Research Article

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2025.60.009409

Doubling in Crop Production, with Dramatic Changes in Relative and Total NPK Fertilization Compliantly in Finland and Western Europe, 1961-2022 Support the Role of Acid-Soluble (K-)Silicates as Fertilizers and the Biosphere-Friendly Roles of Grasslands

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ARTICLE INFO

Received: November 15, 2024

Published: January 06, 2025

Citation: Töysä T. Doubling in Crop Production, with Dramatic Changes in Relative and Total NPK Fertilization Compliantly in Finland and Western Europe, 1961-2022 Support the Role of Acid-Soluble (K-)Silicates as Fertilizers and the Biosphere-Friendly Roles of Grasslands. Biomed J Sci & Tech Res 60(1)-2025. BJSTR. MS.ID.009409.

ABSTRACT

Mineral fertilization increased and then decreased by P and K dramatically from the top years until the end of the 20th century. This survey is assessing relative and total NPK fertilizers and grain and potato yields in Finland (FI) and West-Europe (WE) during 1961-2022 by their 3-year values from 1962-2021.

Results: In FI and WE NPK and N rates were highest at 1988. P and K rates had in FI & WE a peak at 1972-74, but in FI another slightly higher tops in 1986-88. WE fertilizer rates were higher, but explained respective FI-values as follows: N 88 %, P 95 %, K 91 %. In FI annual maximum/end values (kg/ha) were by N 68/41, P 35/5 and K 46/12. Grain and potato yields were two-fold in 2018-23 to yields in 1961-65 in FI and WE.

Discussion: Results can be explained by the results of long-standing fertilizer-soil-yield trials by different soil extractants: acid acetic acid (AAc) and HCl. If K. HCl was > 600 mg/l grasses did not suffer from omission of K supplementation, but in dry summers. The role of the potassium liberation from soil minerals has been increased, associated obviously with liberation of other elements, e.g. Si. About 86 % of the uptake of potassium in Finland came from grasslands, although their proportion of cultivated area (less fallow) was only 39 %. Discussion needs to be continued on the role of grasslands in management of soil pH, moisture and carbon capture.

Conclusions: Observed doubling in crop production and dramatic changes in relative and total NPK fertilization compliantly in Finland and Western Europe seem to be associated with proper weathering, including favourable effects on soil and climate. Grassland crops can have a climate-friendly role.

Keywords: NPK Fertilizers; Fertilizer Ratios; Reserve Fertilizers; Silicates; K. HCl-References; K. AAc; Cropland Potassium Balance; Annual Yields; Plant (N/K) Reference

Abbreviations: FI: Finland/Finnish; K.AAc: K Extracted by 0.5 M Ammonium Acetate, pH 4.65; K.HCl: K Extracted by 2M HCl; SD: Standard Deviation; WE: Western Europe

Introduction

Compliance in the use of NPK fertilizers in the 20th century between Finland and Western Europe has been observed and published earlier [1]. Before the era in the title a remarkable part of fertilization was performed soil improvement materials, which were not included to (nor understood to be) fertilizers. Benefiting of local and transported agricultural soil material has been described earlier [2-4]. The amount of the transported "soil improvement materials", in 1950, was determined by ca 10 million "horse loads", a´ ca 365 kg, (1/2 "peat soil" and ½ "clay or sand"). This article describes changes in the in the use of NPK mineral fertilizers and production of grain and potato in Finland and Western Europe during 1961-2022 and tries to explain the role of the long-standing fertilization-soil-plant studies, the

DOI: 10.26717/BJSTR.2025.60.009409

important role of grasslands and about the role of silicates, "soil improvement materials" and acid-soluble minerals in general. The main mineral element in this survey was potassium.

Material and Methods

Use of soil nutrients (N, P and K) per area of cropland (kg/ha) are from [5]: N (nitrogen as such), P (phosphorus) is attained by multiplying P2O5 by 0.437 and K by multiplying K2O by 0.83. Yields of barley, oats, potatoes, rye and wheat (kg/ha) are from [6]. Mean of barley, oats, rye and wheat yields was accepted as a raw approximate/surrogate for "Grain" yield. Annual yields of potatoes used as such. Cropland Nutrient Balance concerning potassium is from [7]. It includes mineral fertilizers, manure applied to soils, crop removal and seed (kg/ha). All figures are from period 1961-2022, for Finland and Western Europe. Because there is so much discrepancy in nutrient contents between different sources (concerning K in manure and K in crop removal), major soil balance studies are performed only concerning Finnish potassium. The FAOSTAT data are originally given by kg/ha and easily loaded to computer in XLS-format and then transformed P2O5 and K2O to pure P and K. Nearly all values were treated by 3-year means, which is seen in figures by abbreviation of "3ym", but "start" (α) and "end" (ω) values of yields are given by 5-year means. For each fertilizer and yield is calculated ratio "end"/"start" (ω/α) ratio, for fertilizers additionally Maximum/"begin" (Max/α) ratio. Results are represented by tables and figures. Figures are with normal and logarithmic scale and relative to values of 1962 and represented by regressions. Usual calculations and charts are performed by Exel (Microsoft Home and Student 2019).

Regressions, R squares and significances are calculated by IBM SPSS Statistics 29.0.2.0 (20) and represented by (Exel) graphics, If the idea of a chart or Figure is clear by its title and graphics, words may have been omitted, in order to avoid redundance.

Results

Fertilizers

Table 1: presents start (α), maximum (Max) and end (ω) amounts and ratios (Max/α). and (ω/α). of Finnish N, P, K and NPK fertilizers [and N/K ratio (for Discussion)], by 3-year means.

	N.FI.3ym	P.FI.3ym	K.FI.3ym	NPK.FI.3ym	(N/K).FI.3ym
α.1962	17	17	21	56	0.8
Max	68	35	46	141	6
ω.2021	41	5	12	57	3
Max/α	3.9	2	2.1	2.5	7
ω/α	2.3	0.28	0.54	1	4

In Finland, the ratio of the maximum to the start value (Max/α) was by N 4 and by P, K and NPK 2-2.5 and by (N/K) 6, respectively (Table 1). End/start (ω/α) ratio was by N 2-fold, by P, K, NPK and (N/K) respectively ca 1/4, ca 1/2, 1.0 and 4. The Total Finnish NPK fertilizers reached the start value at the end of the period (Table 1).

Table 2: presents start (α), maximum (Max) and end (ω) values and ratios (Max/α) and (ω/α) of West-European N, P, K and NPK fertilizers [and (N/K) (for Discussion)], by 3-year means.

	N.WE.3ym	P.WE.3ym	K.WE.3ym	NPK.WE.3ym	(N/K).WE.3ym
α.1962	46	24	56	126	0,8
Max	136	43	82	242	6
ω.2021	84	6	18	108	5
Max/α	3	1.8	1.5	1.9	8
ω/α	1.8	0.26	0.32	0.9	6

DOI: 10.26717/BJSTR.2025.60.009409

In Western Europe, the ratio of the annual maximum to the start value (Max/α) was by N 3, by P, K and NPK 1.5-1.9 and by (N/K) 7.6. End/start (ω/α) ratio was by nutrients as follows: N 1.8, P 0.26, K 0.32, NPK 0.86 and by (N/K) 5.6. (Figure 1).

The increase in N fertilization from the begin of the 1960's was in Finland nearly 4-fold until 1988 and the decrease ca 40 % until 2022 (Figure 2).

Figure1: N.FI and N.WE - Relative to 1962, on logarithmic scale.

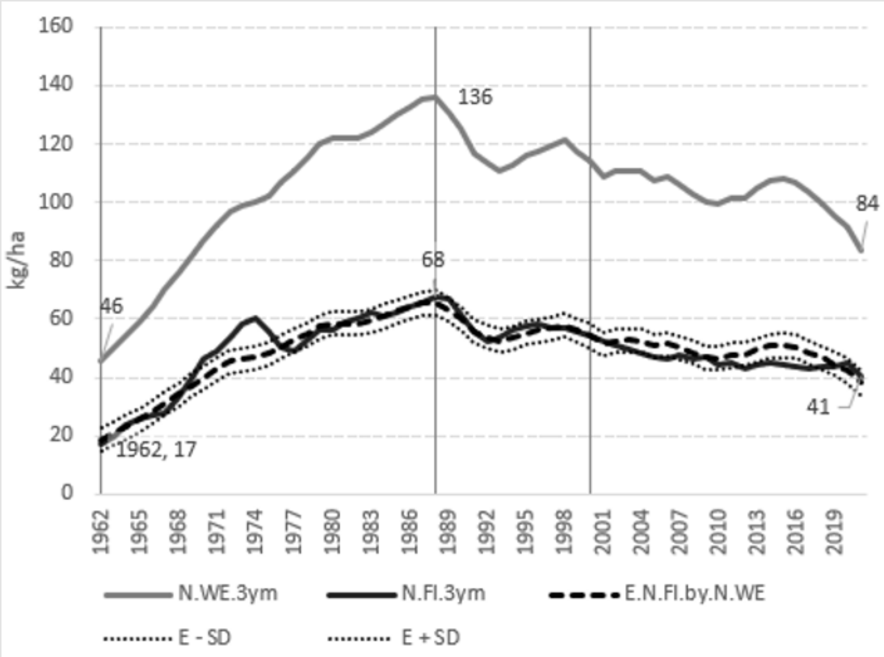

Figure 2: West European N rates explained 88 % of respective Finnish values ($p < 0.001$), via equation: N.FI = -5.2 + 0.52 x N.WE +/- 4.0.

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Phosphor

(Figure 3, 4) shows P.Fi, P.WE and regression of P.FI by P.WE +/- SD. R square 95 % (p < 0.001). Regression equation for P.FI = -1.23 + 0.83*P.WE +/- 2.23. (Figure 5, 6) shows K.Fi, K.WE and regression of K.FI by K.WE, +/- SD. R square 91 % (p < 0.001). Regression equation for K.FI = 1.81+ 0.51*K.WE +/- 3.7. (Figure 7): West European NPK rates explained 96 % of respective Finnish values (p < 0.001). Because SD is small (6.0), for (Figure 7) it was multiplied by 2 (2 x SD), to make it visible.

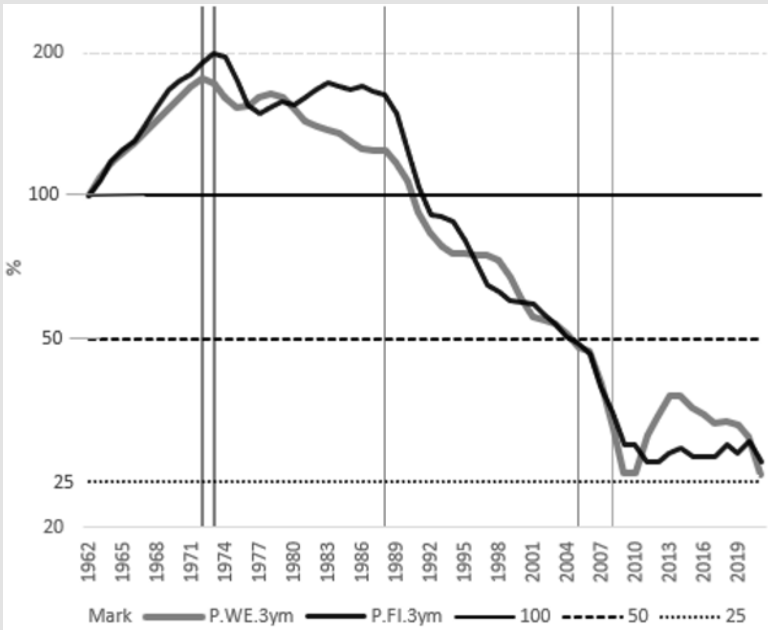

Figure 3: P.FI and P.WE - Relative to 1962, on logarithmic scale.

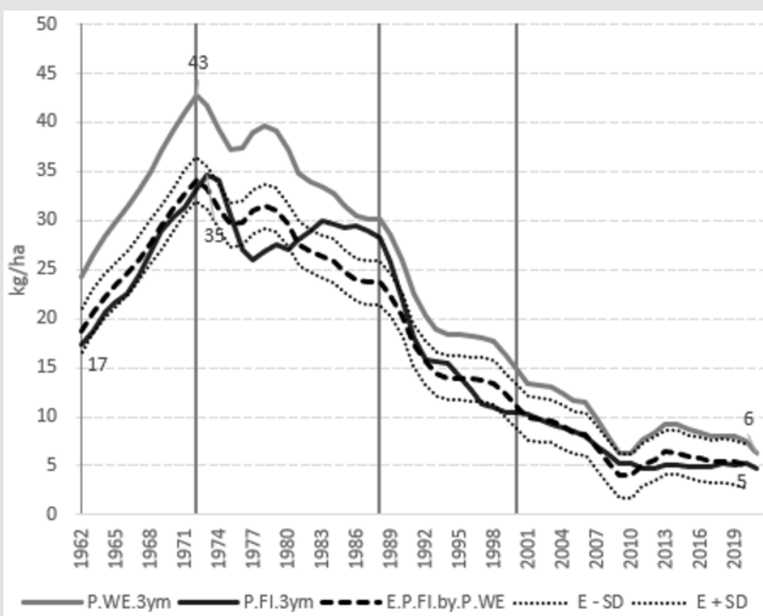

Figure 4: West European P rates explained 95 % of the respective Finnish values (p < 0.001), via equation: P.FI = -1.2 + 0.83 x P.WE +/- 2.2.

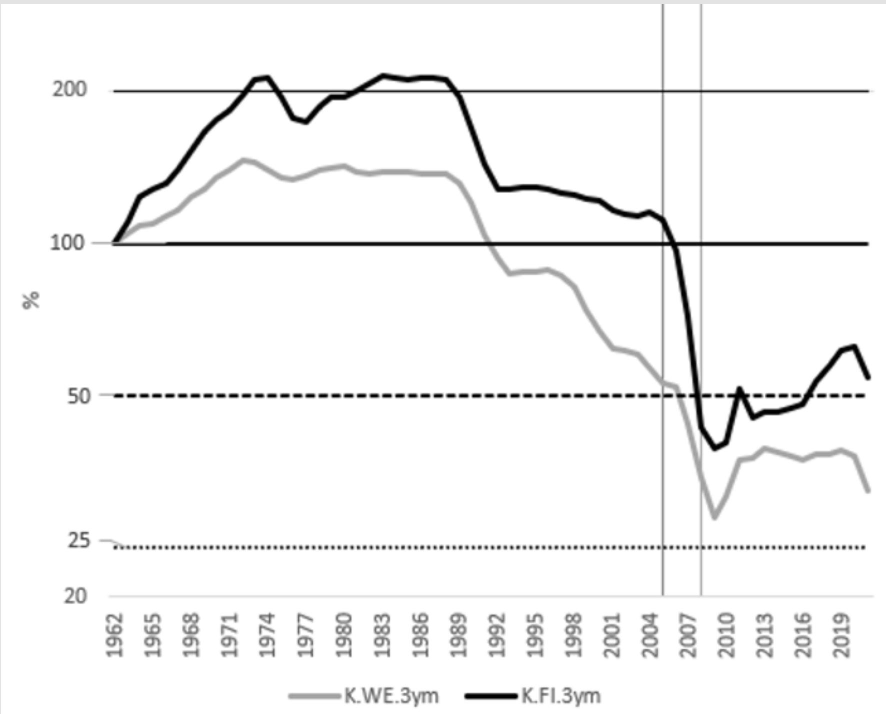

Figure 5: K.FI and K.WE - Relative to 1962, on logarithmic scale.

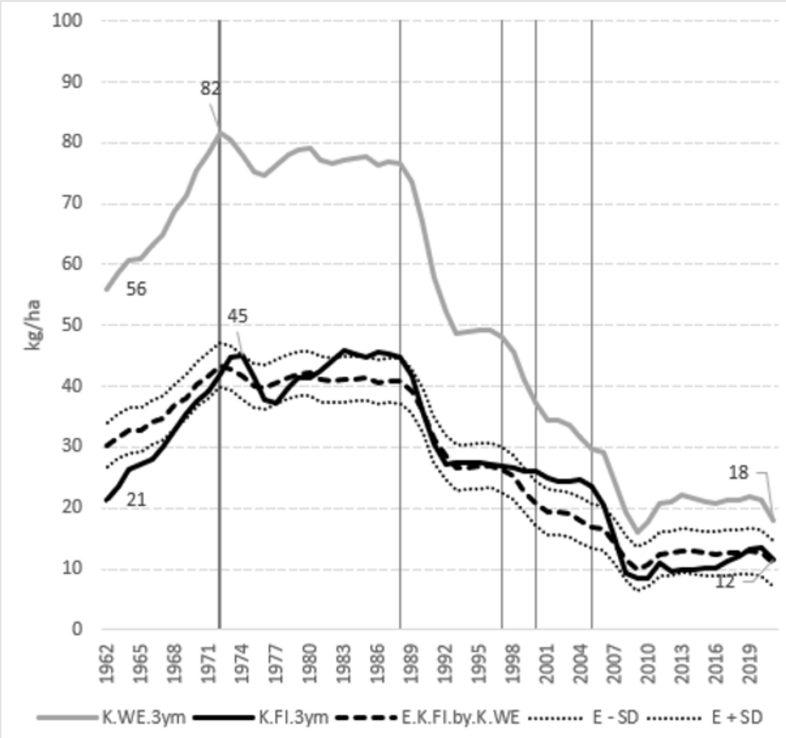

Figure 6: West European K rates explained 91 % of the respective Finnish values ($p < 0.001$), via equation: K.FI = 1.8 + 0.51 x K.WE +/- 3.7.

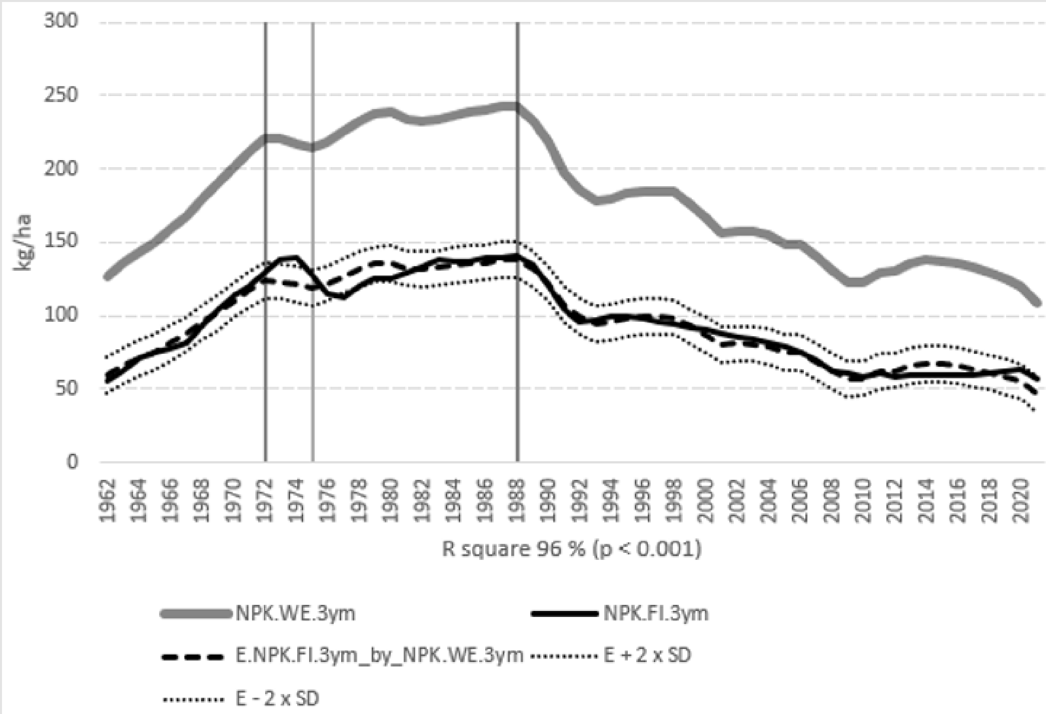

Figure 7: West European NPK rates explained 98 % of the respective Finnish values (p < 0.001), via equation: NPK.FI = -26.2 + 0.68 x NPK.WE +/-6.0.

Yields

Table 3: Mean "Grains" and potato yields in Finland and Eastern Europe, 2018-2022 are from [6]. (Grains: annual mean of the yields of barley, oats, rye and wheat)

	Mean." Grain".FI	μ." Grain". WE	Potato.FI	Potato. WE
α. (1961-65)	1680	2736	14368	20567
ω. (2018-22)	3547	5717	28541	40076
ω/α	2.1	2.1	2.0	1.9

(Figure 8) represents Finnish and West European "Grains" yields (abbr. Grains: annual mean of the yields of barley, oats, rye and wheat), Grains. WE with polynomic trendline and regression of Grains.FI by Grains. WE with +/- SD. R square 81 % (p < 0.001). (Figure 9) shows Potato.FI, Potato. WE with Polynomic Trendline and Regression of Potato.FI by Potato. WE (on logarithmic scale). R square 86 % (p < 0.001)

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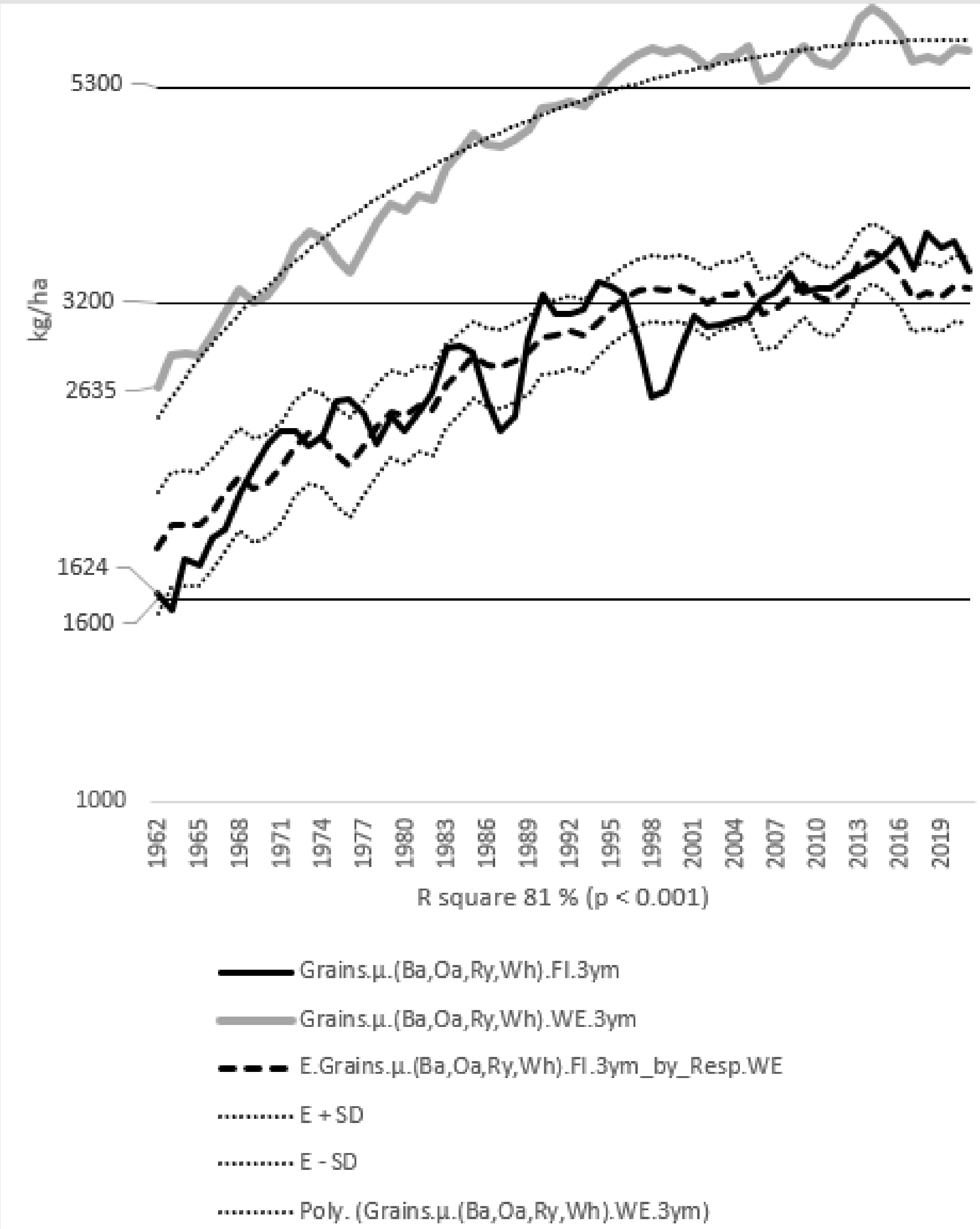

Figure 8: Grains.FI, Grains. WE (with polynomic trendline) and regression of Grains.FI by Grains. WE - Y-axis on logarithmic scale.

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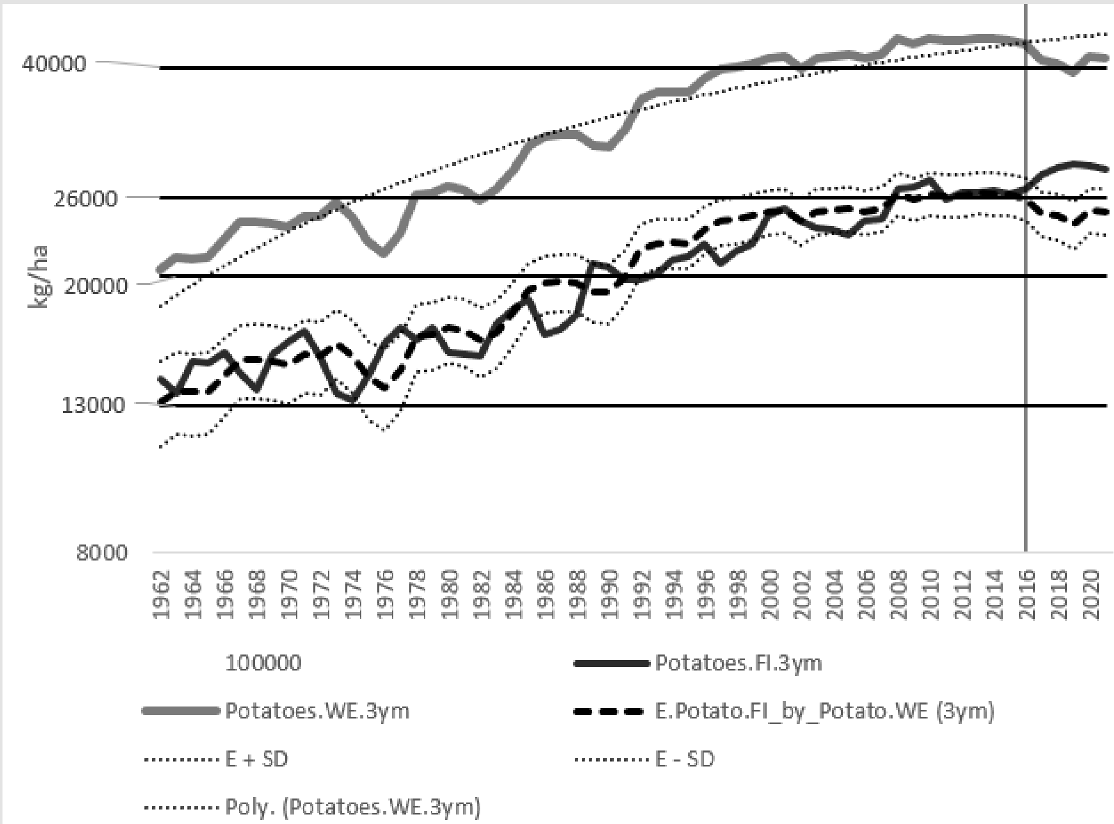

Figure 9: Potato.FI, Potato. WE with Polynomic Trendline and Regression of Potato.FI by Potato. WE - Y-axis on logarithmic scale.

Discussion

Discussion on possibility to evaluate K-balance in Finnish agricultural soils between 2018 and 2022

The conception of potassium balance of Finnish agricultural soils in 2018-2022, according to FAO [5,7] data seems not to be coherent [5,7], (Table 4): Data selection caused difference of 49 kg/ha. Both versions in Table 4 show positive K balance of agricultural soils, without Household K inputs [8], (on the other side even without agricultural losses via leakage).

Table 4: Potassium balance by FAO data.

2018-2022	Inputs			Outputs		Total
	Mineral K [5]	**Mineral K [7]**	**Manure [7]**	**Crop removal [7]**	**Seed [7]**	
Version [7]		11.2	18.4	10.6	0.7	18.3
Version [5,7]	60.2		18.4	10.6	0.7	67.3
Difference						49

Next are presented (and discussed) on approximation of potassium balance of Finnish agricultural soils in 2018-2022 based on factors: (“mineral fertilization”) [5], manure and seed [7], human input [8] leaching [9] and evaluated data on crop removal (collected data in Table 5).

Table 5: shows distribution of cropland (less fallow) used for grain, potatoes, grassland crops and others, yield of grain and potatoes (kg/ha) in 2018-2022 and their K content kg K/kg and average K uptake/ha of grasslands.

					Output/Uptake		
	Area[10]		Yield[6]	K content[11]	K/ha	Total	
	1 000 ha	%	kg/ha	g K/kg	kg/ha	kg/ ha.FI[5]	% of kg/ ha.FI
Grain	1064	52.6	3547	4.4	15,6	8.2	10.6
Potatoes	21	1	28541	5	143	1.4	1.8
Grassland crops[12]	785	38.8			175	67.9	87.6
Assessed, total		92.4					
Others (discussed)		7.6					
Cultivated area (minus fallow)	2024	100					
Output of K						77.5	100

The first step in determining potassium removal of grain, potatoes and grassland crops in 2018-2022 is determining the use of cropland less fallow by subtraction using data in [10]. Then the proportions of cropland use by grain, potatoes and grassland is divided by the remnant cultivated area and the result are given by percents (Table 5). Yields of Finnish Grain and potatoes are from (Table 3) [ω.(2018-22)].Then yields (kg/ha) were multiplied by their K content in [11], K content of potato was unequivocal, but K content of “Grain” varied moderately and selected was 4.4 % by the data in [11]. Multiplying yields of grain and potato gives their uptake per hectare. K uptake by grasslands per hectare are from the longstanding studies performed and collected by (Virkajärvi, et al. [12]). “Others” are not analyzed. The “Total” columns show the K uptake (kg/FI) or (%), i.e. how much each of the assessed crops promote the mean uptake per hectare of Finnish cultivated area (less fallow) - together 77.5 kg/ha. The area of “Others” included, by 0 kg of K/ha. That’s why the Total output can increase, but not decrease by the real K contents of “Others”. 77.5 kg/ha can be seen as a lower estimate of K output. It is many-fold higher than in [7] or in (Table 4). Pure effect of grassland crops is 68 kg to K per hectare of (Finnish cultivated areas, less fallow).

Table 6: Estimated potassium balance in Finnish agricultural soils shows components of K balance: mineral fertilization. manure, household (leakage), crop removal, seed and leaching. Household leakage by 50 %, leaching by 30 % of Mg leakage from clayish fine sand without fertilization [9].

Inputs			Outputs			K balance
	kg/ha	%		kg/ha	%	kg/ha
Mineral fertilization	60.2	75.1	Crop removal	77.5	94.1	
Manure	18.4	22.9	Seed	0.7	0.8	
Household [8]	1.6	2	Leaching [9]	4.2	5.1	
Total	80.2	100		82.4	100	2.2

Leaching of potassium is estimated by the available value of Mg leaching without fertilization: 14 kg/ha/a in clayish fine sand [9]. Because clay material is rich in minerals, this was multiplied by 0.3, with result 4.2 kg/ha. Using Mg leaching was supported by their similar medians in groundwater: Mg 4.5 and K 3 mg/l, respectively [13].

Calculation gave negative value (–2.2 kg/ha/a) to K balance. All crop plants in the group of “Others” were not presented. Mean turnip rape area (in 2018-22) was 3 %-units of this 7.6 %, most of its K uptake obviously stays on the field. If K uptake of “Others” had been 15.6 kg/ha (as by grain), they had given additional 0.076 x 15.6 = 1.2 kg K/ha/a to the Finnish K output from agricultural soils. Because of inaccuracy in K of “Others”, Household K leakage, K leaching in soil and determination of manure K, the best conclusion is to say: “K balance was in 2018-22 rather near zero, but it was/is different in cattle farms to farms without livestock. Weathering of agricultural soils is obviously increased (Closer in the next chapter).

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About History with Considerations

Soil chemistry, soil science and fertilizer industry have been developed dramatically since the years of Liebig (1803-1873) [14]. The roles of N (nitrogen), phosphor (P) and potassium (K) as plant nutrients became accepted during his working period. Optimal amounts of Ca, Mg and K have been evaluated by their "soluble" (easily) extractable contents in soil [15]. Different classifications for soil nutrients have been given by their extractable contents in 16 categories, 1 (low) - 16 (high) [16] (p. 166), or by soil types. (Table 7). gives examples of three fertility soil classes: organic, coarse mineral and clay. Extraction solution was 0.5 N ammonium acetate 0.5 N acetic acid (pH 4.65), closer in [15] and soil values were labeled, e.g. K.AAc.

Proper amounts of soil Ca, Mg and K have been evaluated even by their proportion (in equivalents) of their sum, which is an approximation of Cation Exchange Capacity (CEC) (without H+) [17] (pp 34-36) and [18]. Extraction by strong acids (e.g. by 2 M HCl, as in Finland [12]) seems to have been known since the 1950's [19], (mineral element values of HCl extraction are labeled by HCl postfix, e.g. K.HCl). Its additional promising benefits were discovered in the 1990's, in a compilation of 21 long-term (8-15 years) potassium trials, since the 1970's [12,17]. In general soil dryness decreased and moisture increased plant K. In rainy summers K changed plant mineral composition (Mg decrease), which could affect the magnitude of yield [17].

Table 7: Citation from [16] "Interpretation of potassium figures".

Fertility class	Potassium content in soil K mg/l		
	Organic soils	Coarse miner s.	Clay s.
Fair	60-100	100-150	150-200
Satisfactory	100-200	150-200	200-300
Good	200-350	250-400	300-500

The discovery of the limits of acid extractable K was developed until 2012 [12]: if K.HCl is below 500 mg/l especially on organic soils, K dressing can be planned by the K.AAc-status. If K.HCl > 600 mg/l grasses not always need K-supplementation. 95 % of maximum yield was gained by fertilization, which gave K content of grass 17.5-20 g / kg D.W. and K/N ratio was 0.85 – 0.86. The analyses in [12] (calculated by yield) decreased the estimate for "optimal" K/N ratio of grass from earlier determination, 1 [17], which was given aware that it was a higher estimate, in order to support wintering by the chloride of KCl.

This observed long-standing increased production was not possible without potassium liberation from silicates. The liberated silicon (Si) [20] is written to have several metabolic and structural benefits, e.g. to mitigate several abiotic (e.g. drought) and biotic (insects) stresses. The protective effect is partially indirect: lower need/supply of fertilizers guides roots to the deeper (wet) soil layers.

Although the soil reservoirs of nutrient mineral elements are long-standing, they can need supplementation as in old times by "soil improvement materials" and their fertilizers. Weathering and erosion of soils occurs on the continents on slopes between mountains (or hills) and oceans. Peatlands are to some extend accumulators of this flow [3,4]. Clay, the fine abrasion product of granites of ice-age (in Finland) (particle size < 0.002 mm) is formed mainly from mica by its "softness" and deposited separately from coarse mineral fractions by its physical properties [21], (p. 10). Clays are richer in trace elements than other soil-types [21] (p.16). The trace element composition of Finnish clays resembles the composition of magmatic stones [21] (p. 15), i.e. claying was/is mimicking volcanic eruption (soil rejuvenating). High Mg content of clay material is generally known, e.g. [16,17,21]. The multiplicity of liberated mineral elements can be a part of the explanation of the doubled yields. Because environmental causes restrict benefiting old "soil improvement materials" they can be (partially?) be replaced by increased use of stone meal, which has been introduced as a fertilizer as early as in 1894 [22]. Anyhow the same warnings as by claying are concerning stone meal (sensitivity on degree of moisture/dryness) [17].

Simplified weathering of silicates (e.g. $CaSiO_3$) by H_2CO_3 or by its anhydride (CO_2) binds CO_2: $CaSiO_3 + CO_2 \rightarrow CaCO_3 +$ (soluble) SiO_2 [23]. Because grasses promote this weathering (directly or indirectly), they have a climate-friendly function, as seen in [24], where, besides of soil clay, crop rotation and perennial crops sustain soil carbon. By the use of arable land [10] can be concluded that "perennial" and "rotation" [24] indicate the use of arable land for grassland crops. The difference in (WE and FI) yields after 2016 can be dependent on moisture.

Conclusions

Observed doubling in crop production and dramatic changes in relative and total NPK fertilization compliantly in Finland and Western Europe seem to be associated with proper weathering, including favourable effects on soil and climate. Grassland crops can have a climate-friendly role. effect on soil and climate, but recycling, monitoring and trials are needed.

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per area of cropland; Years: 1961 – 2022; Countries: Finland and Regions: Western Europe + (Total).

6. Crops: Products > Faostat > Data > Production > Crops and Livestock products > [Countries: >Finland [and separately the same with Regions > Western Europe + (Total)] & Items > Crops, primary > List > (Barley, Oats, Potatoes, Rye, Wheat) & Elements > Yields & Years > Select all.
7. K Balance: Faostat > Data > Land, Inputs and Sustainability > Sustainability Indicators > Cropland nutrient balance > Country (Finland) & Elements (Cropland potassium per unit area) & Items (ITEMS AGGREGATED > Select all) & Years > Select all.
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ISSN: 2574-1241

DOI: 10.26717/BJSTR.2025.60.009409

Töysa T. Biomed J Sci & Tech Res