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Climate change, Increased yields in 1961-2020, Reduction of fertilizers and liming agents, Weathering and Carbon binding and Reduction of loss of bound carbon via reduction of liming agents approximated in Finland during 1981–2020

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ABSTRACT

Since the 1980's fertilization decreased and yields increased in Finland. The phenomenon was explained by silicate dissolution. This study is based on old data and describes determination/approximation of Ca, Mg, K, N, P and C (carbon) supply from fertilizers and limes (f) in 1961-2020 by 5-year means (5ym). Soil values (5ym) are shown by their central year. Indicator of yields "COMB" is formed from weighted annual yields per hectare of grain (GR) and potatoes (POT) by their energy content. In the first half of the 1980's the climate begun warming. After that fertilization was reduced, yields and pH continued increasing.

The total supply (including weathering) of main cations [X.tot] was estimated by [COMB]: [X.tot.i]=COMB.i/COMB.83*[X.f.83] (83=1983). Determination of periodical weathering [X.we]=[X.tot–[X.f]+[X.le], le: leaching. 17.5 kg/a was given for each [X.le]. Sum.[X.we].(1983-2018)/35 shows mean annual amounts of weathered elements. Molar ratios and C/X ratio in dissolution reactions were used for determination of bound carbon. Carbon saved via limes was calculated by reduction of lime consumption.

Results: Increased temperature was associated with increased fertility. Carbon binding via dissolution of silicates and reduction via reduced use of limes diminished atmospheric carbon approximately 60 kg/ha/a, produced Ca, Mg, K and silicon (Si), [Si(OH)4] in soluble form, as well as basic anions. In 1961–2020 COMB complied with equivalent ratio of fertilizers [Mg+N]/[Ca+K+P] (Pearson +0.94) and equally with equivalent sum of (Ca+Mg+K) in soil, concerning 5ym values.

Conclusions: Climate change in 1983-2018 correlated with increasing temperature, increase of soil weathering, carbon binding, liberation of nutrients and structural elements, yields, soil pH, decrease of liming agents and fertilizers counteracting phenomena causing carbon loss. Periods before 1983 and after 2018 are discussed.

Keywords: Weathering; Climate Change; Carbon; Silicates; Fertilization; Soil Supply

Abbreviations: 5ym: 5-Year Mean; a: Anno (year); CaMgNPK (in the can be Used Later): Combination of (Ca, Mg, N, K and P) for Sums and Means; (f): Fertilizer -Here as Synonym for (fm): Mineral Fertilizer – Including Limes; FU : Feed Unit (7.72 MJ); µ: Mean, e.g. µ.(NPK): Mean of N, P and K; (s): Soil; ∑: Sum, e.g. [∑.(NPK).f] = [(N+P+K).f]; [x]: Brackets can be Used for Clarity

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Introduction

Several harmful effects have been seen shown to be associated with climate change, global warming and increase of atmospheric CO_2 caused by human interventions during the last decades [1]. Longer perspectives are not so often represented [2]. The annual growth of Nordic pines varied on average by periodicities of 88 years. With collected specimens has been formed Finnish timberline pine chronology, FTPC [2,3]. Since the 1980's fertilization decreased and yields increased in Finland and West-Europe. The phenomenon was described earlier without soil or climate parameters [4].

This study represents (partially approximated) consumption of fertilizers (f) and by acid ammonium acetate (AAc) determined soluble Ca, Mg, K and P contents and pH of Finnish agricultural soils Associations of yield-index are compared with fertilization, soil fertility indicators and temperature in 1961–2020. The quantities of weathered nutrients are roughly approximated by the increase of yields during 1981-2020, when the use of fertilizers was reduced. This study is based on old data, which are represented by 5-year means (5ym).

Material and Methods

Amounts of fertilizers and "soil improvement materials" as limes, (liming agents) are published by "fertilization years": beginning in the preceding year, from the 1st of July, to the 30th June of the year, which is labeled here as the year of (the effective time) of the annual fertilization. The words fertilizer and supplement are interchangeable in this text although official statistics wrote about "magnesium fertilizers" with exclusion of carbonates (lime). Data on Mg supply via "fertilizers" [Mg.(non-lime) or Mg.others] was in 1957 1.7 kg/ha (supposed increased value, after 1956 via nitro chalk production in Oulu, Heinonen, 1956) [5], in 1970–80 from [6] and for 1981–2009 from [7-9]. Values per ha for 1981–2009 are attained by dividing the amounts in [7-9] by cropland area [10]. [Mg.(non-lime)] between 1957 and 1970 are gained by linear interpolation. [Mg.(non-lime)]' consisted of the contents of multi-nutrient fertilizers and $MgSO_4$ [6], (Table 1).

Table 1: The use of Fertilizers in Finland (kg/ha), represented in order of the calculations in the text.

Mg.others is Estimated for 2010–20 to Make Possible Estimation of Total Mg Supply.															
	Lime	Mg proportion of lime	Mg.lime	$MgCO_3$	$CaCO_3$	Ca.lime	P.FAO	Ca in phosphates	Ca.tot	Mg.(others)	Ratio.[Mg.(others)/ Mg.lime]	Mg.others.est.(2010-2010)	Mg.f.est.(2010-2020)	K.FAO	Carbon.lime
1963	183	2	4	13	171	68	19	12	81	2			6	29	22
1968	156	2	3	11	145	58	27	17	75	2			5	39	19
1973	181	3	6	21	160	64	33	22	89	3			7	52	22
1978	282	6	17	59	224	89	27	17	122	3			9	47	34
1983	429	7	30	105	324	130	29	19	169	4			19	53	53
1988	422	7	29	100	322	129	27	18	152	**5**	0.21		30	52	53
1993	354	6	21	74	280	112	16	10	118	5	0.19		29	33	44
1998	424	6	25	86	338	135	11	7	137	3	0.11		**32**	32	53
2003	288	5	14	50	238	95	9	6	97	3	0.16		20	30	36
2008	240	5	12	42	198	79	6	4	81	2	0.16		16	15	30
2013	170	5	9	30	140	56	5	3	60			1.4	10	12	21
2018	165	5	8	29	136	54	5	3	58			1.4	***10***	15	20

Important Mg and Ca sources are the limes (liming agents). Even they are included in and labeled fertilizers in this study. The source of data on Finnish lime sale (SALE) was Finnish Lime Association: Data for 1961-99 and for 1991–2013 are attained from [11,12]. A visual reference for years 1961–2001 is given in [10], by graphics, without numbers, because the data in [11] is not easily available in web nor libraries. Data on lime production (PROD) of "lime stones and other liming agents" ("kalkkikivet ja muut kalkitusaineet") are from Finnish Food Authority [14]. Ratio of the sums SALE [12] and PROD [11] was 0.893 in 2005-09, 0.900 in 2010-13 and 0.897 was used for 2014-21. Sale values are used as such for 1961-2013. Estimated [Lime. sale] values [for 2014–21 were attained by multiplying PROD values of 2014–2021 by the ratio of sums of SALE and PROD in 2005-2013 (0.897). Excluded are by-products, which are used as such for liming ("Sellaisenaan kalkitusaineina käytettävät sivutuotteet") [14] (which have obviously not been included in [11,12]). Excluded is even manure as a source of Mg and Ca. [Lime sale] is a lower estimate for [Lime]'s, but in concordance with the old official statistics, which used [Lime. sale] data.

Proportions of Mg in lime [11,12] [Mg.lime.sale], have been estimated by Lauronen [15]: "before 1972 the average Mg content of limes was 2%.". For 1972 in Table 2 of [3] the amount Calcites (calcitic limestones) was 335,9 (1,000 t) [6], but the place ("box") of [Mg-cont. Calcitic Limestones, (3–7% Mg)] was empty, "because it was not separately represented before 1976". "Obviously the amount was about the same as in 1976, ca 50 (1,000 t)", {(52,3 (1,000 t) [6], Table 2)}, "ca 2, 000 t Mg, i.e. about 1 kg Mg/ha." This correction elevates the calculated [Mg in liming agents] in 1972 from 10.1 [6] to 12.1 (1,000 t) and Mg. lime/ha from 4 to 4.9 kg/ha for 1972" (checked). "Other Mg.lime values per ha for 1976 (14 kg), 1979 (19 kg) and 1980 (25 kg) need no changes [6,15]. A roughly estimated Mg-% in the 1980's was ca 7 %, in the 1990's ca 6 % and after 2000 ca 5 %. In this article 5% is used for Mg content until 2021, because new data were not available. The missing [Mg.lime] values in the 1970's are attained by linear interpolation.

Table 2: pH and Acetic Acid (.AAc) soluble Ca, Mg, K and P of Finnish soils.

	pH	Ca.s	Mg.s	K.s	P.s
5ym		mmol/L			
1963	5,55	69,3	15,5	3,15	5,4
1968	5,59	71,5	14,6	3,58	5
1973	5,66	73,5	15,6	3,61	7,7
1978	5,7	71,5	15,6	3,79	11
1983	5,84	72,2	17,4	3,86	11
1988	5,89	74,8	19,3	3,79	12
1993	5,85	80,8	21,7	3,86	12
1998	5,73	82,5	20,8	3,71	12
2003	6,01	83,2	20,8	3,74	14
2008	6,03	85,6	20,7	3,87	13
2013	6,03	87,7	21,0	3,78	12
2018	6,03	84,5	20,4	3,50	11

Although the Mg supply from limestones was elevated (for 1972 from 4 to 4.9 [6,15]), "there is no need to elevate it from 2% in period before 1972", (last estimation 12/2007) [15]. Jokinen was suspicious on Mg-% 2, before 1972. She told "not over 2%!" [16]. The different geographic distribution of Mg-contents of limestones [14], can explain different opinions. {[17] is based on [2], which is in Finnish}. Annual [Mg.lime] values per ha, including [Mg.SALE] and [Mg.SALE.est], are attained by dividing [Mg.lime] by cropland area [7]. Independently on the uncertainty on data quality and Mg-%, Lauronen [15] wrote that the error of the estimated [Mg.lime.sale] values (before 2007) was not higher than +/- 20% [15]. Mg supply via lime and non-limes are represented in Figure 1 & Figure 2 and Table 1. Table 1 shows even the estimation of [Mg.others] in 2010-20. Figure 1. shows Agricultural Mg supply in Finland from limes and non-limes ($MgSO_4$ and multi-nutrient fertilizers) in 1961-2021. Figure 2 shows proportions of Mg.f.lime and Mg.others [Mg.(non-lime)].

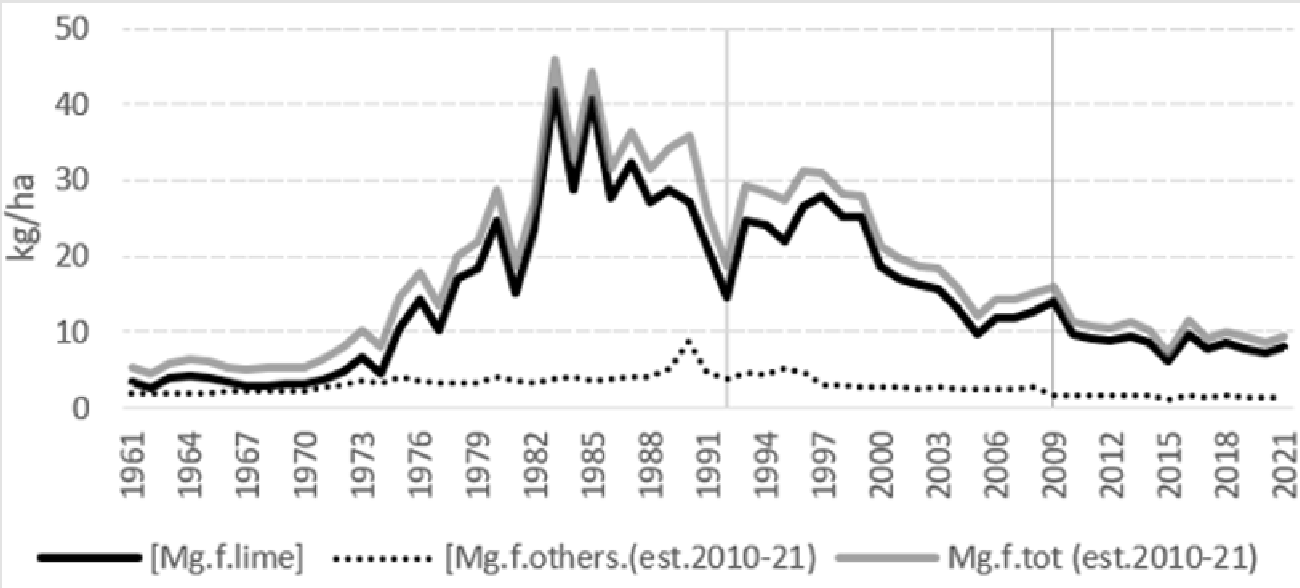

Figure 1: Annual Magnesium Supply from limes (1961-2021) and other sources (1961-2009), estimated (2010-21) in Finland.

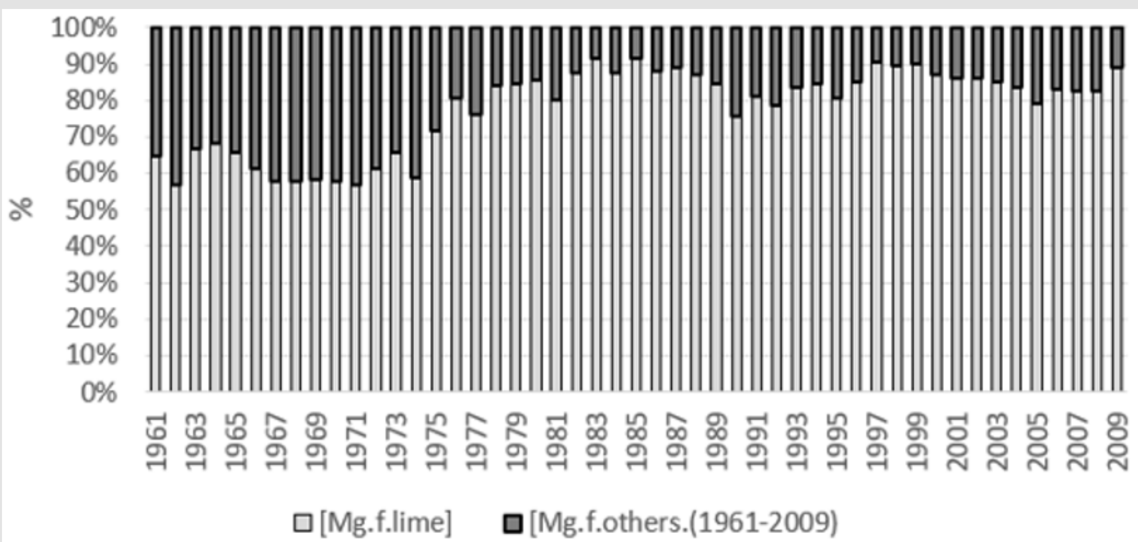

Figure 2: Proportions of [Mg.f.(non-lime)] and [Mg.f.lime] of Total Mg supply.

Ca

[Ca.lime]/ha is attained by 4 steps:

1) Determination of Mg.lime (kg/ha) by multiplying Lime (kg/ha) by Mg-%.
2) $MgCO_3$ via equation = [$MgCO_3$/Mg] x [Mg.lime] = (40.1+12+48)/40.1 x [Mg.lime].
3) [Ca.CO_3.lime] = Lime – $MgCO_3$.
4) [Ca.lime] = [Ca.CO_3/Ca] x [Ca.lime] = 40.1/(40.1+12+48) x [Ca.CO_3].

Annual Ca values from phosphates [Ca.P] are attained via FAO: P values (kg/ha) are gained by multiplying the "Nutrient phosphate total" P_2O_5 [18] by 0.437 P. Multiplying P by 0.65 (the molar weight ratio of Ca/P in superphosphate [$Ca(H_2PO_4)_2$], the result is Ca from phosphates (kg/ha). Superphosphates are the most common P-fertilizer, obviously nearly 100%). The role of phosphor in carbon binding of unclear.

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Ca in Nitrates: In Fertilizers Archive [19] are represented Calcium Nitrate and Calcium ammonium nitrate. Their amounts are so small and not represented after 2001. They are not included in this study. Ca supply via limes and phosphates are represented in Figure 3 and Table 1. Figure 3 shows Finnish Ca supply from limes and phosphates in 1961-2021

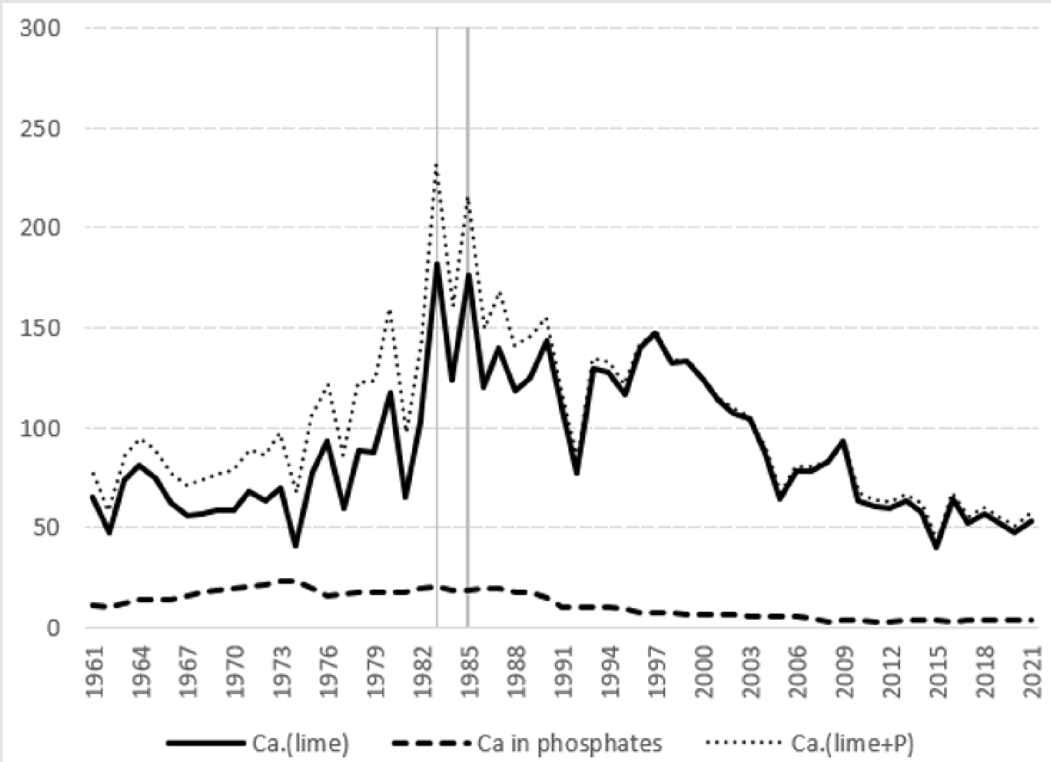

Figure 3: Ca supply from Limes and Phosphates in 1961-2021.

Potassium and Phosphates

The "nutrient potash" K_2O, values (kg/ha) are attained from [18], the amount of K by multiplying K_2O by 0.71 (Table 1). Annual values of phosphates (P_2O_5) are from [18], P values are gained by multiplying P_2O_5 by 0.437, (Table 1).

Table 1 shows annual fertilization data represented by 5-year means (5ym) by kg per ha: lime, Mg-%, Mg.lime, $MgCO_3$, $CaCO_3$, Ca.lime, phosphorus (P), Ca in phosphates [Ca.P], Ca.(lime+phosphate) (= Ca.tot = Ca.f) and Carbon content of lime (C. lime). Estimates for Mg. (non-lime, (labeled in Statistical Yearbook "fertilizers"), or [Mg. others] for 2010-2020 have been approximated by ratio. [Mg. (non-lime)/Mg. lime]. (2000-2008) by annual data (0.189), i.e. less than 20%. Mg.f.is the summary of Mg. lime, Mg. others and Mg. others. estimated. K.FAO is attained from [18]. C. lime = (12/40.1) x Ca. lime + (12/24.3) x Mg. lime. Because of clarity and space, decimals are avoided, but used in calculations.

Agricultural soil values (pH, Ca, Mg, K and P) are from [20,21], with post-fix (.s). Collected by 5-year periods (5ym) (1961-65; 1966-70, ...) they are statistically comparable with fertilization data, when labeled by their central years.

Values of Table 1 & Table 2 are represented in Figures 4-8. Figure 4. Soil Ca (Ca. s) increased rather continuously in 1963- 2018, although supplementation declined since 1983. Figure 5. Finnish soil Ca (Ca. s) increased rather compliantly in 1963- 2018, independently on the changes in the supplementation. Figure 6. Mg supply increased strongly via limes between 1973 and 1998, then decreased until 2013 and kept approximately [15] the same level in 2018.

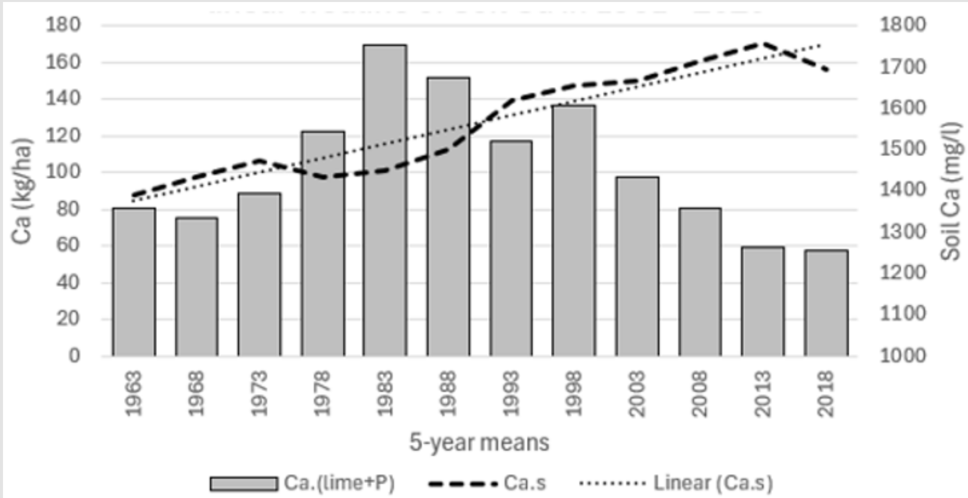

Figure 4: Finnish Ca Fertilization, Soil Ca and linear Tredline of Soil Ca in 1961 - 2020.

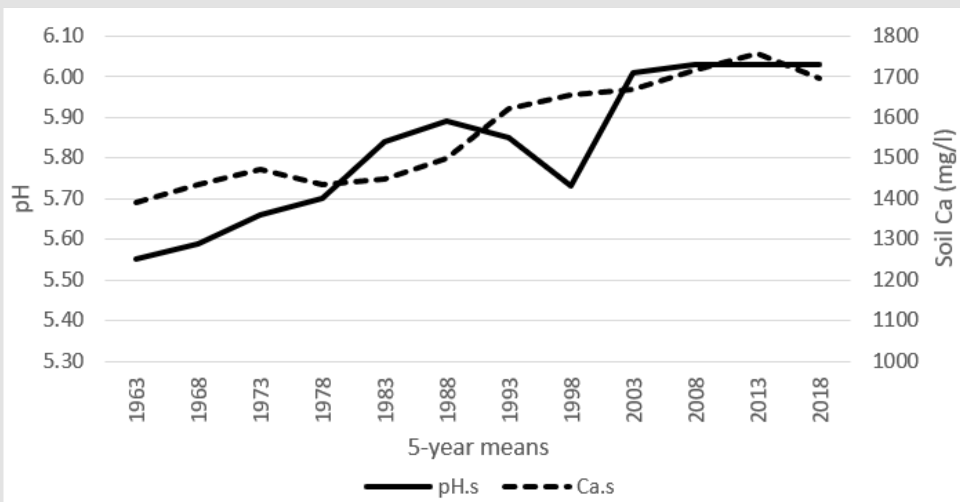

Figure 5: Finnish Soil pH and Ca in 1961 - 2020.

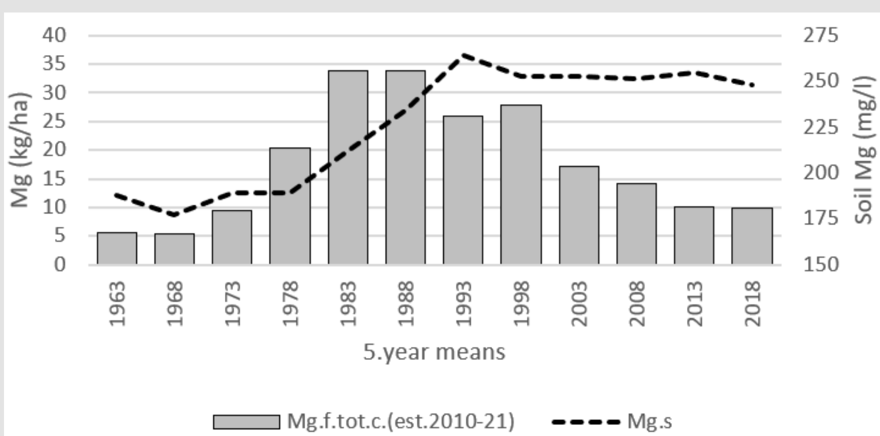

Figure 6: Finnish Mg Fertilization and Soil Mg in 1961-2020.

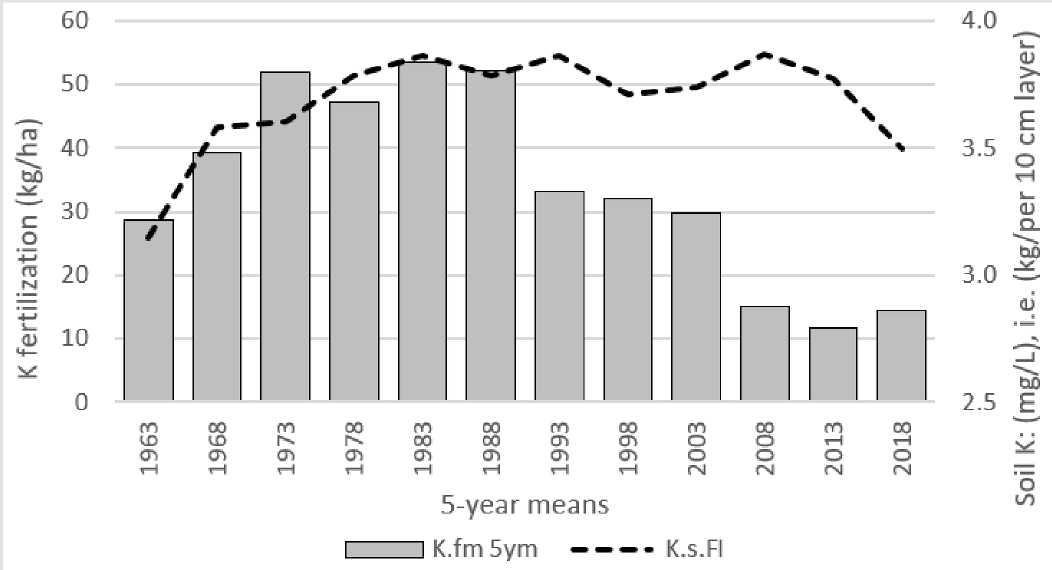

Figure 7: Finnish K fertilization and soil K in 1961-2020.

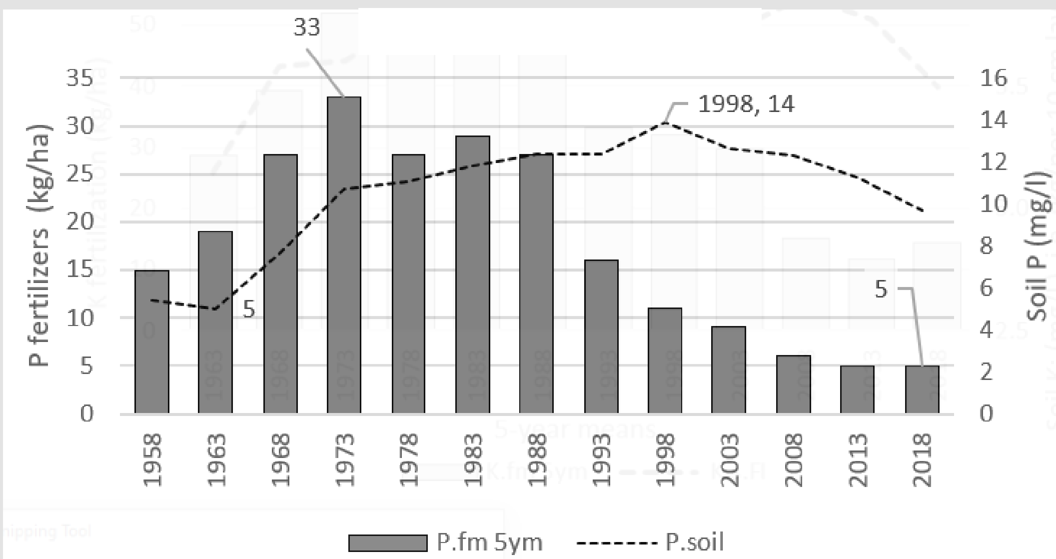

Figure 8: Finnish P fertilization and soil P in 1961-2020.

Soil Mg increased to 1993 and stayed rather stable after that, without clear response to the decreased supplementation. Figure 7. K fertilization shows a general increasing trend ad 1983, then rapid drops 1988-93 and 2003-08. Soil K stayed rather stable in 1993–2013. Figure 8. P fertilization increased ad 1973, decreased nearly continuously to 2018 – with a small deviation at 1983(-88). Soil P increased to 1998, then declined ad 2018, but stayed above the level of 1968 (near the level of 1973). Table 3. Data on annual yields of grain (GR) and potatoes (POT) are collected from FAO [19] after changing them to 5-year means (5ym). The data are changed to feed units (FU) by dividing them by [FU Eq]'s [20]. FU's are changed to megajoules (MJ) by multiplying FU's by 7.72 [21]. Table 3 shows the annual yields of the Finnish main cereals (grain, "GR") and potatoes (kg/ha) by 5-year means, with the keys to change the data to feed units (FU) and FU's to MJ.

Table 3: Finnish Annual Yields of Cereals and Potatoes by kg/ha, And their energy equivalents (FU Eq), 1 FU = 7.72 MJ.

FU Eq	1	1.2	1	1	5
	(kg/ha) 5ym				
	Barley	Oats	Rye	Wheat	Potatoes
1963	1 693	1 786	1 505	1 736	14 368
1968	2 079	2 194	1 722	2 122	15 155
1973	2 411	2 379	2 074	2 636	14 174
1978	2 725	2 676	2 158	2 469	16 896
1983	2 796	2 888	2 124	2 957	16 415
1988	2 767	2 798	2 480	2 930	18 772
1993	3 370	3 355	2 669	3 448	20 238
1998	3 078	3 048	2 049	3 291	22 321
2003	3 316	3 124	2 319	3 479	24 101
2008	3 586	3 245	2 579	3 733	25 429
2013	3 614	3 435	2 935	3 949	26 192
2018	3 777	3 553	3 687	3 772	28 616

Evaluated daily need of energy for humans was 10 MJ in [25]. (The different sizes of cultivated areas for different cereals were ignored). Because yield (by MJ's) was different via potatoes than cereals, yield-index "COMB" was formed. COMB = (2*µ. (grain) + POT)/3 (Figure 9). Defined Daily Dose of energy per ha (DDD/ha) is approximated with presumption: 10% of the yield is needed for the seeds, the remain divided by 10 (MJ) and by 365 (the number of annual days. The approximate sustainable number of people (0.9*COMB/10/365) grew from 3.9 to 8.1 (2.1 - about two-fold and depending on dietary selections.

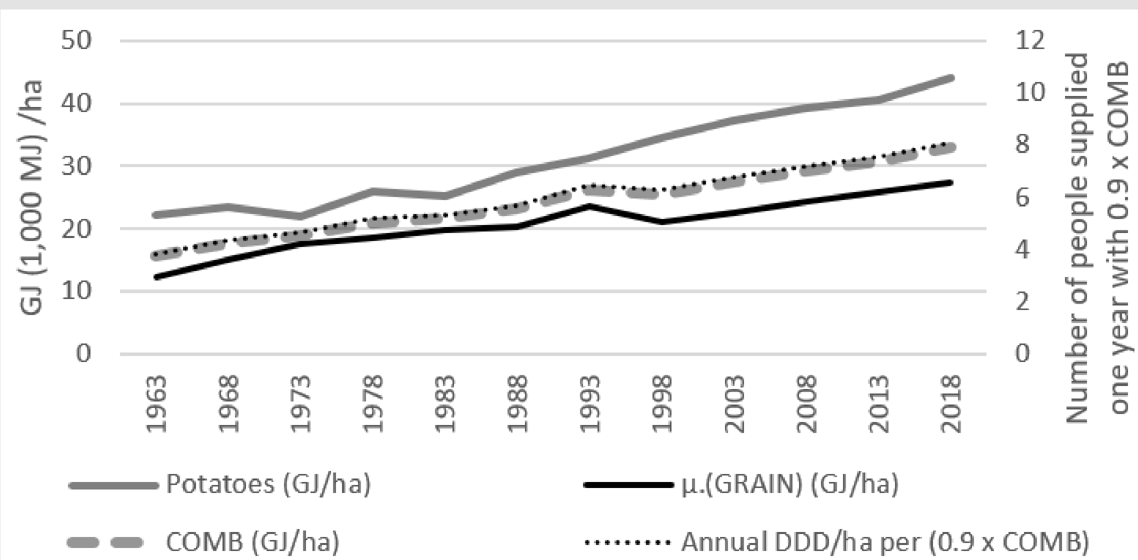

Figure 9: Energy production via potatoes, grain, COMB and annual DDD (COMB x 0.9) per hectare.

Table 4 shows the mean annual energy content of each grain, their mean (µ.GR) and combined weighted energy (COMB) of mean grain (GR) (with weight 2) and potatoes (POT) (with weight 1): [(2*GR+1*POT)/3]. Last column shows the number people, who could live one year with the energy produced by one hectare. Figure 9. shows the increasing trend in the Finnish Annual Energy Yield (MJ/ha) via potatoes, the mean of cereals [µ. (GRAIN)] and the weighted energy supply via cereals and potatoes, 2:1, (COMB) and the number of people, whose energy needs 0.9*COMB satisfies. Annual number of DDD's for one year living is about (0.9 x COMB)/10/365 per hectare. Official reports of Finnish temperature begin in Finland from 1961. Old reports on global temperature development are available e.g. from [2], which includes data e.g. from NAS (National Academy of Science) from 1880–1970, which show the cooling period 1940–70. In Finland there are measurements in "Helsinki Kaisaniemi" and "Parainen Utö" since the 19th century. [2,3] represent "thermometer" based on annual growth of timberline pines. Figure 10 shows temperature development in Utö a Finnish lighthouse island – free from urban influences), in 1930–2026 [26]. It slightly suggests on cooler period.

Table 4: The yield energy of grain, (separate and on average), potatoes and COMB (MJ/ha) additionally the number of people, which could be satisfied by the yield of one hectare**.**

	Barley.MJ	Oats.MJ	Rye.MJ	Wheat.MJ	µ.(GR).MJ	Potatoes.MJ	COMB. [(2*GR+1*POT)/3]	N. of people, whose energy needs 0.9*COMB satisfies
1963	13 067	11 488	11 617	13 402	12 393	22 184	15 657	3,9
1968	16 049	14 116	13 292	16 385	14 961	23 399	17 774	4,4
1973	18 611	15 305	16 010	20 353	17 570	21 884	19 008	4,7
1978	21 038	17 218	16 662	19 062	18 495	26 087	21 026	5,2
1983	21 585	18 582	16 397	22 831	19 849	25 344	21 681	5,3
1988	21 364	18 002	19 145	22 618	20 282	28 985	23 183	5,7
1993	26 019	21 582	20 608	26 618	23 707	31 248	26 220	6,5
1998	23 764	19 612	15 821	25 405	21 150	34 463	25 588	6,3
2003	25 599	20 099	17 903	26 855	22 614	37 212	27 480	6,8
2008	27 686	20 873	19 912	28 817	24 322	39 263	29 302	7,2
2013	27 897	22 099	22 656	30 484	25 784	40 441	30 670	7,6
2018	29 158	22 859	28 462	29 119	27 399	44 182	32 994	8,1

Presumptions

After 1983 yields were increasing and fertilizing was reduced, but the yields needed and took elements (e.g. C) proportionally about the same amounts as earlier. COMB has been used as reference for total (consumption of fertilizers: Given + weathered) (Table 5). In this study the amounts of the total output/uptake of each element (X) since 1983 (= α) has been attained by multiplying [X.α] by (COMB.i/COMB.α).

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Table 5: Shows the given (.fm) fertilizers, their expected (.exp) consumption by yields, the differene of (exp – obs) and the sum of differences by each element X and their sum (kg/ha/a).

	Ca.fm	Mg.fm	K.fm	P.fm	Carbon. lime.fm	Ca.f.exp	Mg.f.exp	K.f.exp	P.f.exp	C.f.exp	Ca.f.∆	Mg.f.∆	K.f.∆	P.f.∆	C.f.∆	Sum
1963	81	6	29	19	22	122	24	39	21	39						
1968	75	5	39	27	19	139	28	44	24	44						
1973	89	7	52	33	22	148	30	47	26	47						
1978	122	9	47	27	34	164	33	52	28	52						
1983	169	19	53	29	53	169	34	53	29	**54**	0	0	0	0	0	
1988	152	30	52	27	53	181	36	57	31	58	29	2	5	4	5	
1993	118	29	33	16	44	205	41	65	35	65	87	15	32	20	21	
1998	137	**32**	32	11	53	200	40	63	34	63	63	12	31	23	11	
2003	97	20	30	9	36	215	43	68	37	68	117	26	38	28	33	
2008	81	16	15	6	30	229	46	72	39	73	148	31	57	33	43	
2013	60	10	12	5	21	240	48	76	41	76	180	38	64	36	55	
2018	58	***10***	15	5	20	258	51	81	44	82	200	42	67	39	61	
Sum											825	166	293	183	228	1695

Figure 11. shows changes in the K fertilization of Finnish agricultural soils and energy of yields (COMB, by gigajoules, GJ = 1, 000 MJ).

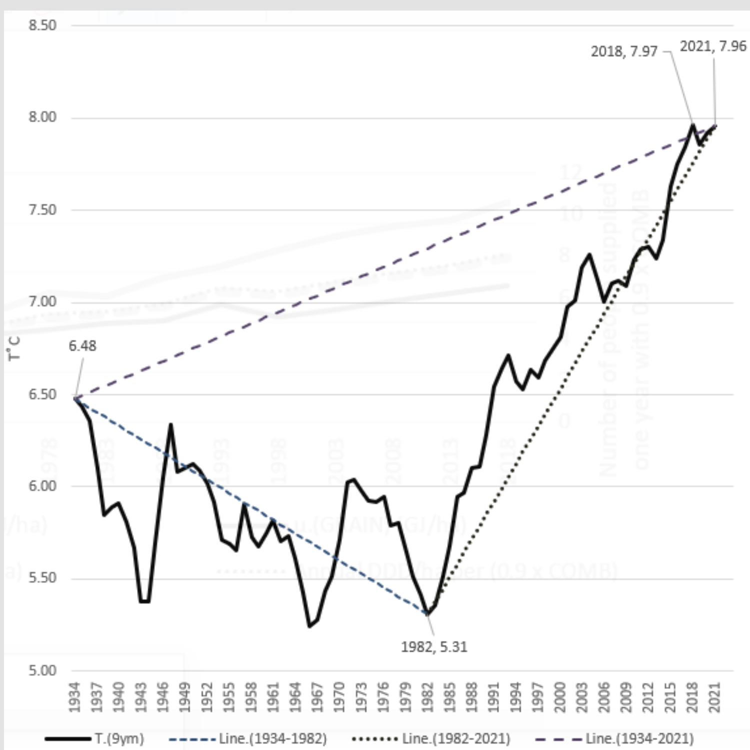

Figure 10: Temperature variation on Utö (a Finnish lighthouse island), by 9-year means, in 1930-2026.

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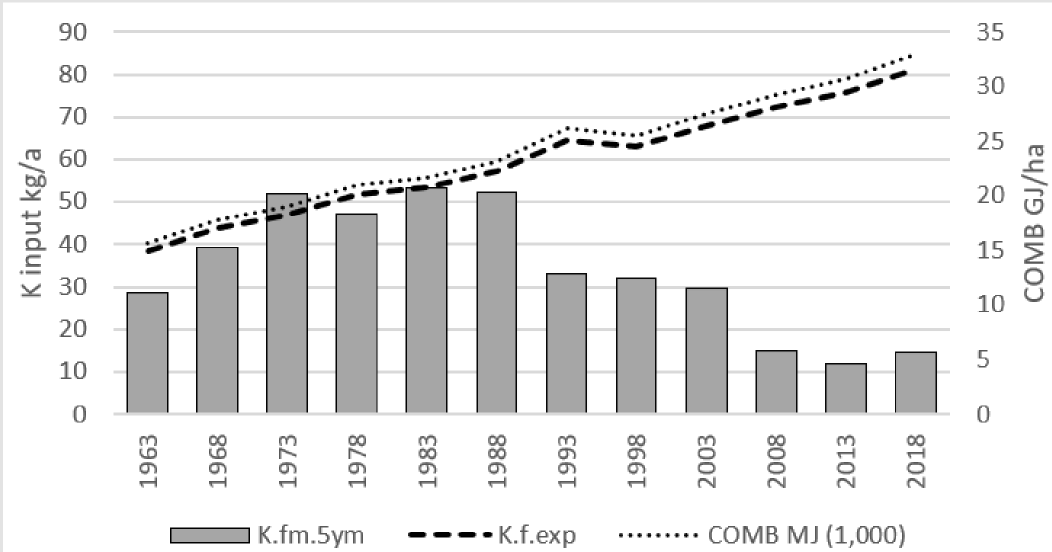

Figure 11: Observed and expected K Input to Croplands, with Yield enegy indicator COMB 1983-2018 in Finland.

Because the yield increased not as predicted after 1983, the difference in Ca+Mg+K was taken from soil reserves, via weathering. The role of P in carbon binding is insignificant [27]. In an experiment granite powder was used (50 – 200 tn/ha), on acid soil, i.e. roughly 0.25 – 1% of plough layer was diluted, but C-content decreased only 0.4 – 0.8 g/kg, 0.9 – 4.5 g/kg less than expected [27], obviously via carbon binding 2–9 tn/ha. The role of P in carbon binding is not known, although there are data on P fixation and liberation (Fig. 8, Table 5). The dissolution reactions for Ca, Mg and K can be as follows:

1. **Calcium**: $2CO_2 + 3\ (H_2O) + CaSiO_3$ -> $[Ca^{2+}] + 2\ [H_2CO^{3-}] + H_4SiO_4$ [28], the first picture.
2. **Magnesium**: Olivenite: $Mg_2SiO_4 + 4\ CO_2 + 4\ H_2O \rightleftharpoons 2\ [Mg^{2+}] + 4\ [HCO^{3-}] + H_4SiO_4$ [29], ratio C/Mg=2.
3. **Potassium**: Ortoclase + carbonic acid + water ⇌ kaolinite (a clay mineral) + silicic acid in solution + potassium and bicarbonate ions in solution: {2 KAlSi3O8 (Ortoclase) + $2\ H_2CO_3 + 9\ H_2O \rightleftharpoons Al_2Si_2O_5(OH)_4 + 4\ H_4SiO_4 + 2\ [K^+] + 2\ [HCO^{3-}]$} [29]. The molar carbon ratios per cations (Ca, Mg, K] are: C/Ca = 2, C/Mg = 2, C/K = 1 (2:2) and weight ratios (Table 6).

Table 6: Shows differences between expected and observed amounts of fertilizers in 1981–2020, by 5ym, between 1983 and 2018, in 35 years. Visible total difference (X.i.WE.0), visible annual difference [μ.[X.i.we.0], total annual weathering, [X.i.we.tot], C/X,i ratio in weathering, atomic weights, C-binding (exp-obs) values WE.[X.i] = [WE.0+13.5 kg], WE.(C/X.i) ratio, Atomic weights,C-binding during weathering.

	Ca.f.Δ	Mg.f.Δ	K.f.Δ	Lime.C.f.Δ	Sum	P.f.Δ	∑ with P
	kg/ha						
Total [X.i.we.0] in 35 yrs	825	166	293	228	1512	183	1695
Annual [X.i.we] =μ.[X.i.we.0]	24	5	8	7	44	5	49
Annual [X.i.we.tot] =μ.[X.i.we.0] + 17,5 kg	41	22	26				
(C/X.i) ratio in weathering	2	2	1			-	
Atomic weight	40,1	24,3	39,1	12		31	
C-binding (kg/ha/a) (Ca, Mg, K)	25	22	8		55		
C-binding + saving loss via limes	25	22	8	7	62	-	
N.B. approximate of leaching, [X.le] =17,5 kg/ha/a							

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Additionally, to Ca, Mg, K and Si liberation and carbon binding the production of basic bicarbonates in each reaction helps pH managing. A remarkable part of soil minerals is lost via leaching (le), [X.le], (Table 6). By comparing different sources Jokinen gave an estimate for annual leaching 15–20 kg/ha for Mg and Ca [6]. An approximate value for annual [K.le] is given in [30]: 27.3 kg/ha/a. Because every estimate for one country is at least somewhat obscure and dependent on soil type distribution, weather and use, 17.5 kg/a was accepted for each of 3 main cations element as [X.le].

Results

Table 6 shows periodical (1983–2018) and annual liberation of elements and reduction of C-loss via liming. Because liberation of P is different, data (approximates) on it are scanty. Its use was reduced by 5 kg annually. [X.we.0] is the visible part of the weathering, "invisible part" is that what is lost via leaching (and compensated). [X.le] for limes is determined to be 0, Ca of limes are included in Ca. Calculated and approximated liberation of elements from soil occurred as follows (kg/ha) visibly (and totally): Ca 24 (41), Mg 5 (22), K 8 (26), P 5 (23). Annual C-binding (kg/ha) by elements: Ca 25, Mg 22, and K 8, together 55 kg. Reduced use of limes saved carbon losses 7. Together weathering and reduced use of limes (7 kg) saved carbon loss ca 62 kg/ha/a.

Correlatios with Yield Energy Production COMP

Table 7 shows correlation of energy production of yields (COMB), use of mineral fertilizers (fm), ratio of (Mg+N) to (Ca+P+K) of fertilizers in equivalents, Temperature by 9-year means [26] and soil (Ca+Mg+K) in equivalents.

Table 7: Shows correlation of energy production of yields (COMB), use of mineral fertilizers (fm), ratio of (Mg+N) to (Ca+P+K) of fertilizers in equivalents, Temperature by 9-year means [26] and soil (Ca+Mg+K) in equivalents.

	COMB (GJ/ha)	pH.s	Ca.fm.Eq	Mg.fm.Eq	N.fm.Eq	P.fm.Eq	K.fm.Eq	[(Mg+N)/(Ca+P+K)].f.Eq %	T.(µ.9-v)	(Ca+Mg+K).s.Eq
1963	16	5,6	1007	116	1468	205	733	81	5,7	24
1968	18	5,6	941	110	2459	286	1003	115	5,4	25
1973	19	5,7	1110	194	4028	357	1330	151	6,0	26
1978	21	5,7	1527	420	3758	286	1208	138	5,8	26
1983	22	5,8	2112	695	4335	313	1367	133	5,4	26
1988	23	5,9	1896	696	4750	294	1336	154	6,1	27
1993	26	5,9	1466	533	3883	167	847	178	6,7	30
1998	26	5,7	1705	575	4025	118	818	174	6,7	30
2003	27	6,0	1215	351	3558	101	759	188	7,2	30
2008	29	6,0	1008	293	3326	68	384	248	7,1	30
2013	31	6,0	742	208	3151	53	303	306	7,2	31
2018	33	6,0	720	201	3121	54	371	290	8,0	30
Pearson.(1963-78)	1,00	0,98	0,84	0,88	0,89	0,63	0,84	0,85	0,34	0,84
Pearson.(1983-2018)	1,00	0,73	-0,98	-0,96	-0,93	-0,91	-0,95	0,95	0,96	0,83
Pearson.(1963-2018)	1,00	0,92	-0,27	0,08	0,24	-0,82	-0,69	0,94	0,92	0,94

Table 7. Pearson correlations from periods 1963–78 show that all parameters correlated positively with yield (COMB), but in 1983–2018 the fertilizer correlation were negative. pH, ratio of fertilizers [(Mg+N)/(Ca+P+K)], temperature and soil fertility parameter (Ca+Mg+K) correlated positively. In summary (1963–2018) association of Mg and N were positive, with other fertilizers negative (Figure 12 & Figure 13).

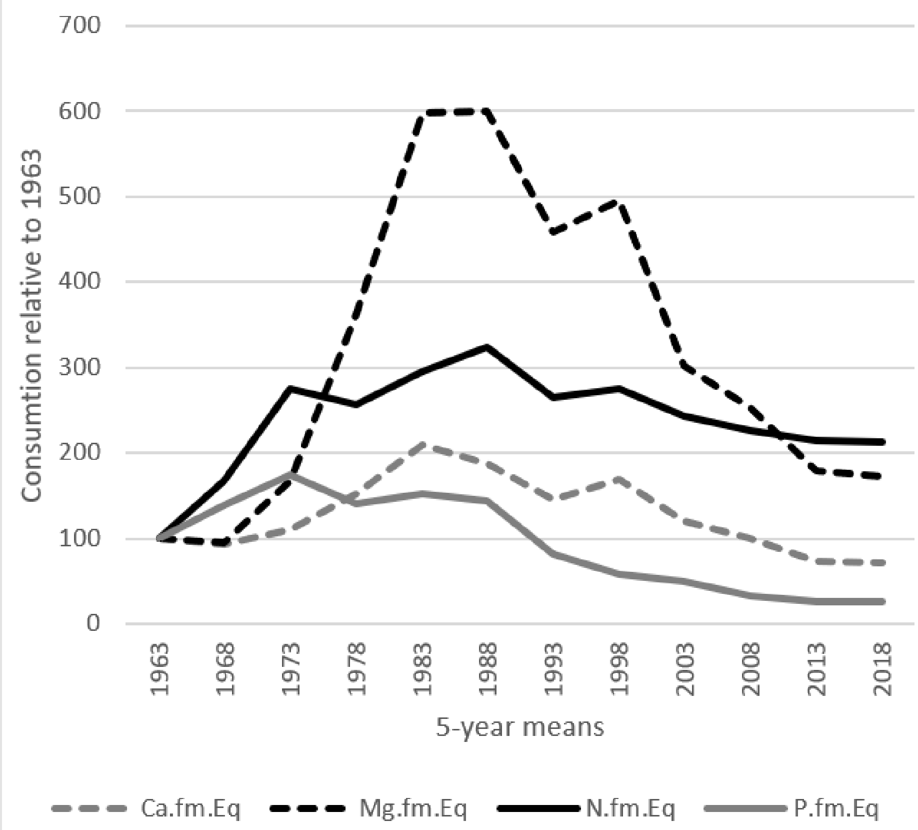

Figure 12: Relative use of fertilizers in Finland 1961-2020.

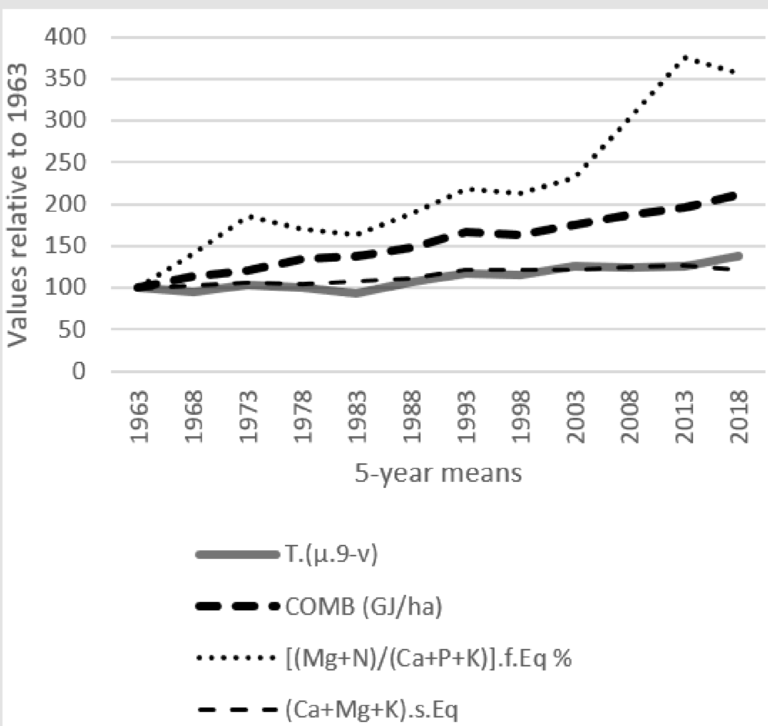

Figure 13: Relative changes in temperature, yield (COMB), fertilization ratio [(Mg+N)/(Ca+P+K)] and soil (Ca+Mg+K).

Discussion

Climate change associated with increased productivity (COMB), reduced acidity and improved soil parameters of agricultural soils in Finland (Table 7). Increase in yields was observed in West-Europe, too [4]. The approximated annual amount of carbon binding 62 kg/ha/a via erosion was increasing Table 5 and compensated partially, ca 30 %, of the losses (220 kg/ha/a) caused by erosion [31]. Elevated temperature was known to be associated with soil weathering and pH increase [32-34] and weathering can work like a thermostat [33]. A prerequisite for proper pH is ditching [35]. Swamps can be harmful [36].

During cooling temperature (Figure 10) [26,37] fertilizers worked weaker: Yields were disproportionate to increased fertilization. From (1955-60) to (1966-70) soil pH increased only 0.1 units, although ditching was executed with strong machines and the use of limes increased [38]. Winter wheat gave its highest yield, when pH was between 5.6–5.9] [39] Optimum range for Silicon buffer is 5.0 ≤ pH < 6.2 [40], which is obviously best for silicate "digestion" for agricultural ecosystem (different microbes).

Molybdate test measures only monomeric SiO_2, $Si(OH)_x$ [41]. The amount of total soluble silicon in soil is possibly best to evaluate via local groundwater or via milk [42], but even it is sensitive to temperature.

Remarkable is, that in dry surroundings, which are obviously less acidic, silicate fertilizers can even reduce growth [43]..

Outside of the range of deficiency can exist non-optimal amounts or non-optimal relative ratios of fertilizers, e.g. equivalent ratio (Mg+N)/(Ca+P+K), which complied well with yield energy production, during the whole period 1963–2018. Table 7.

Association of reduced fertilizing with increased yields, is paradox only if it is not possible include the fertilizing by the own resources of the soil, which have become moderately possible predictable by HCl-analyses [44]. The rules of temperature variation [2,3] "prognostigated" temperature changes backwards for hundreds of years, even in 1934–82 better than [1]. The warmest year of Utö, until 2026, was 2020, the years 2021-25 have been cooler. It seems possible that the next turning point occurs during the last quarter of this century as predicted in [2], (Figures 7 & 8).

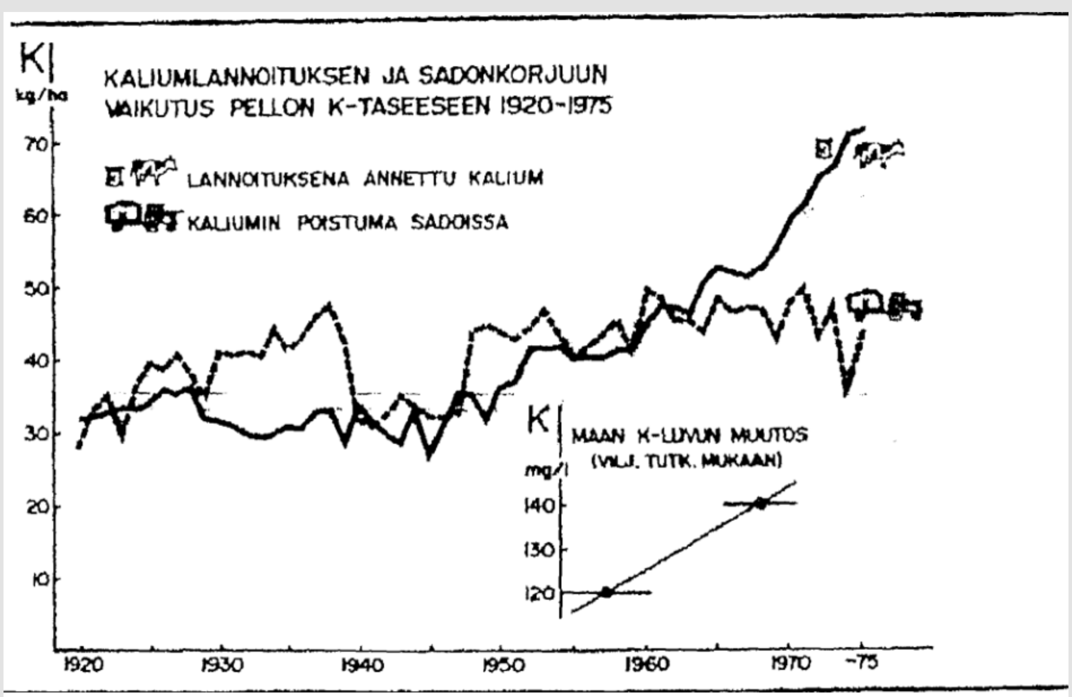

Figure 14.

Conclusion

Increased yields, liberation of soil reserve elements, obviously silicates, improved soil parameters (including pH), and elevation of temperature in 1980–2020, were associated typically with a millennial period of rapid growth (1983-2018) and carbon binding counteracting phenomena causing carbon loss. The different periods before and after can be predicted by Finnish timberline pine chronology, FTPC.

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