MAIN PRINCIPLES OF PLANTS CULTIVATION FOR THE LIFE SUPPORT SYSTEM'S PHOTOSYNTHESIZING LINK AND TERRESTRIAL APPLICATION

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Cardinal problems of formation of BLSS PHOTOSYNTHESIZING LINK:

1. Full satisfaction of the human requirements in plant food.
2. High productivity of edible biomass
3. Using human liquid and solid wastes as a source of elements for plant mineral nutrients in a closed system.
4. Higher plants and BLSS technologies of wastes utilization

1. Full satisfaction of the human requirements in plant food.

- **Starting with human requirements, the vegetative portion of the daily ration should contain:**
- **1) 45–50 g of protein;**
- **2) 20–25 g of fats, of which 3–6 g are essential fatty acids;**
- **3) 400–500 g of carbonhydrates, of which about 80% are in the form of starchy polysaccharides;**
- **4) the required quantity of vitamins and mineral components;**
- **5) a sufficiently and subjectively determined collection of components that can guarantee gustatory variety.**
- ***These human requirements can realistically be provided only by creating a higher plant link composed of many species*.**

The main crop for the higher plant link wheat was preferred in BIOS-3 as because of high product quality and a simpler cultivation technology and product processing.

- Wheat occupied about 40% of sown area of photosynthesizing link (left). The plants were cultivated in air subirrigated culture. A planting plate with plants is shown (right). To use the phytotron light area more effectively, the planting plates were first positioned at short intervals, being fitted into slots of special stands. As the plants grew, the plates were transferred, and the distance between them increased. The position changed many times until stem elongation. After that the nutrition area of the plant remained constant until maturity. The planting density was 1600–3200 plants/m^2 during the first days of their life cycle and 800–1100 plants/m2 from stem elongation to maturity.

Many oil-producing (oleaginous) plants were investigated while keeping in mind the general criteria enumerated above for selecting closed-system crops. Chufa, *Cyperus esculentus L.* was a more promising crop. Chufa multiplied by vegetative propagation, forming numerous edible tubers on its root system that was 15–20 mm long and 5–10 mm wide .

Crop of chufa, *Cyperus esculentus L.*, occupied about 35% of sown area in BIOS-3

Dried chufa tubercles contained 20–25% fats, about 60% carbohydrates, of which about a half were starch types, and around 8% proteins. Experiments that included 130 g/day of chufa in the human diet showed that the test subjects experienced no negative reaction to this product (Okladnikov *et al.*, 1977). 100–150 g/day of chufa tubercles fully satisfied the human daily requirement for vegetable fats, including essential fatty acids. Besides, chufa could supplement wheat in providing carbohydrates, including polysaccharides.

When wheat and chufa provided the main dry-mass portion of the human vegetable ration in a closed system, then 10–20% of the growing area was left for cultivating vegetables.

The fragment of the photosynthesizing link with vegetable plants (radish and beet) in BIOS-3

- **Crops such as cucumber, tomato, potato, beet, radish, dill, kohlrabi, sorrel, and a number of others were included in the composition of the higher plant link.**

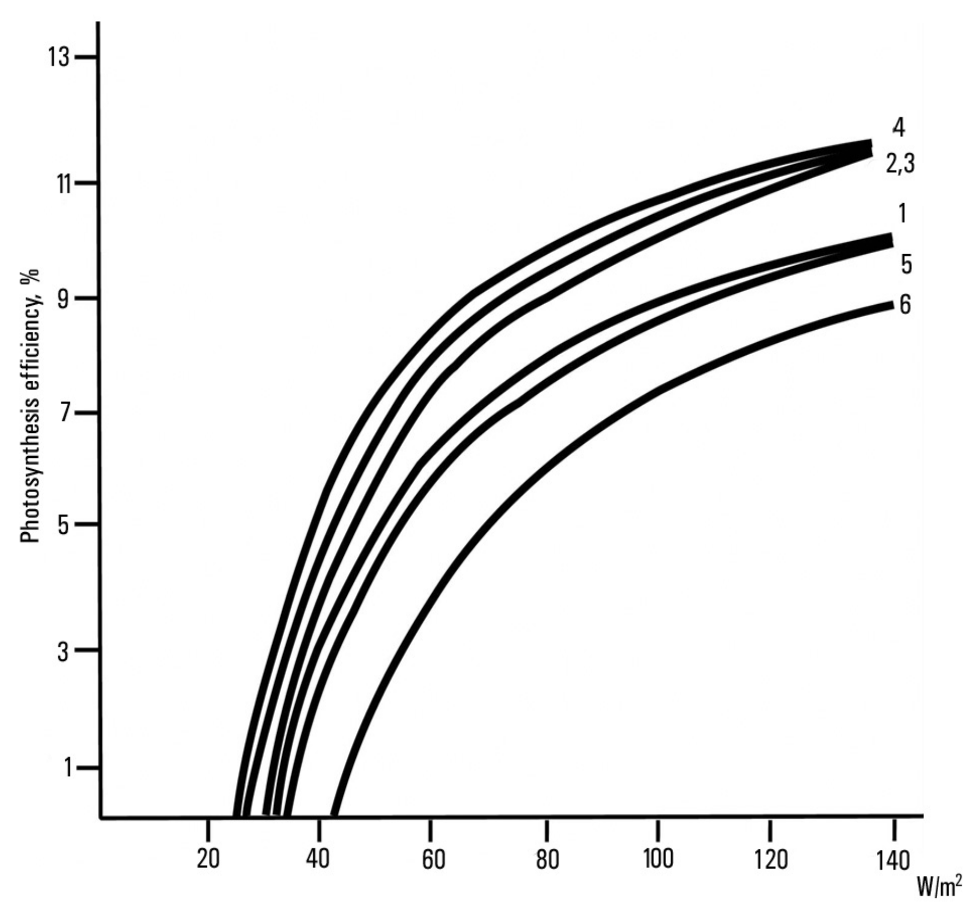
Table . Productivity of different crops in the Bios-3 phytotrons

Crop, cultivar	Growth period, days	Yield for the growth period, g/m2			
		Total		Edible	
		fresh	dry	fresh	dry
Wheat cv. 232	63	–	3182	–	1118
Chufa	90	14500	4556	4464	2476
Carrot cv. Chantane	80	24219	3491	12322	1709
Beet cv. Bordo	80	17149	1813	7125	927
Radish cv. Virovsky White	27	8705	624	5330	342

2.ПУТИ ДОСТИЖЕНИЯ High productivity of edible biomass and high harvest index.

1) the role of photosynthetically active radiation (PAR)

a) energy characteristics



- It is well-known that light saturation of a separate leaf lies in an approximate diapason of 100-150 Wt/m^2 PAR. In the figure it is seen that light saturation of photosynthesis for canopies is significantly higher. It means that canopy productivity will increase under PAR intensity more than 150 Wt/m^2.
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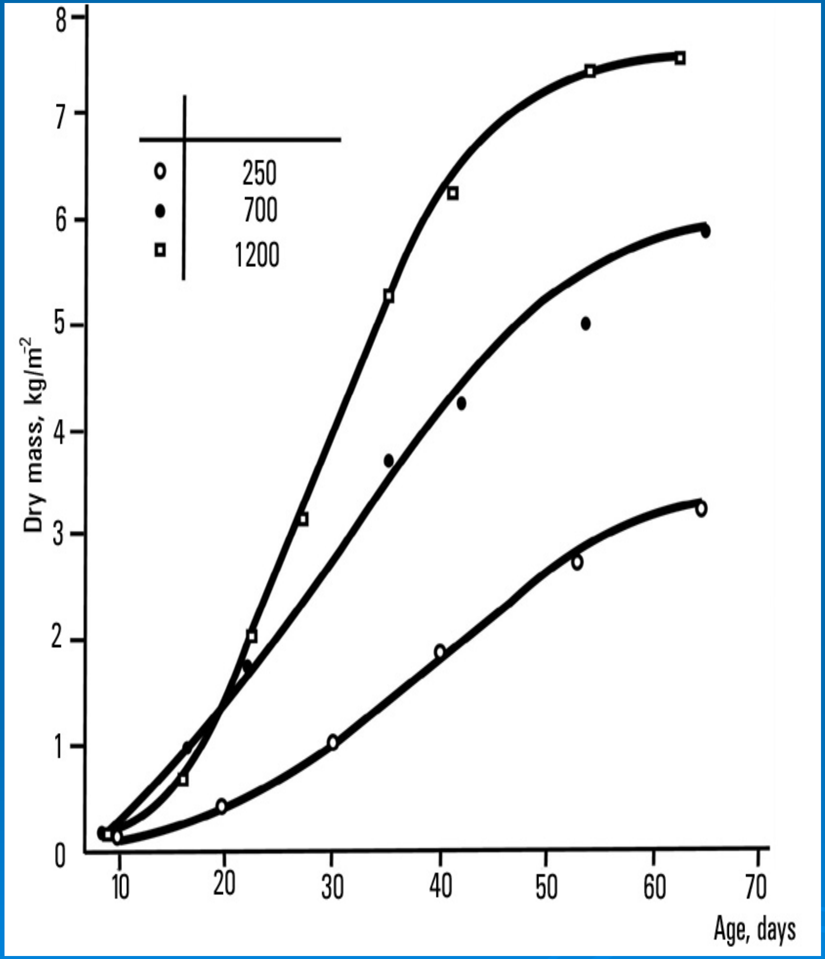
- Figure. Efficiency of wheat cenosis photosynthesis vs. radiant flux rate for plant age: 1—17–18 days; 2—22–24 days; 3—26–27 days; 4—33–34 days; 5—44–45 days.

Figure . The age dependence of accumulation of dry biomass of shoots in wheat crops at various (250–1200 W/m^2) PAR irradiances .



- The wheat cenosis was able to respond with an increase in total productivity and in grain productivity when the radiant stream measured from 700–1200 W/m^2 PAR, when it passed the PAR in noontime sunlight by double or more (Figure). But this productivity at heightened PAR levels was achieved only by substantially changing the structure of the wheat cenosis itself to significantly increase the plant stand density from 500–800 plants/m^2 to 2000–4000 plants/m^2

Fig .Average size of radish plant at 400 Wt/m^2 PAR irradiance by xenon lamp

- At increase of PAR irradiance from 100 to 650 Wt/m2 the radish root yield increased from 4.2 до 15.5 kg/m^2 .

Table. Productivity of plants in the “BIOS-3” phytotrons at high radiation intensity (280-300 W/m2 PAR) versus the ‘usual’ intensity (150-180 W/m^2 PAR)

Culture	Productivity, g/m^2 · day (dry biomass) at usual PAR intensity 150-180 W/m^2		Productivity, g/m^2 · day (dry biomass) at 280-300 W/m^2 PAR		Deviation of productivity (%) at high PAR intensity in comparison with usual accepted as 100%	
	Total biomass	Edible biomass	Total biomass	Edible biomass	Total biomass	Edible biomass
Wheat	46.48	187.9	53.77	18.56	+ 15.7	- 1.2
Chufa	55.27	27.14	80.53	39.28	+ 45.7	+ 44.7
Cucumber	36.76	16.60	59.92	24.16	+ 63.0	+ 45.5
Sugar beet	52.38	29.94	56.47	37.28	+ 7.8	+ 24.5
Table beet	44.79	29.44	67.81	31.26	+ 51.4	+ 6.2
Pea	87.65	26.33	82.13	27.10	- 6.3	+ 2.9
Vegetable beans	66.94	9.58	23.63	3.63	- 64.7	- 62.1
Radish	60.32	6.10	7.63	4.03	- 26.1	- 33.9

The high radiation intensity led to a certain increase of temperature of air and plant leaves and root-inhabited environments. As a result, the plants of different species treated as the structural elements of the conveyor displayed an ambiguous reaction to the increase in irradiance (Table). The productivity of the total and edible biomass of the thermophilic cultures (chufa, cucumbers, table and sugar beets) increased, whereas the non-thermophilic cultures (radish, beans, peas and wheat) reduced rather than increased their productivity.

b) spectral characteristics

Table. Productivity and harvest structure of the wheat grown in certain regions of PAR at the radiant flux intensity of 100 and 600 W/m2

Radiant flux, W/m2	PAR region, nm	Total number of		Mass of 1000 seeds, g	Growth period, days	Daily average productivity, g/m2 · day (dry mass)	
		shoots	seeds			Total biomass	Seeds
100	400–500	1.0	7.0	15.9	85	7.4	1.2
	500–600	1.7	20.5	33.0	80	20.6	8.6
	600–700	1.1	20.8	27.0	80	19.3	8.0
600	400–500	1.0	27.1	30.8	80	23.3	9.6
	500–600	3.0	41.7	29.8	75	47.1	16.7
	600–700	3.2	55.3	30.4	75	51.8	22.8

The table analysis shows that with increase of light intensity efficiency of red rays reduces, and the same time efficiency of blue rays grows.

- Similar experiments with some other crops (cucumber, tomato, maize, etc.) proved that intensively cultivated plants of different species exhibit specific responses to certain spectral regions. It should be noted that none of the separate spectrum regions (blue, green, and red light) caused higher productivity than that obtained in “white” light.
- **Nevertheless, various combinations of 2 or 3 components, with one or another radiation prevailing, may be more effective than the equal-energy “white” light with equal fractions of blue, green and red light**

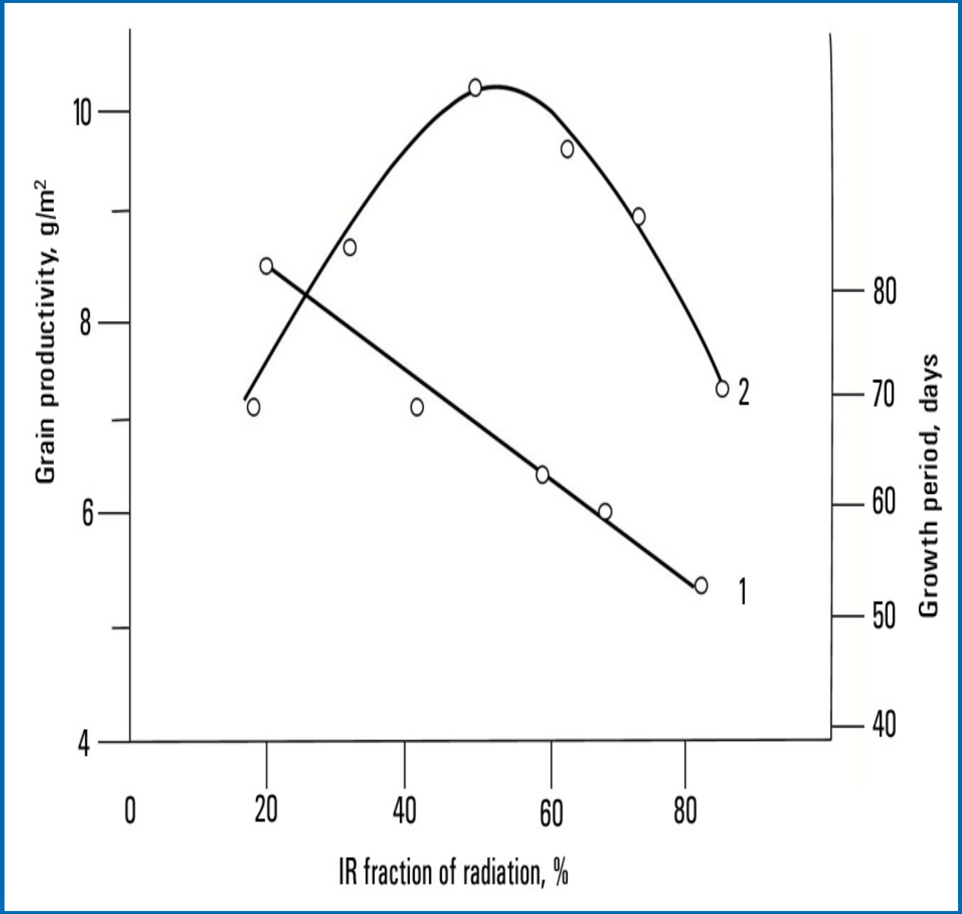


Figure. Effect of different infrared fractions in the radiant flux of intensity 150 W/m2 PAR on the duration of growth period (1) and grain productivity of wheat cenosis (2).

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- . Experiments with artificial lighting, demonstrated (Tikhomirov *et al.*, 1991) that reduction of the IR-radiation fraction in the total radiant flux below 40% (the flux rate in the PAR range being 150 W/m^2) leads to a longer growth period and lower daily average productivity of wheat (Figure) Similar results were obtained by the same authors in experiments with radishes. As IR-radiation makes up not more than 50% of solar radiation, it would hardly be worthwhile reducing this fraction of the integral radiant flux confined within the LSS.

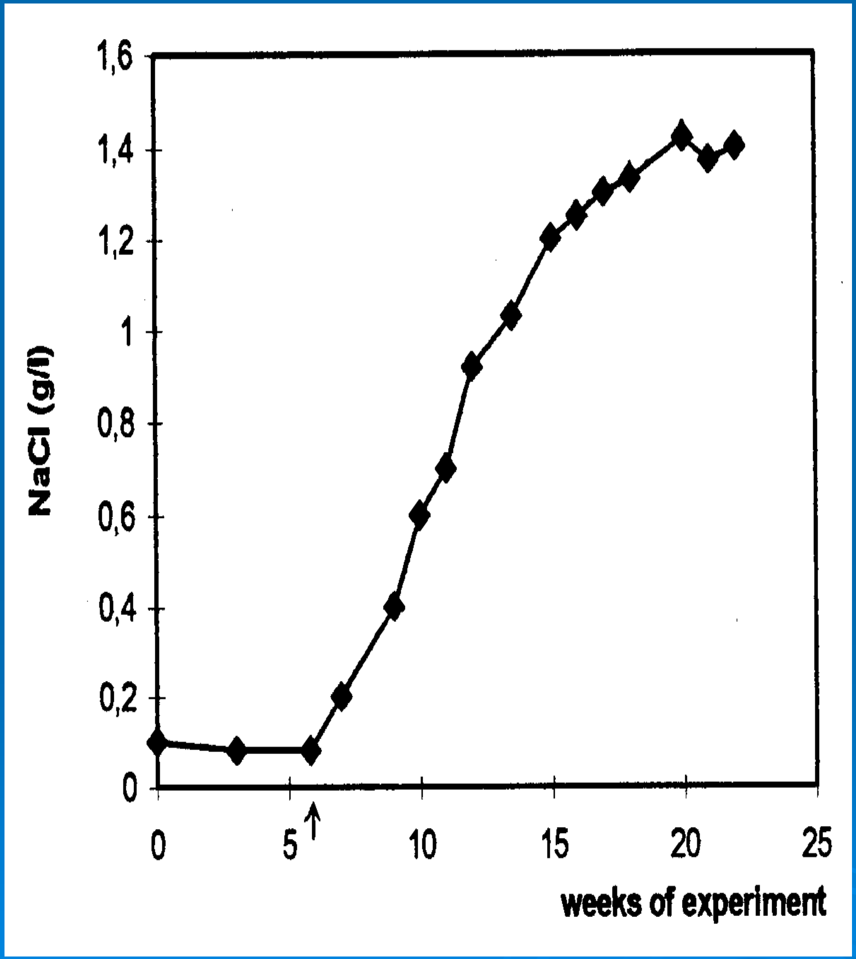
- At cultivation of multispecific cenosis as it was done in BLSS white light was the most effective as in this case under PAR intensity corresponding to maximum output of photosynthesis various plants species gave though not always maximum, but guaranteed high productivity. Therefore equal energy spectrum of xenon lamps with water cooling was used in BIOS-3.

Fig. Prof. F. Salisbury (Utah State University, USA) is measuring light intensity of xenon lamps in BIOS-3(June,1992).

Fig. Tomato growing in multi deck narrow shelf arrangement during vegetative (left) and fruiting (right) phases.

- Technologies of cultivation of some plants species under their arrangement not on a plane, but in space are possible. At the expense of this method the economy of the greenhouses areas and more rational use of compartments volume are possible. Thus the output of vegetable production from the unit of the projective area of a greenhouse increases in 1.5-2 times and more .

3. Using human liquid and solid wastes as a source of elements for plant mineral nutrients in a closed system.



One of unsolved BLSS problems is including of the human liquid wastes in turnover. The first attempt was made in BIOS-3 in 1979. Within these experiments the human liquid wastes were added in nutrient medium for wheat. NaCl accumulated in wheat straw. The straw was stored in BLSS as inedible plant biomass (Fig.). This approach allowed eliminating from liquid wastes but it did not solve the problem of their complete inclusion into internal turnover.

- Fig. Sodium chloride accumulation in the nutrient medium for wheat. ↑ is the time the human liquid wastes began to be introduced.

Fig. ***Salicornia europaea grown on modeling solutions with nitrogen amide (left) and nitrate (right) forms.***

- ***To solve this problem Salicornia europaea*** seems to be a perspective plant for NaCl utilization out of the human liquid wastes and its return to internal turnover after Salicornia europaea consumption by a human. At IBP SB RAS the investigations on growth and development of this culture on the human liquid wastes and modeling solutions have been carried out (fig.) It has been experimentally proved that: 1) nitrogen amide form is more preferable in comparison with its nitrate and ammonia forms; 2) NaCl concentration up to 2% does not limit plants growth (NaCl concentration in urine is about 1%); 3) high concentration of mineral salts in urine does not limit plants growth.

Utilization of plants inedible biomass with a help of "biological combustion"

Mushroom mycelium

Soil- like substrate: spent mushroom compost plus inedible biomass tops

Worms: red California worm (Eisenia foetida)

- Biological combustion with use of soil-like substrate (SLS) is an efficient method of utilization of plants inedible biomass. At the same time SLS is a root-inhabited layer for plants. Inclusion of inedible biomass into internal turnover due to biological combustion allows increasing BLSS closure. SLS specific feature is its ability to depress pathogenic microflora in a root-inhabited plants layer. This is one of the SLS main distinctions from neutral substrate used in hydroponics.

- The physicochemical method of waste utilization is based on using hydrogen peroxide, which can be derived from water within the system. Unlike other physicochemical methods based on this principle, this one does not require high temperatures or pressures and is energy efficient, environmentally friendly, and safe (Kudenko et al , 1997).
- The activation of H_2O_2 with alternating electric potential results in the formation of the active radicals of –OH and of atomic oxygen in the reactor. The latter play the major part in the oxidation of the human or plant wastes added to the reactor. The output oxidation products were metabolite water, carbon dioxide, and mineral residue. The mineral residue consisted of the mineralized organic matter (NH4+, SO_4^{2-}) and phytomass ash (P, K, Mg, Ca, Na, S, Si). The mineral residue was returned to the irrigation water. Thus, oxidation yielded a solution of oxides that did not contain any substances harmful for plants. It was added to the SLS as a nutrient for plants.

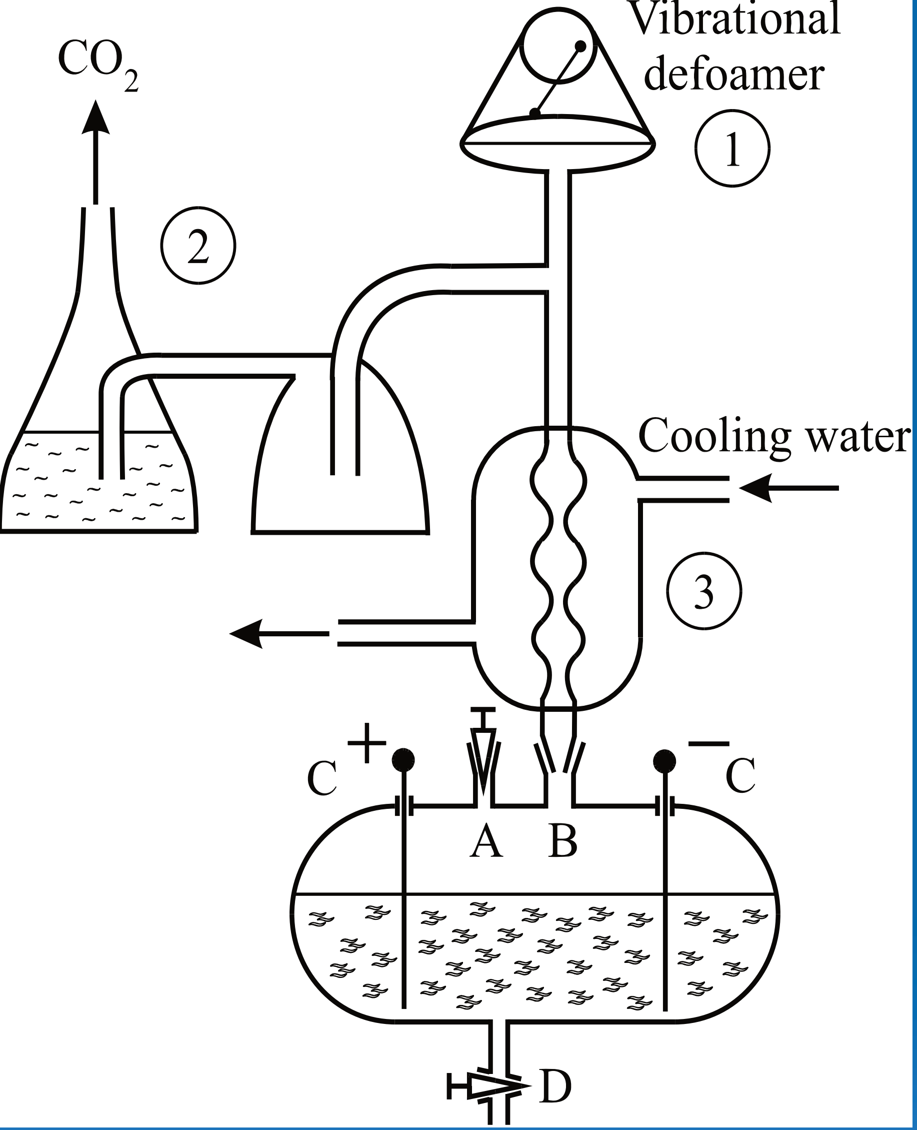


Fig. Facility to oxidize wastes of human vital activity and/or inedible plant biomass

- **.Quartz reactor:**
- **A** is the filler neck, **B** is the cooler neck (as the reaction is exothermal and the passing current produces heat, the equilibrium can be reached by taking away the heat, which is done by the water cooler), **C** is the carbon electrodes, **D** – removal of ready product, **1** is the vibration foam quencher, **2** is the system that collects NH3 and oxidizes it on the platinum catalyst, **3** is the water cooler

Use of SLS and physicochemical methods for increase of closure degree of biotic cycle

- The degree of closure of the biotic cycle was determined in accordance with the approach proposed in Finn’s works (1976, 1978) for the determination of the cycling index: as the ratio of the flow rate of the substance supplied by heterotrophic organisms to producers (autotrophic organisms) to the sum of the flow rates of the substance supplied by heterotroph to autotrophs and the substance going to the unrecyclable form:

$$\boxed{Cl_i = \frac{\sum_k \dot{\Omega}_{ik}}{\sum_k \dot{\Omega}_{ik} + \sum_l \dot{U}_{il}},}$$

- element and the matter as a whole, *k* and *l* are all possible channels through which the substances move from heterotrophic organisms to producers and to the dead end

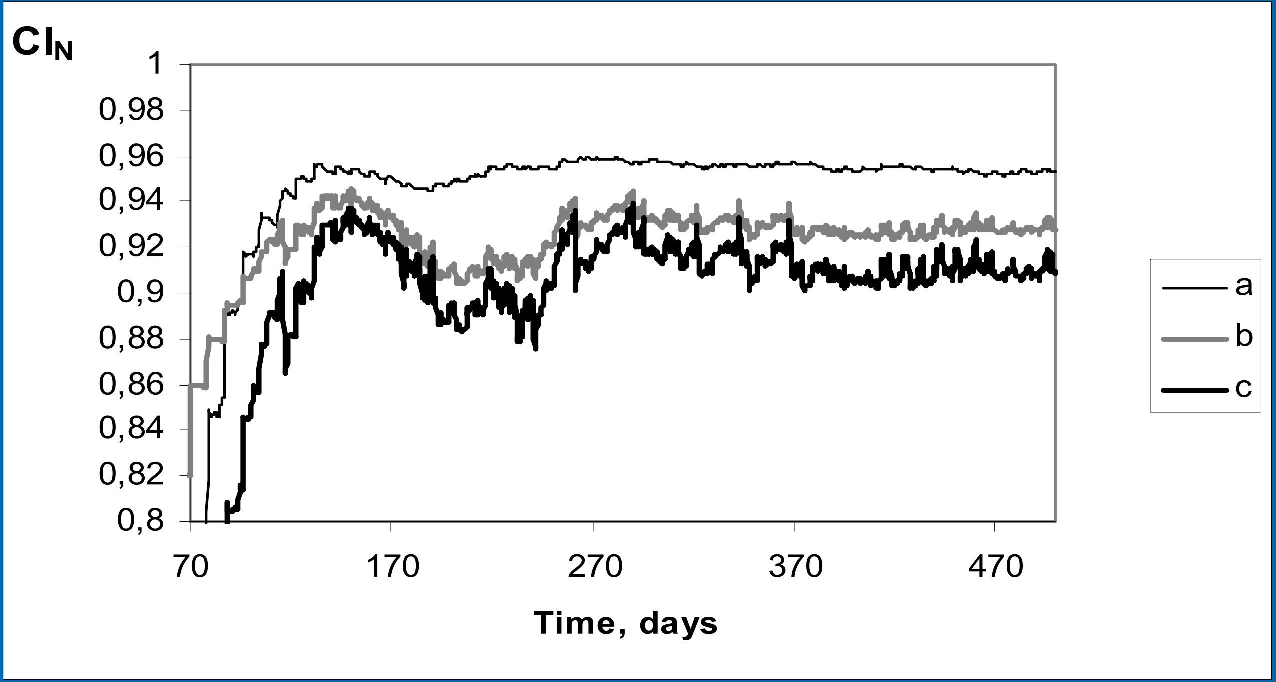


Fig. . Model calculation of dynamic closure coefficients for nitrogen . a – the system with the SLS – biological utilization of the straw; b – the system with the physicochemical mechanism of straw utilization (combustion); c – the system without straw utilization

- Fig. gives an example of calculating the dynamics of the closure coefficient for nitrogen in 3 variants of the model of LSS: the system with the SLS and biological utilization of the straw; the system using the physicochemical method of straw utilization (combustion and partial re-involvement in the cycle of some elements, such as carbon and nitrogen); and the system in which the straw irretrievably leaves the mass exchange cycle (as a store).

CONCLUSION

- 1. It has been shown that in BLSS wheat and chufa can be the basic cultures in providing a human with proteins, carbohydrates and fats. The rest components of vegetative diet can be represented by traditional vegetable cultures.
- 2. It has been experimentally proved that white light is the most optimal due to its spectral composition for multispecies BLSS cenosis.
- 3.The ways of inclusion of inedible plant biomass into BLSS internal turnover has been considered.