other berries and fruits of the genus vaccinium n.e.c.	1,021,643	75	0.3	0.8	1	0
Kola nuts	315,024	25	0.2	0.8	20	0
Figs	1,242,449	82	0.2	1.0	0.1	0
Flax, raw or retted	875,995	75	0.2	0.8	20	0

Continued

Other sugar crops n.e.c.	872,416	75	0.2	0.8	40	0
Canary seed	245,568	12	0.2	0.8	20	0
Kapok fruit	283,287	25	0.2	0.8	0.2	0
Cinnamon and cinnamon-tree flowers, raw	222,524	12	0.2	0.8	1	0
Currants	764,499	75	0.2	1.0	0	0
Bambara beans, dry	246,511	24	0.2	0.8	20	0
True hemp, raw or retted	247,064	25	0.2	1.0	0.2	0
Quinces	702,015	75	0.2	0.8	0.1	0
Kenaf, and other textile bast fibres, raw or retted	224,926	24	0.2	0.8	20	0
Sisal, raw	213,305	24	0.2	1.0	20	0
Cloves (whole stems), raw	183,452	12	0.2	0.8	20	0
Cranberries	582,924	75	0.1	0.8	1	0
Quinoa	158,985	12	0.1	0.8	10	0
Other fibre crops, raw, n.e.c.	554,146	75	0.1	1.0	0.1	0
Other stone fruits	615,695	80	0.1	0.8	1	0
Nutmeg, mace, cardamoms, raw	138,888	12	0.1	1.0	0.1	0
Hop cones	158,545	24	0.1	0.8	0	0
Carribean sprout	396,407	75	0.1	0.8	0	0
Raspberries	947,852	90	0.1	1.0	0	0
Abaca, manila hemp, raw	107,495	24	0.1	0.8	20	0
Brazil nuts, in shell	79,278	12	0.1	0.8	0.5	0
Agave fibres, raw, n.e.c.	40,639	12	0.04	0.8	20	0
Hempseed	42,267	24	0.03	1.0	20	0
Other pome fruits	129,481	80	0.03	1.0	0.2	0
Chicory roots	32,662	24	0.02	0.8	0.2	0
Gooseberries	95,425	80	0.02	1.0	0	0
Poppy seed	14,857	12	0.01	0.8	1	0
Peppermint, spearmint	51,081	75	0.01	0.8	0	0
Locust beans (carobs)	56,423	80	0.01	1.0	0	0
Vanilla, raw	7704	24	0.01	0.8	1	0
Ramie, raw or retted	7625	24	0.01	0.8	20	0
Pyrethrum, dried flowers	5049	12	0.004	0.8	1	0
Jojoba seeds	147	12	0.0001	0.8	20	0
Total	9609.9		5165.8			100

Appendix 2. Fodder

Anhydrous fodder consumed by global animal production in 2022 (FAO, n.d.) capture-photosynthetic period (CP), restitution by mineralization period (RM) of livestock products and share of total production, sorted by decreasing dry fodder weight. The protein contents were taken from https://www.la-viande.fr/nutrition-sante.

Product	Fresh weight (t)	Protein content %	Dry fodder (Mt)	CP (y)	RM (y)	Share %
Meat of chickens, fresh or chilled	123,631,335	30	1453.9	0.8	0.5	21.1
Meat of pig with the bone, fresh or chilled	122,585,397	30	1441.6	2	0.5	20.9
Raw milk of cattle	753,320,578	3.2	945	1	0.5	13.3
Meat of cattle with the bone, fresh or chilled	69,346,116	32	869.9	3	0.5	11.9
Hen eggs in shell, fresh	86,999,551	12.7	433.1	0.8	0	14.9
Raw milk of buffalo	143,573,178	4.8	267.3	1	0.5	2.5
Meat of sheep, fresh or chilled	10,272,315	30	120.8	2	0.5	1.8
Edible offal of cattle, fresh, chilled or frozen	9,570,874	25	93.8	3	0.5	1.6
Edible offal of pigs, fresh, chilled or frozen	8,013,905	25	78.5	2	0.5	1.4
Meat of buffalo, fresh or chilled	6,903,484	25	67.7	3	0.5	1.2
Meat of goat, fresh or chilled	6,367,497	25	62.4	2	0.5	1.1
Meat of ducks, fresh or chilled	6,068,757	25	59.5	0.8	0.5	1
Fat of pigs	11,125,681	0	47.1	0.8	10	0.8
Meat of turkeys, fresh or chilled	5,081,498	25	49.8	0.8	0.5	0.9
Meat of geese, fresh or chilled	4,418,972	25	43.3	0.8	0.5	0.8
Raw hides and skins of cattle	8,698,960	0	36.8	0.8	10	0.6
Raw milk of goats	19,191,573	4.3	32	1	0.5	0.3
Eggs from other birds in shell, fresh, n.e.c.	6,171,896	12.7	30.7	0.8	0	1.1
Raw milk of sheep	10,093,016	5.8	22.7	1	0.5	0.2
Game meat, fresh, chilled or frozen	2,032,707	25	19.9	2	0.5	0.3
Edible offal of sheep, fresh, chilled or frozen	1,823,000	25	17.9	1	0.5	0.3
Cattle fat, unrendered	3,392,343	0	14.4	0.8	10	0.2
Other meat n.e.c. (excluding mammals), fresh, chilled or frozen	1,563,630	25	15.3	0.8	0.5	0.3
Edible offal of goat, fresh, chilled or frozen	1,260,496	25	12.4	1	0.5	0.2
Edible offal of buffalo, fresh, chilled or frozen	1,173,340	25	11.5	3	0.5	0.2
Raw hides and skins of sheep or lambs	1,981,013	0	8.4	0.8	10	0.1
Natural honey	1,830,768	0	7.7	0.8	100	0.1
Shorn wool, greasy, including fleece-washed shorn wool	1,759,760	0	7.4	0.8	10	0.1
Horse meat, fresh or chilled	775,543	25	7.6	4	0.5	0.1
Meat of rabbits and hares, fresh or chilled	756,476	25	7.4	0.8	0.5	0.1

Continued

Raw hides and skins of buffaloes	1,409,455	0	6	0.8	10	0.1
Raw hides and skins of goats or kids	1,267,834	0	5.4	0.8	10	0.1
Meat of camels, fresh or chilled	604,530	25	5.9	3	0.5	0.1
Raw milk of camel	4,116,669	3.4	5.5	1	0.5	0.1
Sheep fat, unrendered	576,409	0	2.4	0.8	10	0
Buffalo fat, unrendered	416,812	0	1.8	0.8	10	0
Silk-worm cocoons suitable for reeling	414,788	0	1.8	0	2	0
Goat fat, unrendered	256,756	0	1.1	0.8	10	0
Meat of asses, fresh or chilled	104,305	25	1	3	0.5	0
Edible offals of horses and other equines, fresh, chilled or frozen	99,085	25	1	3	0.5	0
Edible offals of camels and other camelids, fresh, chilled or frozen	88,365	25	0.9	3	0.5	0
Beeswax	65,063	0	0.3	0	100	0
Meat of other domestic camelids, fresh or chilled	33,135	25	0.3	3	0.5	0
Snails, fresh, chilled, frozen, dried, salted or in brine, except sea snails	20,799	25	0.2	0.8	0.5	0
Meat of other domestic rodents, fresh or chilled	18,701	25	0.2	0.8	0.5	0
Meat of pigeons and other birds n.e.c., fresh, chilled or frozen	18,669	25	0.2	0.8	0.5	0
Fat of camels	27,655	0	0.1	0.8	20	0
Meat of mules, fresh or chilled	13,839	25	0.1	4	0.5	0
Total	1,439,336,530		6319.9			100

Appendix 3. Forestry Products

World forestry anhydrous production in 2022 (FAO, n.d.), capture-photosynthetic period (CP), restitution by mineralization period (RM) of forestry products and share of total production, sorted in order of decreasing dry weight. Densities distinguished non-coniferous and coniferous trees, at 0.7 and 0.49 t/m^3 respectively.

Product	Mm^3	Density (t/m^3)	Dry weight (Mt)	CP (y)	RM (y)	Share %
Wood fuel, non-coniferous	1725	0.70	1208	35	2	48
Sawlogs and veneer logs, coniferous	760	0.49	372	25	30	15
Sawlogs and veneer logs, non-coniferous	382	0.70	268	50	30	11
Pulpwood, round and split, non-coniferous (production)	355	0.70	249	50	30	10
Pulpwood, round and split, coniferous (production)	360	0.49	177	50	30	7
Wood fuel, coniferous	242	0.49	119	25	2	5
Other industrial roundwood, non-coniferous (production)	115	0.70	80	50	300	3
Other industrial roundwood, coniferous (production)	43	0.49	21	25	100	1
Total	3983		2 493	37.6	24.4	100

Appendix 4. Aquatic Products

World anhydrous fisheries and aquaculture production in 2021 (FAO, 2024), capture-photosynthetic period (CP), restitution by mineralization period (RM) of aquatic products and share of total production.

Product	Fresh weight (Mt)	Water content %	Dry weight (Mt)	CP (y)	RM (y)	Share %
Algae	36.34	85	5.5	1	0.5	12
Animals	182.10	78	40.1	3	0.5	88
Total	218		46	2.8	0.5	100

Appendix 5. Increase in Animal Populations

Unlike the previous cases, there is no CP, this having already been included in fodder production. The CSD is equal to the mean longevity weighted by the anhydrous weights of the livestock divided by 2 since it is intended for human consumption. For humanity, the restitution by mineralization period is taken equal to life expectancy at birth, i.e. 72 years according to the World Bank. We divided it by 2 to consider the renewal of the carbon pool during life.

Population increase	Fresh weight (Mt)	Water content %	Dry weight (Mt)	CP (y)	RM (y)	Share %
Livestock (mean 2020-2022)	23.8	73.1	17.4	0.0	10.0	85.5
Humanity (mean 2020-2022)	4.0	73.1	2.9	0.0	72.0	14.5
Total	28		20	0.0	19.0	100