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Biogeosystem Technique transcendental intra-soil pulse continuous-discrete watering paradigm for soil organic matter sustainable regime and heavy metal passivation

Big Vyazyomy – Persianovka – Rostov-on-Don

We have an “Ecosphere – technology” conflict now

The climate change issue is related to soil water regime.

Current level of the land and water use needs for critical rethinking.

Outdated imitative Nature use causes:
✓soil and water health deterioration;
✓waste, biosphere, climate uncertainties;
✓false calls for outdated technologies slight modernization;
✓false calls for carbon direct sequestration.

Technological platform of Noosphere is to be developed.

The way has been proposed by Aristotle:

The “techne” is not a simple imitation. Techne helps human to find a proper niche for completion the phenomena or processes "which nature does not bring to a finish" in her nonchalance.

Aristotle

We propose a new field of science and technology for the world strategic development – Biogeosystem Technique (BGT*) transcendental (uncommon for Nature) methodology to overcome the large-scale calls:

sustainable evolution of healthy soil, water saving, high soil fertility, high quality environment – stable Biosphere and Climate system.

BGT* interdisciplinary institutional integrated solutions are environmentally and economically sound.

BGT* increases the Earth biogeochemical flux, ensuring the synthesis of highly stable biogeosystem.

Improved soil provides water and soil saving.

Water operates in pedosphere as a major soil-biological driver.
Soil-biological result of the precipitation and irrigation depends on the soil properties.
We are studying the Chernozems and Kastanozems of South Russia.
These soils are similar the most world semiarid and arid soils.
Our propositions can be extrapolated throughout the world.

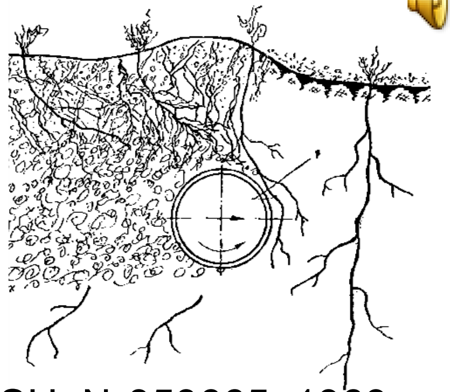
Copying the Nature leads to soil upper layer excessive dispersion and illuvial horizon dead-end porosity and heavy block structure.

Water is used improperly.

30 years after three-tier tillage, macro-aggregates of the 20-45 cm soil illuvial layer remain impervious for roots.

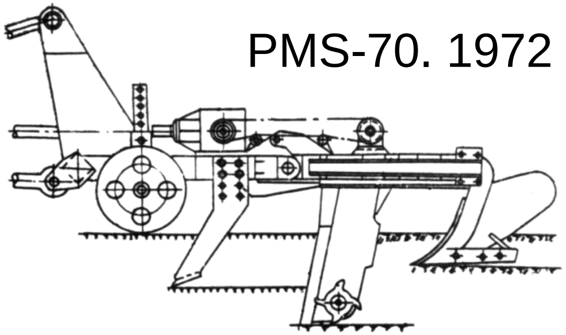
Soil improvement

BGT* intra-soil milling technology provides soil illuvial layer transcendental artificial mechanical weathering.

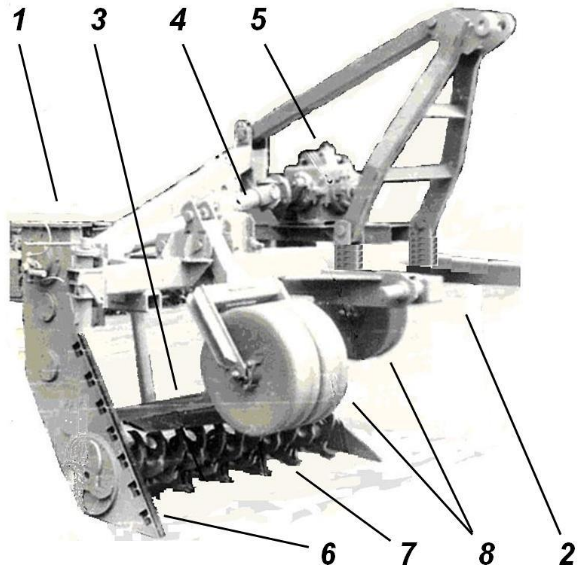


Patent SU №353665. 1969.
Milling working body fully immersed into the soil.

20-45 cm illuvial layer intra-soil milling improves micro- and mezo-aggregate structure of the soil.
Favorable conditions are creating for the rhizosphere and plants.

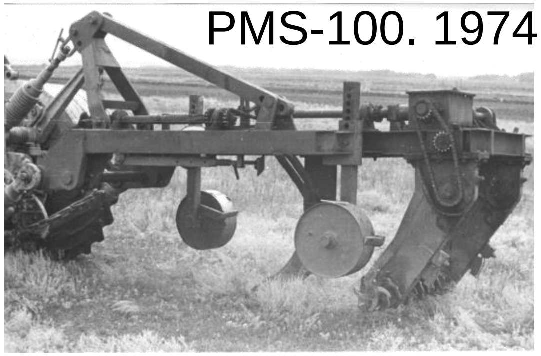


PMS-70. 1972



FS-1.3. 1976

1 – frame, 2 – hitch,
3 – topsoil layer plow, 4 – driveline,
5 – onboard reducer,
6 – final side drive,
7 – soil inner layer milling ripper, 8 – support wheels.



PMS-100. 1974

Dubovka experimental site. PMS-70 trial, 1972.

Standard agronomy practice.
Dense gray soil illuvial horizon impermeable for roots.

36 years after 20-45 cm layer intra-soil milling

Fine aggregates prevail.
The internal soil geophysical structure surface and organic-mineral structure become stable. Water penetrates the soil freely.

Soil microbiological process is optimized. C content is increased: in 0-20 cm layer for 25%, in 20-40 cm layer for 60%.

C and nutrients turnover is getting richer. Atmosphere CO_2 is sequestered to biological phase.

Ionized O_2 is released.

CH_4 and other air pollutants are oxidized.

Soil biogeochemical equilibriums become better controlled.

30 cm depth
Soil structure is stable. Roots.

35 cm depth
Soil structure is stable. Roots.

40-45 cm depth
Good soil aggregate structure. Roots.
No signs of illuvial horizon restoration.

Intra-soil milling ripper PMS-280
Factory test

New development

The mills on the horizontal shaft.

The cutters on the outer edge of the annular chisel provide soil slotting.

Passive traction resistance reduced for 10 times.

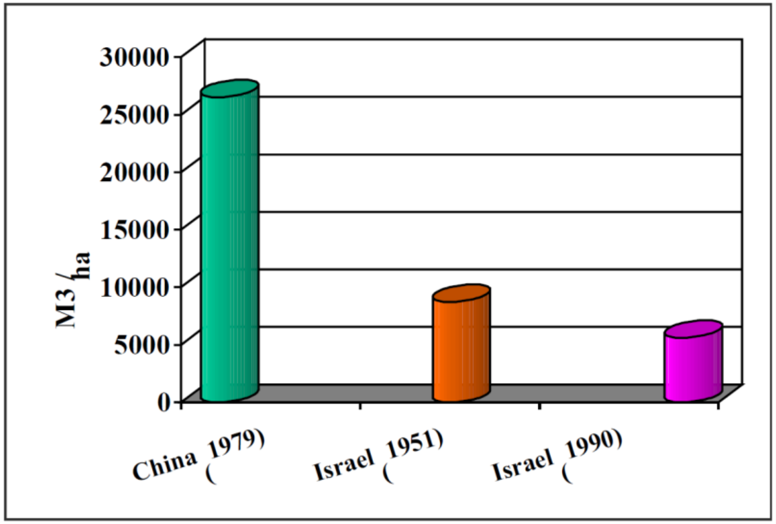
Performance 2 times higher than before.

Processing of the illuvial soil layer.
Long-term mineral-water interfaces improvement.
Fine soil aggregate system.

Water scarcity. Current irrigation paradigm

Irrigation consumes about 95% planet’s freshwater resources. This amount is for 4-15 times greater compared to empirical assessments of plant requirement for water.
The current outdated irrigation paradigm is imitating, gravitational, frontal, and continuous-isotropic.

Water consumption for irrigation, m^3/ha per year.

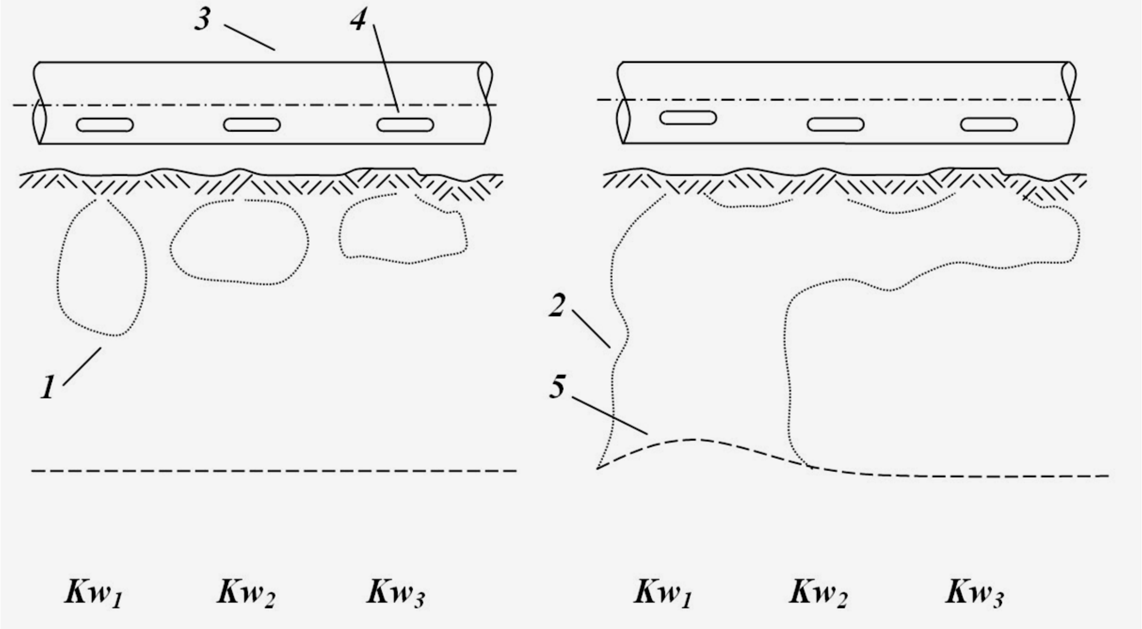


In the world – up to 50 000 m^3/ha per year.

USA
Water consumption up to 6 ft per year

Drip irrigation

Water consumption is up to 12 000 m^3/ha



Drip irrigation causes a profile and lateral water loss. This is due to the emitter water discharge deviation.

The local soil over-moistening, dispersion, and soil and vadose zone water preferential fluxes are significant.

Current simulating gravitational frontal continuous-isotropic irrigation paradigm is environmentally dangerous.

Uncontrolled preferential soil solution fluxes manifestations in the dry steppe chestnut soil profile (Kastanozem)

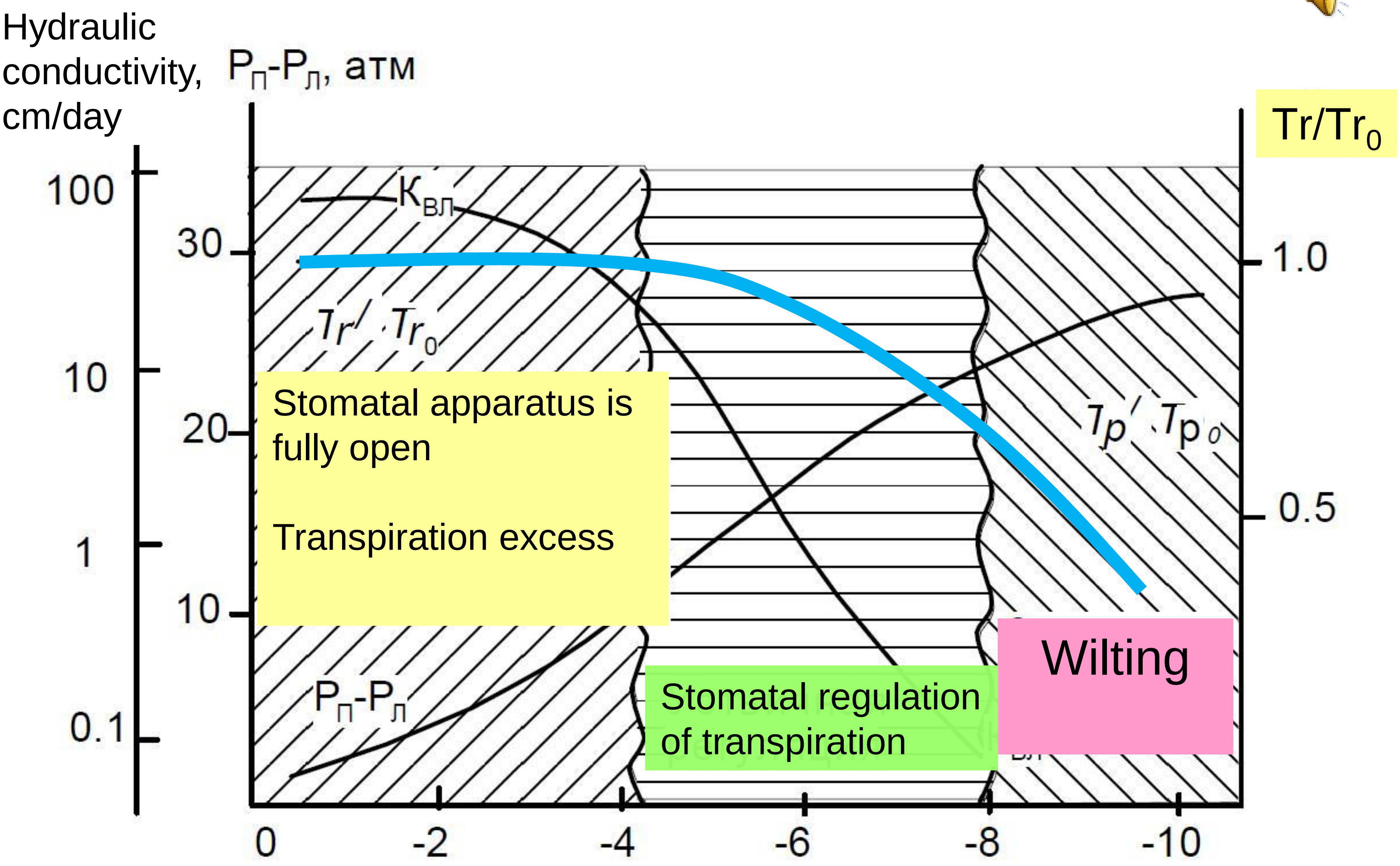
The combination of a phase of water supply to the soil and a phase of water spreading in the soil is *a systemic hydrological “defect” of the biosphere.*

Imitating nature in irrigation, a man imitates accordingly this *hydrological defect.*

Imitation leads to excessive soil wetting to the soil total capacity state (TC 0.0 MPa), which then transforms to the field capacity (FC −0.033 MPa).

At irrigation (including greenhouse business), the soil water potential is too high for most plant species growth.
The plant’s stomatal apparatus is fully opened.
Soil solution is extremely diluted, and plants pump out the excess water.
Soil aggregates become dispersed.
A high soil moisture is to be maintained. Otherwise a poor soil aggregate system limits a plant growth and productivity **(blue curve)**.

Standard irrigation results:
Excessive evaporation and transpiration, soil and vadose zone preferential water fluxes, irreversible water loss, soil and landscape degradation.



Hydraulic conductivity, cm/day

Tr/Tr_0

Stomatal apparatus is fully open

Transpiration excess

Stomatal regulation of transpiration

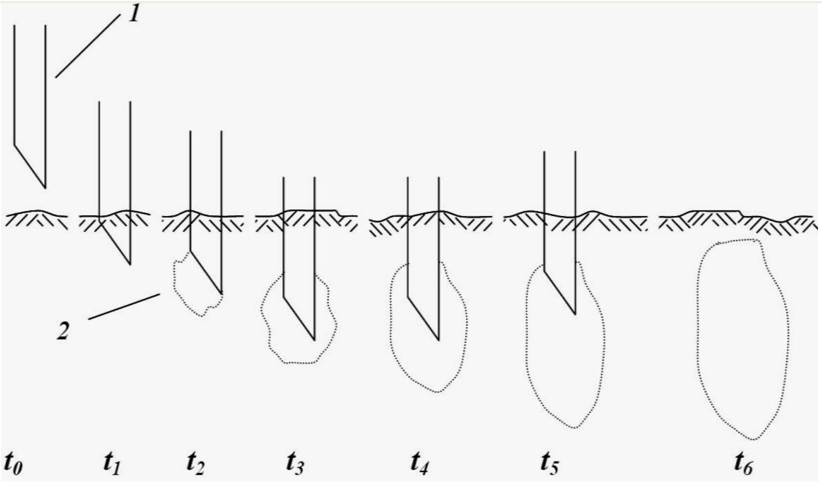
Wilting

P – thermodynamic water potential, bar

Relative transpiration (Tr/Tr_0)

BGT* Intra-soil pulse continuous-discrete paradigm of watering. This is a transcendental approach, dividing a phase of the water supply to soil, and a phase of water spread in soil.

Water **is injected** with a syringe 1. The injection stages are t_0-t_5. Water dissipates into the preliminary moistening cylinder 2. Its diameter is circa1.5–2.5 cm, a depth is of 10–35 cm. In 5–10 min **after injection**, water redistributes via capillary, film and vapor transfer.
Ambient dry soil carcass forms the soil stable geophysical mechanical aggregate structure.
Soil overwatering is excluded. No excessive dispersion of the soil aggregate structure.
Plants are supplied with the soil solution of optimal concentration.
There is no need for plants to pump out the excess of water.
Evaporation and seepage of water are reduced. Stomatal apparatus regulates transpiration.
CO_2 fertigation is provided. Best conditions are ensured for soil biota.
Plant biological productivity is highest at soil water potential around −0.3 MPa **(red curve).**

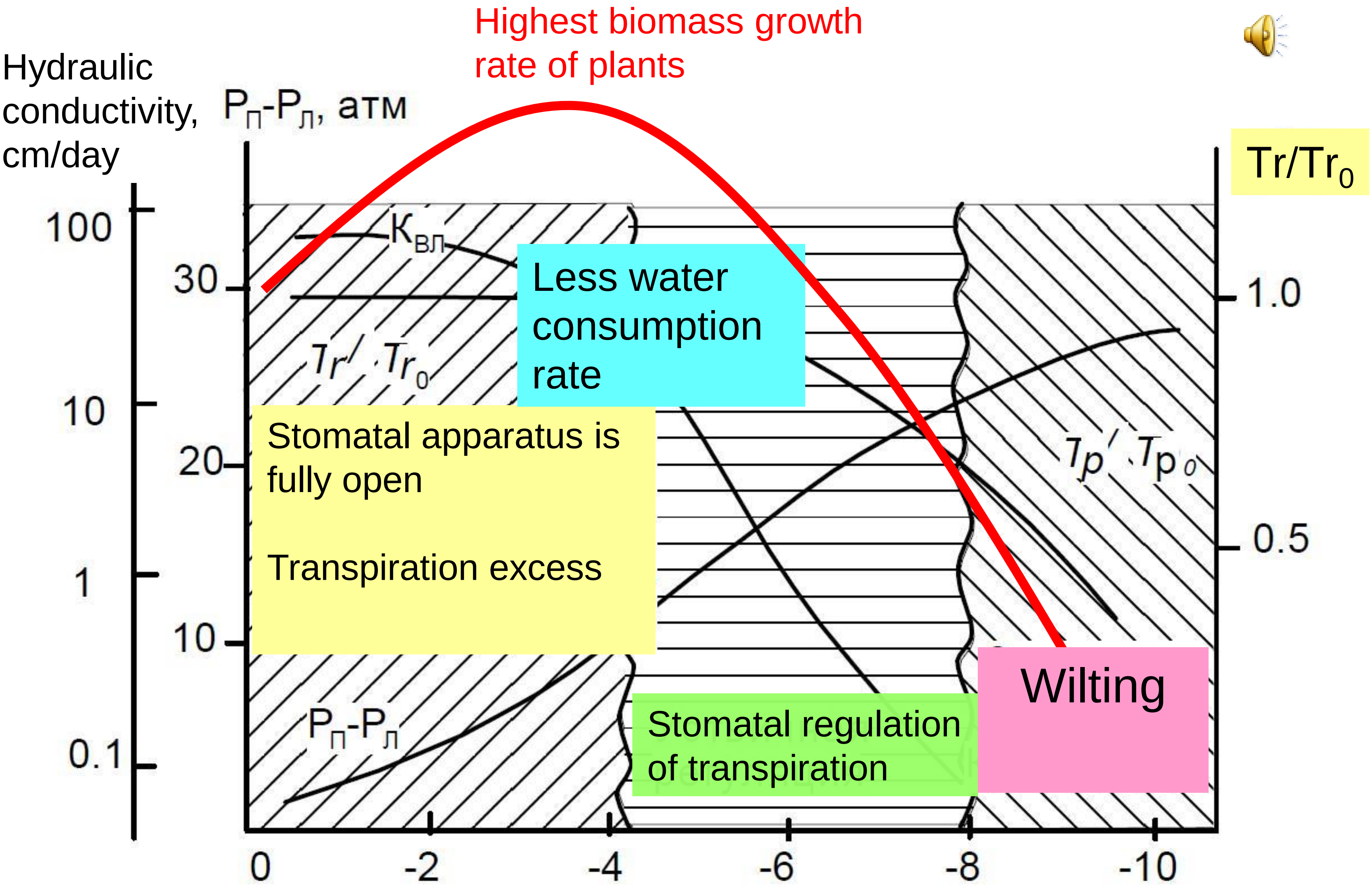


Biotechnology, mechatronics, robotics.

Water consumption is reduced for 5-20 times.
Resource and energy economy – for 10-30 times.

Water is supplied precisely into the individual soil volume without transition through the soil continuum.

Most dangerous greenhouse gas H_2O release reduces.



Highest biomass growth rate of plants

Less water consumption rate

Stomatal apparatus is fully open

Transpiration excess

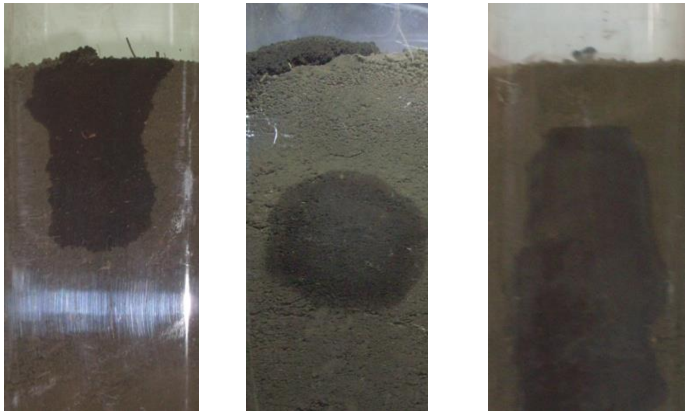
Stomatal regulation of transpiration

Wilting

P – thermodynamic water potential, bar

Relative transpiration (Tr/Tr_0)

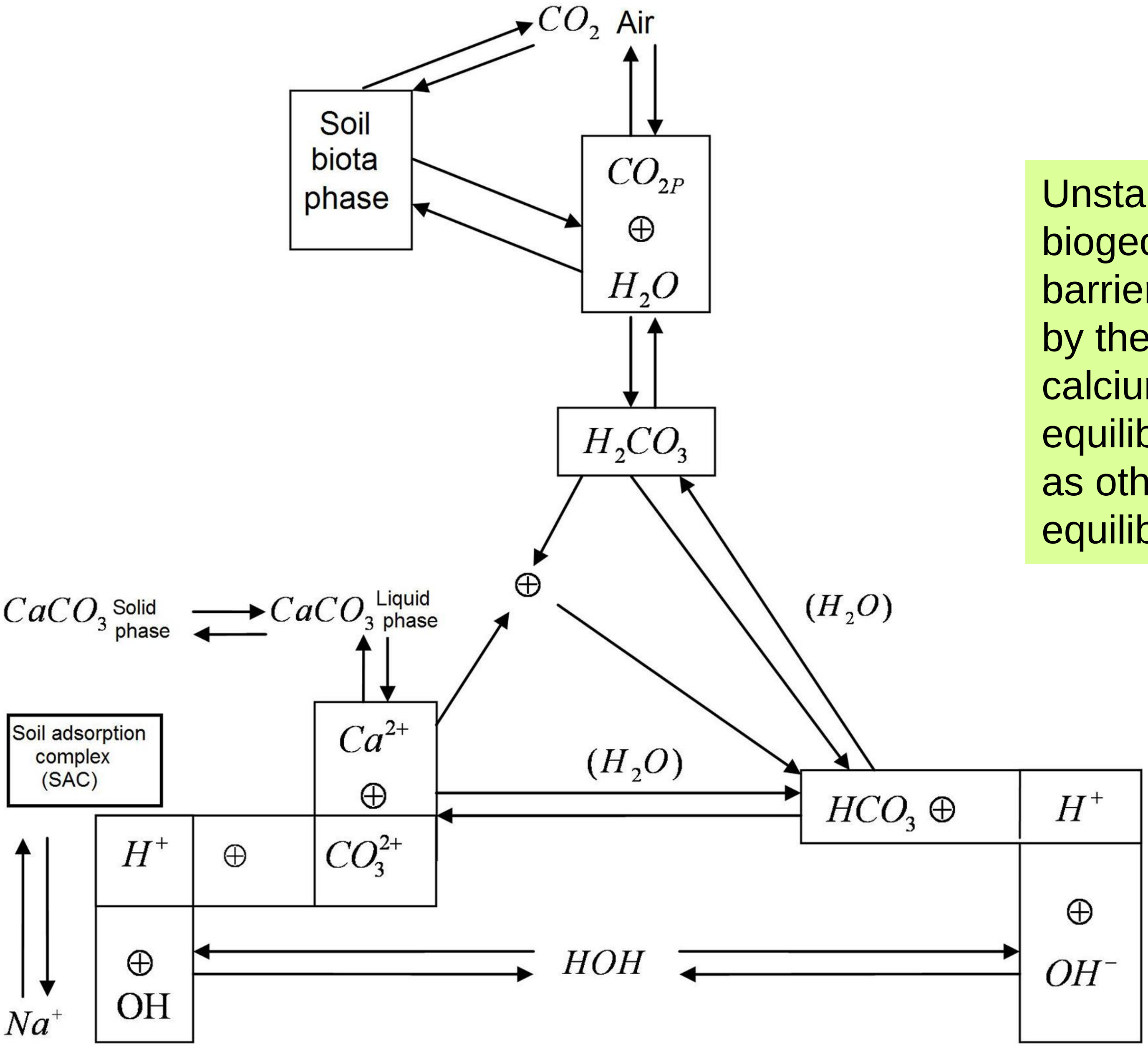
Intra-soil pulse continuous-discrete watering (model experiment)



No soil dispersion.
Spring barley seedlings are in optimal condition.

Standard irrigation

Standard irrigation
Soil dispersion is obvious – cracks, crusts, subsidence, and deformation of soil carcass.
The spring barley seedlings are weakened.



Unstable soil biogeochemical barriers are caused by the soil solution calcium-carbonate equilibrium, as well as other chemical equilibriums.

Ion association in soil solution

The electrically neutral ion pairs $CaCO_3^0$, $CaSO_4^0$, $MgCO_3^0$, $MgSO_4^0$ are formed in the soil solution, and the charged ion pairs $CaHCO_3^+$, $MgHCO_3^+$, $NaCO_3^-$, $NaSO_4^-$, $CaOH^+$, and $MgOH^+$ as well. The ion associates, mineral and organic complexes influence the transfer and accumulation of the mineral and organic matter.

The ion activity in soil solution determines dynamics of material composition, migration, and accumulation of salts into the soil continuum aggregate system, vadose zone, saturation zone, and landscape.

Soil solution material balance

$$\sum Ca^{2+} = [Ca^{2+}] + [CaCO_3^0] + [CaHCO_3^+] + [CaSO_4^0] \qquad (1)$$

$$\sum Mg^{2+} = [Mg^{2+}] + [MgCO_3^0] + [MgSO_4^0] \qquad (2)$$

$$\sum Na^{2+} = [Na^{2+}] + [NaCO_3^-] + [NaSO_4^-] \qquad (3)$$

$$\sum CO_3^{2-} = [CO_3^{2-}] + [CaCO_3^0] + [MgCO_3^0] + [NaCO_3^-] \qquad (4)$$

$$\sum HCO_3^- = [HCO_3^-] + [CaHCO_3^+] + [MgHCO_3^+] \qquad (5)$$

$$\sum SO_4^{2-} = [SO_4^{2-}] + [CaSO_4^0] + [MgSO_4^0] + [NaSO_4^-] \qquad (6)$$

where $\sum Ca^{2+}$, $\sum Mg^{2+}$ and others are the total concentrations of ions; $[Ca^{2+}]$, $[Mg^{2+}]$, and others are the equilibrium concentrations of ion free forms; and $[CaCO_3^0]$, $[MgCO_3^0]$, and others are equilibrium concentrations of ion associated forms (ion pairs).

Equilibriums

The ionic pair dissociation constants *K* for groups of cations were determined with Eqs. (7)–(9):

$$K_{CaCO_3} = \frac{[Ca^{2+}][CO_3^{2-}]}{[CaCO_3^0]};\ K_{CaHCO_3} = \frac{[Ca^{2+}][HCO_3^-]}{[CaHCO_3^+]};\ K_{CaSO_4} = \frac{[Ca^{2+}][SO_4^{2-}]}{[CaSO_4^0]} \tag{7}$$

$$K_{MgCO_3} = \frac{[Mg^{2+}][CO_3^{2-}]}{[MgCO_3^0]};\ K_{MgHCO_3} = \frac{[Mg^{2+}][HCO_3^-]}{[MgHCO_3^+]};\ K_{MgSO_4} = \frac{[Mg^{2+}][SO_4^{2-}]}{[MgSO_4^0]} \tag{8}$$

$$K_{NaCO_3} = \frac{[Na^{+}][CO_3^{2-}]}{[NaCO_3^-]};\ K_{NaSO_4} = \frac{[Na^{2+}][SO_4^{2-}]}{[NaSO_4^-]} \tag{9}$$

Using the dissociation constant (Eqs. (7)–(9)), and thermodynamic equilibrium constants K^0, the equation system of ions material balance in Equations (1)–(6) were transformed as follows:

Transformed equation system

$$\sum Ca^{2+} = [Ca^{2+}]\left(1 + \frac{[CO_3^{2-}]}{K_{CaCO_3}} + \frac{[MgCO_3^-]}{K_{CaHCO_3}} + \frac{[SO_4^{2-}]}{K_{CaSO_4}}\right) \tag{10}$$

$$\sum Mg^{2+} = [Mg^{2+}]\left(1 + \frac{[CO_3^{2-}]}{K_{MgCO_3}} + \frac{[HCO_3^-]}{K_{MgHCO_3}} + \frac{[SO_4^{2-}]}{K_{MgSO_4}}\right) \tag{11}$$

$$\sum Na^{2+} = [Na^{2+}]\left(1 + \frac{[CO_3^{2-}]}{K_{NaCO_3}} + \frac{[SO_4^{2-}]}{K_{NaSO_4}}\right) \tag{12}$$

$$\sum CO_3^{2-} = [CO_3^{2-}]\left(1 + \frac{[Ca^{2+}]}{K_{CaCO_3}} + \frac{[Mg^{2+}]}{K_{MgCO_3}} + \frac{[Na^{+}]}{K_{NaCO_3}}\right) \tag{13}$$

$$\sum HCO_3^{-} = [HCO_3^{-}]\left(1 + \frac{[Ca^{2+}]}{K_{CaHCO_3}} + \frac{[Mg^{2+}]}{K_{MgHCO_3}}\right) \tag{14}$$

$$\sum SO_4^{2-} = [SO_4^{2-}]\left(1 + \frac{[Ca^{2+}]}{K_{CaSO_4}} + \frac{[Mg^{2+}]}{K_{MgSO_4}} + \frac{[Na^{+}]}{K_{NaSO_4}}\right) \tag{15}$$

Thermodynamic equilibrium constants were recalculated to the concentration dissociation constants by Davies via Eq. (16):

$$\mathrm{p}K = \mathrm{p}K^0 - \mathrm{A}\Delta \mathrm{z}^2\left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.2I\right), \tag{16}$$

where *K* denotes the concentration constant of dissociation of the ionic pairs; K^0 is a corresponding thermodynamic constant; *A* is the Debye–Huckel constant 0.5085 at 25°C: Δz^2 is the algebraic sum of the squares of individual particle’s charge (ion or associate); and *I* is the ionic strength of solution.

The first iteration step soil solution formal ionic strength was calculated using ion analytical concentration (Eq. (17):

$$I = 0.5[2^2(\mathrm{Ca}^{2+}) + 2^2(\mathrm{Mg}^{2+}) + (\mathrm{Na}^+) + 2^2(\mathrm{CO}_3^{2-}) + (\mathrm{HCO}_3^-) + 2^2(\mathrm{SO}_4^{2-}) + (\mathrm{Cl}^-), \mathrm{mol\ L}^{-1} \tag{17}$$

The next iteration step soil solution effective ionic strength *I** was calculated using ion and associated ions equilibrium concentration via Eq. (18):

$$I^* = 0.5([2^2[\mathrm{Ca}^{2+}] + 2^2[\mathrm{Mg}^{2+}] + [\mathrm{Na}^+] + 2^2(\mathrm{CO}_3^{2-}) + (\mathrm{HCO}_3^-) + 2^2(\mathrm{SO}_4^{2-}) + [\mathrm{CaHCO}_3^-] + [\mathrm{MgHCO}_3^-] + [\mathrm{NaCO}_3^-] + [\mathrm{NaSO}_4^-] + [\mathrm{Cl}^-]), \mathrm{mol\ L}^{-1} \tag{18}$$

Using the soil solution effective ionic strength *I**, the concentration dissociation constants were recalculated via Eqs. (7)–(9) for the next iteration step.

The activity coefficient (*y*) of free ions and associates (Eq. (21):

$$-\lg y = Az^2\left(\frac{\sqrt{I^*}}{1+\sqrt{I^*}} - 0.2I^*\right) \tag{19}$$

The next iteration step was made using the recalculated *K* values.

HMs activity in soil solution

A potentially hazardous HM in soil can be considered as a microelement. Its thermodynamic state in soil solution can be characterized by the microelement association coefficient $k_{as(ME)}$ as a degree of potentially hazardous HM binding into associates and complexes with main soil solution ions:

$$C_{ME} = \left(1 + k_{asME}\right)\left[C_{ME}\right],$$

where $C_{(ME)}$ is the total concentration of microelement in solution, and $[C_{(ME)}]$ is the equilibrium concentration of free microelement (or any HM) ion.

Taking into account the coefficients of ion association, the molar fractions of free and bound HM ion are as follows:

$v_{free} = 1/(1 + k_{asME})\cdot 100$, %,

$v_{bound} = 100 - v_{free}$.

In the case of hazardous ion, the higher the k_{asME} value, the lower the hazard for ecosphere.

The association coefficient $k_{as(ME)}$ for Pb^{2+} is as follows (Eq. 20):

$$k_{asPb} = \frac{\left[CO_3^{2-}\right]}{K_{PbCO_3}} + \frac{\left[CO_3^{2-}\right]^2}{K_{Pb(CO_3)_2}} + \frac{\left[HCO_3^{-}\right]}{K_{PbHCO_3}} + \frac{\left[SO_4^{2-}\right]}{K_{PbSO_4}} + \frac{\left[Cl^{-}\right]}{K_{PbCl}} + \frac{\left[OH^{-}\right]}{K_{PbOH}} + \frac{\left[OH^{-}\right]^2}{K_{Pb(OH)_2}} \qquad (20)$$

Unstable Pb associates were not considered.

Intra-soil milling and intra-soil pulse continuous-discrete watering provide better soil solution equilibriums control.

This decreases a soil organic matter mobility and leaching.
At the same time, the heavy metal association and complexation rate become higher, and heavy metal bioavailability is reduced.

Biogeochemical barriers “soil – plant”, “soil – vadose zone” are reliable.

Climate system will become certain.

We have proposed the BGT* methodology for the new environmentally safe robotic high level soil – water – organic matter – mineral matter engineering.

We promote the BGT* as a new niche for harmony which Aristotle has called us to.

BGT* is an alternative method (maybe the only method) to enhance the efficiency of policy makers and managers in the Noosphere.

We offer the BGT* approach as a framework of the international scientific and technical project. It will be a contribution to the development of high world level nature-based technology.

Reason to accept our point of view

Research, patents and applied results acknowledgement:

- Golden medal of VDNKh (Exhibition of Achievements of the National Economy of the USSR), 1975;
- Silver medal of VDNKh, 1976;
- Bronze medal of VDNKh, 1977 and 1986;
- Vernadsky Award, 2008;
- Golden medal of X Moscow International Saloon of Innovation and Investment, 2010;
- Golden medal of All-Russia Exhibition Center (Exhibition “Golden Autumn”), 2010;
- Two Silver medal of All-Russia Exhibition Center (Exhibition “Golden Autumn”), 2010;
- Bronze medal of All-Russia Exhibition Center (Exhibition “Golden Autumn”), 2010;
- Diploma of IX Investment Economical Summit, Sochy, 2010;
- Diploma of High Technology Exhibition, Rostov-on-Don, 2010.

Vernadsky Award, 2008

Thank you for your kind attention

Colleagues with V.P. Kalinitchenko (right)