Original Research Article

The effect of sapropel addition on soil properties and tomato yield in the open field in the south of West Siberia

New title:

Effect of sapropel addition on selected soil properties and field tomato yield in South West Siberia

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ABSTRACT

Aims: Recently freshwater lake sapropels have attracted increasing attention due to their use in agriculture and environmental engineering. To study the effect of unprocessed sapropel on soil properties and tomato (*Licopersicon esculentum* Mill.) yield we conducted a microplot open field experiment in the south of West Siberia (Russia, Asian part).

Study design: Experimental sites were located NL 54.96-55.01, EL 82.38-83.30 on agricultural loamy soils. Sapropel was added at the rate of 450 kg C_{org} ha^{-1} and 40.5 kg N ha^{-1} once at the start of the experiment after transplanting tomato seedlings into the open field. Both control (no sapropel) and sapropel-amended soil received mineral fertilizers at the rate of 30 kg N, 60 kg P and 75 kg K per hectare. Experiment was performed in factorial design, and the order of experimental units in each sites was randomized.

Place and Duration of Study: Laboratory of Agrochemistry, Institute of Soil Science and Agrochemistry, Novosibirsk, Russia, between June and September 2013.

Methodology: Major soil chemical and microbiological properties were determined at the end of the experiment. Mature tomato fruits were collected during the growing period, and their nutritional qualities determined. The data were analyzed by ANOVA and PCA.

Results: Sapropel was not found to influence tomato fruit yield that overall averaged 2.2 kg/plant, or 88,000 kg ha^{-1}, but was shown to increase lycopene content in fruits by 80% (from 19 up to 34 mg/kg), thus improving fruit quality. Sapropel had no effect on soil chemical properties, but increased soil microbial biomass nitrogen and its contribution into soil organic matter. Thus soil microbiological properties, pertaining to organic matter mineralization and nitrogen immobilization, were shown to be more responsive to sapropel addition than soil chemical properties.

Conclusion: To justify use of freshwater lake sapropel as a fertilizer agronomically, economically and ecologically one should take into consideration many factors, ranging from soil to intercultivar properties variation and temporal aspects such as after-effect.

Keywords: freshwater lake sapropel; tomato Licopersicon esculentum Mill.*; soil chemical properties; soil microbiological properties; open field experiment; the south of West Siberia, North Asia*

1. INTRODUCTION

Sapropels, i.e. organo-mineral bottom sediments of water bodies, allegedly a valuable source of diverse substances with broad economic and environmental potential, are globally rather popular objects for both basic and applied research.

The increasing popularity of environmentally safe and resource efficient technologies of agricultural production resulted in the increasing interest of farmers, decision-makers and researchers in the use of local natural resources as fertilizers and/or soil ameliorants [1, 2, 3].

The agricultural and environmental potential of such a unique natural resource as sapropel has been increasingly attracting attention also due to the growing popularity of organic agriculture [4, 5]. According to the Expert Group for technical advice on organic production [6], freshwater lake sapropels comply with the goals, criteria and principles of organic agriculture and can be used adequately.

The south of West Siberia (the Asian part of Russia) is home for more than 20,000 lakes differing in area, water regime, salinity etc., of which *ca.* 3,000 lakes with estimated sapropel stock as 2.5 billion m^3 being located in the Novosibirsk region. The use of locally produced, and hence unprocessed and cheap, fresh sapropel as a crop fertilizer by farmers in the region may be a cost-effective way to enhance agricultural production and, consequently, boost small- and middle-size farming; as a result, the regional sapropel studies have been gradually increasing [7]. Surprisingly, however, the influence of fresh sapropel addition into soil on plant growth and development is poorly studied [8].

Tomato (*Licopersicon esculentum* Mill.) is a vegetable crop of global significance, and its production has been growing recently in many countries, including Russia. Alongside large scale industrial production, small- and middle size farming, as well as private gardening are popular throughout the world, both in open field and protected conditions. The forecast of further climate warming in the Asian part of north Eurasia actualized studies of tomato growth and development in the open field of the region, including the south of West Siberia. So the aim of our study was to investigate the effect of fresh (unprocessed) sapropel addition on a) biological and marketable yield of tomatoes grown in the open field in the south of West Siberia, and b) some soil chemical and biological properties.

2. MATERIAL AND METHODS

2.1 Experimental sites

To study the effect of sapropel addition on the quantity and quality of biological and marketable tomato production a microplot open field experiment was carried out at four experimental stations during 2013 growing season in the forest-steppe zone on loamy agricultural soils not far from Novosibirsk (Russia).

The climate of the region is classified as sharply continental with average (June, July, August) maximal temperatures in summer ranging 22-26 ºC and average precipitation ranging 40-65 mm/month [9]. At each experimental station air (2 m above soil surface) and soil (2 and 10 cm depth) temperatures were monitored during daytime and the respective temperature sums calculated for the duration of the experiment, i.e. 92 days. The latter varied insignificantly among experimental stations, averaging 1335, 1353 and 1215 ºC·day for air and soil at 2 and 10 cm depth, respectively.

Experimental plots had rather high soil organic carbon and soil total nitrogen content, neutral or slightly alkaline pH, favourable for plant growth and development (Tab.1). Overall the diversity of soil properties at experimental stations where microplot field experiments were performed allows extending the obtained conclusions over a wider gradient of soil and environmental conditions.

Table 1. Geographical location of experimental sites and some chemical properties before the start of the microplot field experiment

	Site 1	Site 2	Site 3	Site 4
NL	54.96	55.01	54.98	54.97
EL	83.18	83.30	82.38	83.25
pH_{H2O}	7.51	7.18	7.90	7.06
SOC* (%)	3.70	1.71	9.25	1.45
SIC (%)	0.18	0.13	4.06	0.14
STN (%)	0.56	0.22	1.39	0.21
SIN (mg/kg)	32	61	111	68
P_2O_5 (mg/kg)	2.4	6.8	0.4	5.2
Na^+ (mg/kg)	99	40	365	24
K^+ (mg/kg)	198	100	163	103
Mg^{2+} (mg/kg)	356	240	996	396
Ca^{2+} (mg/kg)	6.9	2.9	8.8	3.1

**SOC – soil organic carbon content, SIC – soil inorganic carbon content, STN – soil total nitrogen content, SIN – soil inorganic nitrogen content, P_2O_5 – available phosphate, Na^+, K^+, Mg^{2+} and Ca^{2+} - available forms of the elements. See Materials and methods for details.*

2.2 Experimental setup

Sapropel was extracted from the bottom of Menzelinskoye freshwater lake (Novosibirsk region, Russia, NL 55.548934, EL 83.244816) and applied at the rate of 0.5 kg (fresh mass) per plant, which was equivalent to 450 kg organic carbon and 4.05 kg of organic nitrogen per hectare. Mineral fertilization ($N_{30}P_{60}K_{75}$) was applied on all experimental plots, i.e. with or without (control) sapropel addition.

Tomato plants of determinate (Rannyaya Lyubov cultivar) and indeterminate (Delta 264 cultivar) growth type, both bred by the Central Siberian Botanical Garden SB RAS (Novosibirsk, Russia) were planted June 10, 2013 at the age of 50 days into the open field microplots at the density of 1 plant per 0.25 m^2. At each experimental station the experimental setup was similar with 2 cultivars, 2 rates of sapropel addition (no addition and the tested one) and 2 replicates of each experimental variant, so overall 8 plants/microplots on each of the 4 experimental stations.

2.3 Phytomass collection and analyses

Since the growing season in the open field in West Siberia is short with rather cool nights occurring already in August (12 ºC [9]), thus preventing the majority of fruits to ripen *in situ*, tomato fruits were collected repeatedly during the growing season, starting at the end of July, as soon as they stopped increasing in size and reached technical maturity, while at the end of the experiment all consumable fruits were collected. Above- and belowground phytomass was also determined at the end of the experiment, just prior to the first night frosts in the middle of September. In ripe tomato fruits some physical and chemical properties of juice (pH, sugar and nitrate content, specific gravity) as well as sensory qualities of whole ripe fruits were estimated by standard techniques [10, 11]. Lycopene content was determined spectrophotometrically [12].
Soil samples were collected at the end of the experiment in the middle of September 2013 from 0-20 cm layer on each microplot, brought into laboratory, sieved 2 mm and stored at +4 ºC prior to analyses.

2.4 Soil sampling and analyses

Soil was sampled before the start (June 2013) and at the end of the experiment (September 2013). At each experimental microplot, i.e. from under each plant, 6 subcores were taken from 0-20 cm soil layer and bulked together to comprise one composite sample. Field-moist soil samples were 2-mm sieved and stored in a refrigerator (+4 ºC) before analyses. The content of soil organic (SOC) and soil inorganic carbon (SIC) were determined by stepwise loss on ignition method [13] using 2-4 g soil aliquots. Soil total nitrogen (STN) was determined by Kjeldahl technique. For these analyses soil was air-dried. Available forms of macronutients (NO_3^-, NH_4^+, P_2O_5) were determined in field-moist samples by standard techniques: briefly, nitrate was determined potentiometrically in 0.03M K_2SO_4 extracts, while ammonium was measured colorimetrically in 2N KCl extracts, and available P was extracted with 0.5 M $NaHCO_3$ solution and determined colorimetrically. Soil pH was measured in a supernatant of soil-water solution (1:5 v/v). Exchangeable K^+, Na^+, Ca^{2+} and Mg^{2+} were determined by atomic adsorption in ammonium citrate extracts.
Soil microbial biomass C and N were determined by fumigation extraction method [14, 15]. Soil basal respiration (CO_2) was measured as CO_2 released by soil in laboratory conditions without any amendments, while substrate-induced respiration (SIR) was measured as CO_2 released by soil in laboratory conditions after amendment with mineral nutrients and glucose at the rate of 0.8 mg C per 1 g of oven-dry soil. The ratio of basal to glucose-induced respiration was used to calculate the respiratory quotient (Q_R) [16], while the ratio of basal respiration and soil microbial biomass carbon was used to estimate the metabolic quotient (Q_{met}) [17].

2.5 Statistical analysis
The data were analyzed by ANOVA and PCA using *Statistica 6.1 software* package [18] .

3. RESULTS AND DISCUSSION

3.1 Tomato yield

At each experimental site tomato plants grew and developed fruits very well. Averaged over experimental sites tomato fruit yields were *ca.* 2.5 and 1.9 kg (fresh mass) per plant of indeterminate and determinate growth type, respectively. As 1 plant grew on 0.25 m^2, these yields were equivalent to 10.0 and 7,6 kg m^{-2}. These values are higher or equal to tomato yields reported for the open field conditions in the European part of Russia [19, 20], comparable to the ones reported for Turkey [21] or similar or even higher than glasshouse yields [22, 23]. Surprisingly, in this study tomato fruit yields were higher than the ones reported for the open field conditions in Vietnam [24], Cameroon [25]. The data confirm that tomato *Licopersicon esculentum* is a plant of great adaptability, displaying sustainable performance in the open field in North Asia under much lower temperatures as compared to the ones widely believed to be required for productive tomato growth and development.

As expected, tomato plant performance of cultivars differing in their growth type differed as well (Table 2): indeterminate growth resulted in higher average fruit mass (1.4 times, P= .016), as well as above- (2.1 times, P= .007) and belowground (2.3 times, P= .000) phytomass. It should be noted that over the recent years studies of non-consumable above- and/or belowground production of agricultural plants has been receiving increasing attention [26], but such information for tomato, especially in the open field in North Asia, are lacking.

Sapropel addition was not found to affect the quantitative characteristics of marketable tomato yields of both cultivars (Table 2.). However, the studied tomato cultivars differed significantly (almost 2 times) in their ratio of the aboveground phytomass to fruit mass, thus evidencing the higher expenses of indeterminate growth plants for fruit production as compared to that of the determinate growth plants. This ratio was not found to be influenced by sapropel addition. The latter did not affect the ratio of above- to belowground phytomass as well, which, if had increased, may have evidenced more favourable soil environment for plant development [27].

Table 2. Quantitative properties of tomato phytomass production in the microplot field experiment with sapropel amendment (mean ± standard error of the mean)

Particulars	Indeterminate growth type		Determinate growth type	
	Control	Sapropel	Control	Sapropel
Number of fruits per 1 plant (pcs)	38 ± 4	47 ± 9	48 ± 10	34 ± 8
Fruit yield per 1 plant, F, (g*)	2273 ± 238	2846 ± 911	2053 ± 416	1546 ± 444
Maximal fruit mass (g*)	165 ± 26	150 ± 37	139 ± 29	143 ± 39
Mean fruit mass (g*)	61 ± 6	59 ± 10	43 ± 2	44 ± 6
Aboveground phytomass, AG (g*)	617 ± 85	944 ± 311	362 ± 111	290 ± 124
Belowground phytomass, R, (g*)	46 ± 4	61 ± 14	22 ± 4	21 ± 3
Ratio AG/R	13.8 ± 2.3	15.1 ± 3.7	15.4 ± 3.0	14.2 ± 5.5

Ratio AG/F	0.27 ± 0.02	0.32 ± 0.04	0.16 ± 0.02	0.16 ±0.02

** Fresh mass*

ANOVA results for tomato production revealed the major part of data variance to be due to the experimental site effect (Table 3), which embraces soil and weather (solar radiation, precipitation etc.) conditions of plant growth and development. The effect of sapropel addition turned out to be a negligible part of the total data variance, both statistically and ecologically, being statistically significant only for the aboveground phytomass. As for tomato fruit yields, even if it had been found statistically significant, it would not have been significant from the economic point of view. Therefore sapropel addition for tomatoes in the open field was not justified economically by marketable yields, which agrees with the findings by other researchers in similar studies with tomato [28], as well as some other crops [29]. We have an increasing impression that the effect of sapropel on agricultural crop yields and their quality is multifaceted due to the unique biogeochemical nature of each lake sapropel [30], strongly depending on interaction between physiology and biochemistry of crops and the chemistry of sapropel [31].

Table 3. Results of multivariate and univariate ANOVA of tomato production data: the contribution of factors (%) into the total variance and the probability of null's hypothesis

Particulars	**Factor**					
	Cultivar (A)	**Sapropel (B)**	**Site (C)**	**A * C**	**B * C**	**A * B**
Number of fruits	1 (0.83)	1 (0.58)	**33 (0.05)**	12 (0.29)	3(0.77)	7 (0.13)
Fruit mass	**11 (0.04)**	0 (0.92)	**58 (0.00)**	2 (0.80)	6 (0.36)	5 (0.12)
Maximal fruit mass	1 (0.18)	1 (0.63)	**77 (0.00)**	3 (0.21)	1 (0.51)	0 (0.42)
Mean fruit mass	**24 (0.00)**	0 (0.89)	**38 (0.00)**	**22 (0.00)**	3 (0.18)	0 (0.46)
Aboveground phytomass	**30 (0.00)**	**2 (0.05)**	**46 (0.00)**	4 (0.09)	4 (0.10)	**6 (0.01)**
Belowground phytomass	**53 (0.00)**	2 (0.09)	**28 (0.00)**	**7 (0.04)**	1 (0.59)	**3 (0.03)**

Multivariate	(0.195)	(0.516)	**(0.008)**	**(0.018)**	(0.484)	(0.220)

** values with P ≤ 0.05 are highlighted in bold.*

Tomato juice pH and sugar content of fruits produced in the study were similar to the ones reported by other researchers [32, 33]. It should be reminded that in our study tomato fruits were collected at the stage of physiological maturity and then ripened during storage at room (22 ºC) temperature. The results show that at least some characteristics of fruits' nutritional quality were not compromised by such harvesting; albeit there is no doubt that nutritional quality is at its highest *in situ* ripened mature fruits [33]. These properties were not found to be affected by sapropel (Table 4). However, lycopene was shown to be significantly increased by sapropel addition in fruits of both cultivars: almost 2 times in plants of determinate growth type, and 1.6 times in plant of indeterminate growth type. Sensory qualities were not found to be affected by sapropel. Previously we found that doubling the rate of potassium fertilizer also increased lycopene content in fruits [34]. As *ca.* 15 kg ha^{-1} of potassium was added with the sapropel in the study, the mechanism for lycopene content increase in tomato fruits might be similar.

Table 4. Some chemical and sensory properties of tomato fruit juice (mean ± standard error of the mean)

Particulars	Indeterminate growth type		Determinate growth type	
	Control	Sapropel	Control	Sapropel
pH	4.38 ± 0.09	4.44 ± 0.11	4.40 ± 0.08	4.20 ± 0.12
NO_3 (mg/kg)*	0.6 ± 0.1	0.8 ± 0.1	0.4 ± 0.0	0.4 ± 0.1
Sugar(%)*	5.3 ± 0.0	5.3 ± 0.1	4.2 ± 0.0	5.1 ± 0.1
Specific gravity (g/ml)	1.022 ± 0.001	1.022 ± 0.001	1.016 ± 0.002	1.020 ± 0.002
Lycopene (mg/kg)*	18 ± 1	35 ± 3	21 ± 2	33 ± 5
Flavour (points)	3.3 ± 0.5	2.5 ± 0.4	2.0 ± 0.3	3.3 ± 0.6
Colour (points)	1.1 ± 0.1	1.3 ± 0.2	1.8 ± 0.3	1.8 ± 0.4
Aroma (points)	0.6 ± 0.1	0.5 ± 0.0	0.8 ± 0.1	0.6 ± 0.0

** fresh mass*

3.2 Soil properties at the end of the experiment

Soil chemical properties were not found to change under sapropel addition (Table 5). ANOVA, performed with these data, revealed no effect of sapropel addition, and that most (60-80%) soil chemical data variance was due to the experimental site, or, more accurately, with the whole multitude of environmental factors, associated with experimental site, such as solar radiation, precipitation, etc., which were not recorded during the experiment and hence were not explicitly accounted for in ANOVA.

However, soil microbiological properties seemed to be affected by sapropel: SMBN increased 1.7 times, while SMBN/SON increased 1.5 times. Interestingly, SMBN was the only soil characteristic experiencing the effect of all factors, i.e. cultivar, sapropel addition and experimental site (Table 6). Sapropel did not influence soil respiration, both basal and glucose induced.

Thus microbiological properties of soil, pertaining to organic matter mineralization and nitrogen immobilization, seemed to be more sensitive to sapropel addition than soil chemical properties. Our data agree with some results obtained earlier [25] that sapropel addition could affect processes and components of nitrogen transformation in soil. It is very likely that in course of our experiment some shifts in soil microbial community structure, possibly nitrogen-fixing bacteria, occurred, and this aspect invites detailed investigation.

It should be emphasized that our experimental design, i.e. several microplot experiments set up similarly on sites differing in soil and other environmental conditions (Table 1) allowed for testing the effect of sapropel addition along the gradient of soil chemical and soil ecological factors and, hence, for broader application of the results.

Table 5. Some chemical and microbiological properties of soil at the end of the microplot field experiment with sapropel addition (averaged over both studied cultivars , mean ± standard error of the mean)

Particulars	Control	Sapropel added
pH_{H2O}	7.16 ± 0.13	7.18 ± 0.18
SOC (%)	5.95 ± 0.75	5.83 ± 1.07
SIC (%)	1.65 ± 0.62	1. 66 ± 0.86
STN (%)	0.38 ± 0.06	0.38 ± 0.08
SOC/STN	20.0 ± 0.8	19.6 ± 0.7
NO_3^- (mg N·kg^{-1} soil)	38 ± 4	44 ± 8
NH_4^+ (mg N·kg^{-1} soil)	11 ± 3	7 ± 1
P_2O_5 (mg·kg^{-1} soil)	47 ± 12	27 ± 9
Na^+ (mg/kg)	125 ± 24	140 ± 45
K^+ (mg/kg)	239 ± 27	296 ± 67
Mg^{2+} (mg/kg)	577 ± 75	563 ± 127
Ca^{2+} (mg/kg)	5. 3 ± 0.8	5.4 ± 1.3
SMBC(µg C · g^{-1} soil)	342 ± 58	326 ± 77

SMBN (μg · g^{-1} soil)	60 ± 10	103 ± 27
SMBC/SMBN	13 ± 4	7 ± 2
CO_2 (μl · hr^{-1} · g^{-1} soil)	0.73 ± 0.09	0.63 ± 0.14
SIR (μl · hr^{-1} · g^{-1} soil)	3.8 ± 0.4	3.2 ± 0.6
Q_R	0.19 ± 0.02	0.19 ± 0.03
Q_{met} (μg C-CO_2 ·mg $SMBC^{-1}$· hr^{-1})	2.55 ± 0.32	2.16 ± 0.41
SMBC/SOC (%)	0.62 ± 0.09	0.56 ± 0.08
SMBN/STN (%)	2.5 ± 0.6	3.7 ± 1.2

Principal component analysis was performed to visualize the relationship between tomato production characteristics and air and soil temperature sums, soil chemical (Figure 1) and microbiological (Figure 2) properties. The analysis revealed negative relationship with temperatures, especially the air temperature sum, showing the harmful effect of high air and surface soil temperatures on tomato production process even in Siberia. Negative relationship was also displayed by tomato production characteristics and labile nutrients content in soil, indicating, most likely, their uptake by plants. Negative relationship between tomato fruit characteristics and soil organic C and N content, though, was unexpected and more difficult to explain. One can hypothesize that the higher the SOC content is, the higher the SMBC and SMBN are, consequently increasing the plant-microbe competition for available nutrients. Moreover, the effect of C and N on tomato quality parameters may not be as direct as that of K due to the role of the different plant nutrients in plant physiological processes.

Table 6. Results of multivariate and univariate ANOVA of soil microbiological properties at the end of the microplot field experiment: the contribution of factors (%) into the variance and the probability of factor's effect (in brackets)

Particulars	Factor					
	Cultivar (A)	Sapropel (B)	Site (C)	A * C	B * C	A * B
SMBC	0 (0.99)	0 (0.88)	**56 (0.04)**	1 (0.98)	2 (0.92)	2 (0.56)
SMBN	**4 (0.05)**	**13 (0.00)**	**42 (0.00)**	**11 (0.05)**	**10 (0.05)**	**5 (0.03)**
SMBC/SMBN	0 (0.81)	5 (0.36)	26 (0.25)	6 (0.77)	3 (0.90)	5 (0.34)
CO_2	0 (0.56)	**1 (0.05)**	**77 (0.00)**	1 (0.35)	2 (0.24)	**2 (0.03)**

SIR	0 (0.54)	**4 (0.02)**	**75 (0.00)**	0 (0.83)	2 (0.42)	1 (0.33)
Q_R	0 (0.65)	0 (0.96)	**74 (0.00)**	1 (0.83)	1 (0.86)	4 (0.15)
Q_{met}	4 (0.43)	2 (0.54)	26 (0.27)	1 (0.97)	7 (0.73)	0 (0.84)
SMBC/SOC	0 (0.95)	1 (0.77)	27 (0.33)	1 (0.98)	3 (0.93)	5 (0.41)
SMBN/STN	0 (0.57)	**4 (0.02)**	**85 (0.00)**	1 (0.47)	3 (0.20)	0 (0.44)
All variables	(0.60)	(0.39)	**(0.03)**	(0.82)	(0.44)	(0.41)

** values with P ≤ 0.05 are highlighted in bold.*

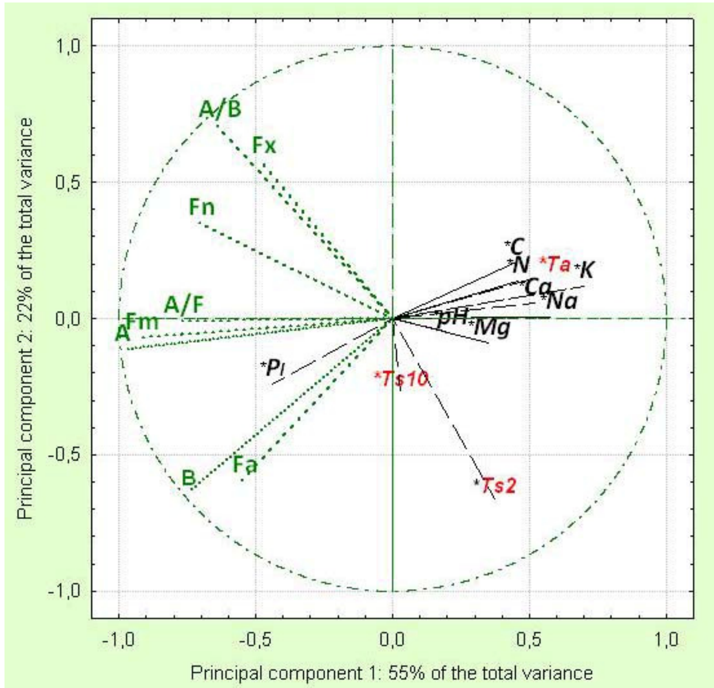

Figure 1. Location of tomato production characteristics (variables for analysis) and soil chemical characteristics (supplementary variables, *) in the plane of the first two principle components.

Abbreviations used for plant variables: A – aboveground phytomass, B – belowground phytomass, Fn – the number of fruits, Fm – fruit yield (mass), Fa – average fruit mass, Fx – maximal fruit mass, A/F – the ratio of aboveground phytomass to fruit yield and belowground phytomass, respectively.

Abbreviations used for temperature and soil chemical variables: Ta – daytime air temperature sum, Ts2 and Ts10 - daytime soil temperature sum at 2 and 10 cm depths; C and N – soil organic carbon and nitrogen, respectively.

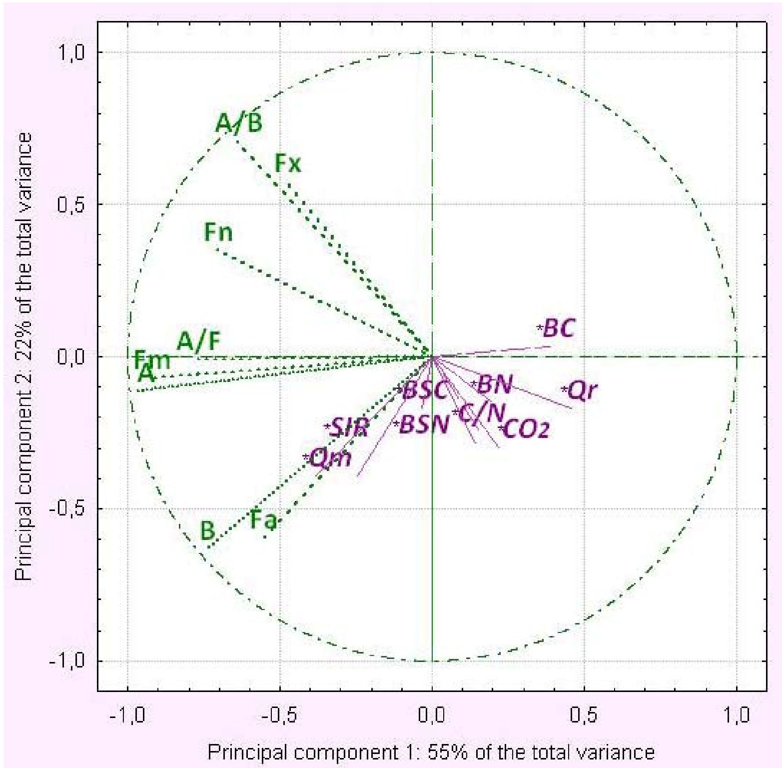

Figure 2. Location of tomato production characteristics (variables for analysis) and soil microbiological characteristics (supplementary variables, *) in the plane of the first two principle components.

Abbreviations used for plant variables: A – aboveground phytomass, B – belowground phytomass, Fn – the number of fruits, Fm – fruit yield (mass), Fa – average fruit mass, Fx – maximal fruit mass, A/F – the ratio of aboveground phytomass to fruit yield and belowground phytomass, respectively.

Abbreviations used for soil microbiological variables: Ta – daytime air temperature sum, Ts2 and Ts10 - daytime soil temperature sum at 2 and 10 cm depths; C and N – soil organic carbon and nitrogen, respectively.

4. CONCLUSION

Addition of sapropel once at the beginning of the growing season at the rate of 450 kg C/ha did not influence the biological phytomass production and marketable fruit yield of tomato plants of the two studied cultivars, grown in the open field in the south of West Siberia, and thus such fertilization is not economically reasonable. However, sapropel was found to increase significantly (by 80%) the lycopene content in fruits, improving their quality.

No changes in soil chemical properties at the end of the growing season were found due to sapropel addition, while soil microbial biomass nitrogen was shown to increase, indicating some changes in microbial community due to sapropel addition. The latter can exert some after-effect of sapropel addition in the following growing season.

More detailed (different rates of sapropel addition, recording solar radiation in the open field, etc.) and long-term experiments should be carried out to establish more solid scientific basis for sapropel use as a fertilizer from agronomic, economic and environmental points of view.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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