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USE OF CONCEPT OF HORMESIS PHENOMENON TO EXPLAIN THE LAW OF DIMINISHING RETURNS PART II

Stanisław Szarek
Department of Economics and Agribusiness Organization, University of Podlasie, Siedlce, Poland

ABSTRACT

In the paper there was presented functioning of hormesis phenomenon, which is understood as stimulating effect on living organisms of low doses of substances, which are growth inhibitors in higher doses. It was pointed out that the law of diminishing returns is a consequence of hormesis phenomenon.

Key words: economics of agriculture, law of diminishing returns, production intensity, production efficiency, hormesis phenomenon.

THE AIM OF THE PAPER, MATERIAL AND METHODS

In the paper, the attention was paid to hormesis phenomenon, which is understood as stimulating effect on living organisms of low doses of substances being growth and development inhibitors in higher doses for these organisms. The aim of the paper is to present an influence of substances recognized as toxic on growth and development of cultivated plants. This factor has not been considered in agricultural sciences so far. As results of researches show, it belongs to a group of important factors, which stimulate yielding of cultivated plants and have an influence on production efficiency.

The additional aim is to present that the law of diminishing returns is a consequence of hormesis phenomenon. It was also described how these two issues are connected with each other and what consequences result to agricultural practice from their acceptance.

Empirical data are results of researches on stimulating effect of low doses of toxic substances on living organisms conducted all over the world since the beginning of the XX century.

Because of the fact that there are not any terms describing hormesis phenomenon in the Polish scientific literature, at the beginning there was presented a dictionary of essential terms in order to allow to smoothly operate within issues presented in this paper.

Vocabulary:

- hormesis phenomenon – a positive response of living organisms, resulting in raise in rate of growth and development,

lowering proneness to diseases and as effect growth of yielding under the influence of low doses of substances, which in higher doses are toxic for these organisms,

- hormetization factor – substance, which causes hormesis phenomenon,
- production threshold of hormesis – a point in which further growth of quantity of hormetization factor causes inhibition of growth, yielding and productivity of a plant or farm animal,
- economic threshold of hormesis – a point in which additional input into increase in production is equal with value of this additional production. In economics of agriculture this threshold is defined as marginal cost,
- threshold dose – quantity of hormetization factor, which causes occurrence of productive or economic threshold,
- hormetic zone – an area between points of the hormesis curve illustrating positive influence of hormetization factor.

HORMESIS PHENOMENON IN SCIENTIFIC RESEARCHES

Hormesis phenomenon described more and more in literature is effect, which can contribute a lot of cognitive and practical elements to body of work of economic and agricultural sciences. Theoretical bases of this effect were created in 1902 by British physiologists E. Starling and W. Bayliss, who discovered secretin – substance stimulating excretion of pancreas. Substances with this influence, excreting in small doses were named hormones. A term "hormone" has its etymology in the Greek word *hormán* which means stimulate, and originates directly from the word *hormé* which means impulse, attack, assault. In this place it cannot be forgotten that a pioneer of researches on exocrine glands and the same hormones was Th. Addison, who in 1855 noticed a connection between skin darkening and injury of suprarenal cortex.

In 1926 C. Southam and J. Ehrlich observed that extract from heartwood of cedar wood used for experiments hampers growth of fungi. At the same time this extract – but in small doses stimulated these fungi to growth. Published results of their researches included a modified Starling's word – "hormesis", which means stimulating effect of small doses of substances on living organisms, which in higher doses are growth and development inhibitors [22].

Although Southam and Ehrlich as first used the word hormesis, it does not mean that they were first, who began researches in this area. Stimulating effect of toxic arsenic on development of potatoes was observed at the beginning of last century [24, as well as effect of sodium arsenate on growth and increment in raw mass of oat [7]. Between the two world wars, stimulating effect of low doses of compounds of aluminium on growth and yielding of plants was observed [16, 19, 21].

Since that time a lot of papers describing an occurrence of hormesis phenomenon have appeared in databases all over the world [5]. At the end of the last century the term "hormesis" got a new meaning thanks to works of toxicologist E. Calabrese, who made a synthesis of research works on symptoms of hormesis phenomenon in the world of living organisms – plants and animals. His works and also works of researches engaged in an issue of influence of ionizing radiation on organisms caused that in 1994 UNSCEAR accepted hormesis phenomenon[1] [27]. It means an important step for mankind because it can contribute to severance with linear hypothesis in radiological and toxicological protection, which presumes that each, even the smallest, dose of harmful factor has unfavourable influence on living organisms.

All organisms are surrounded by harmful substances – heavy metals, toxic gases. Furthermore these organisms are exposed to various kinds, working with different intensity, ionizing and UV radiation. The same species of plants live in environments, where a content of heavy metals in soil is very low [25] or a level of ionizing radiation is very law [13]. On the other hand the same species chose as their habitat and place of development or a human did it consciously – places, where concentration of harmful chemical elements, gases or a level of radiation is relatively high or very high. The fact that the same organisms live and reproduce in such different conditions is effect of homeostasis, whereas an influence of particular doses of harmful substances on these organisms can be explained only with use of hormesis.

The idea of hormesis assumes that each substance – even very toxic – has stimulating effect on organism of living creatures, evincing in growth, wholesomeness, resistance to diseases and ability to reproduction [23]. Selected examples prove occurrence of symptoms of hormesis phenomenon in plants' world.

Cadmium chloride toxic for living organisms ($CdCl_2$) in a dose to 10 ppm clearly increased height of plants and yield of dry mass of soya [15]. Increase in a dose to 20 ppm of $CdCl_2$ practically led to death of plants[2]. There was also observed stimulating effect of low doses of aluminium on maize, rise and root crop [3, 4, 12], of arsenian salt on growth and development of pea, radish, wheat, and potatoes [2, 7, 26]. Cadmium, which is perceived as especially toxic substance, stimulated in low doses growth of oak, maple and soya [6, 28]. Chrome, cobalt and copper in low

concentrations also had stimulating effect on growth and development of plants [9, 18].

Perceived as very toxic and dangerous elements for peoples life compounds of lead, lithium and nickel also had stimulating effect on plant's growth [1, 10]. It is worth to notice that even a positive influence of uranium on growth and development of grasses was proved [14, 17, 20]. A positive response of plants to using hormetization factors in these experiments exceeded a level – in comparison with attempts where hormetization factor was not used – even by several dozen of percent points.

In this situation, an existence of stimulating effect of toxic metals and their salts cannot be denied. Polish soils characterize a various content of trace elements. Researches of Institute of Soil Science and Plant Cultivation [25] show that ranges of variability of trace elements in Polish soils are:

Cd 0.01 – 49.73 mg · kg^{-1}
Cu 0.2 – 725 mg · kg^{-1}
Ni 0.1 – 328.3 mg · kg^{-1}
Pb 0.1 – 5000 mg · kg^{-1}
Zn 0.5 – 5754 mg · kg^{-1}

This data point out that appearance of hormesis phenomenon can be expected in case of plants cultivation on Polish soils. This effect will consist in the fact that particular concentration of trace elements in soil will have an advantageous influence on growth and yielding of plants. Exceeding of this level will result in lowering of yielding and considerable deterioration in quality of produced food.

Experimental data, which can be qualified as hormesis phenomenon should fulfil the following requirements [own elaboration and supplementation based on [5]:

a. substances causing hormesis phenomenon should be potentially toxic, even very toxic,

b. the best results can be achieved if researched objects are subjected to operation of hormetization factor in at least 6 various doses,

c. an experiment should include a control sample, in which hormetization factor is not used,

d. it is essential to achieve maximal, positive response of an organism, which is higher than in a control sample. Maximal stimulation displays in achieving production threshold of hormesis. This increase can be slight but it is not something unusual if in comparison with a control sample it achieves several dozen or even a few hundred percents,

e. after achieving production threshold of hormesis further increase in quantity of hormetization factor causes lowering of positive response of an organism. Depending on the degree of harmfulness of substance this decrease can be slow or sudden.

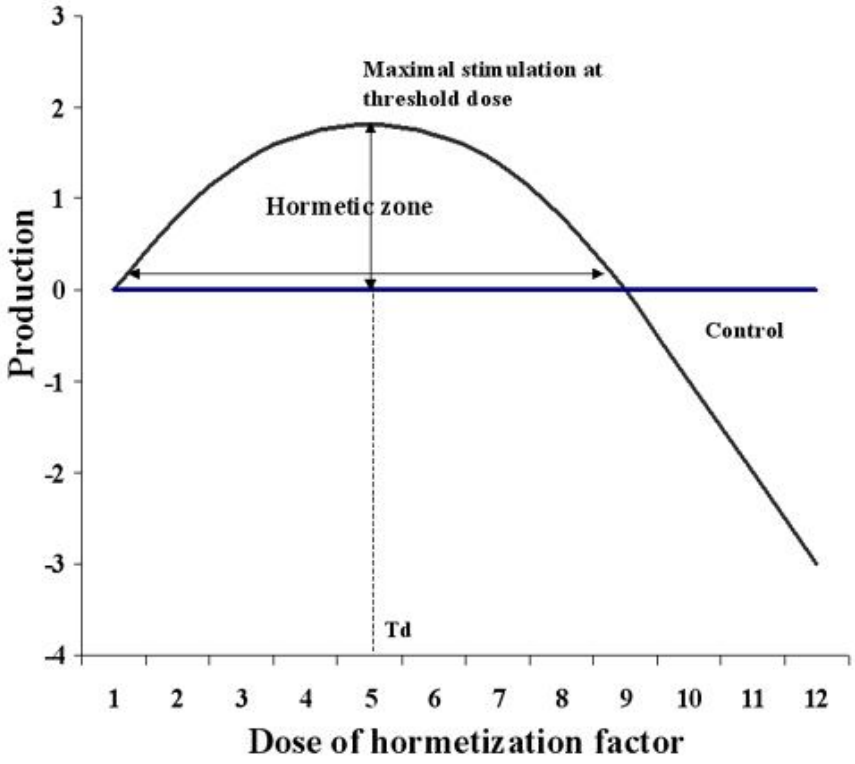
Hormesis phenomenon can be graphically described by function presented on the figures 1 and 2. If regression rates $b_1$and b_2 have opposite signs, hormesis phenomenon occurs in this case [Hickey et al. 1983]. On the figure 1 there is hormesis phenomenon described by the equation:

$$Y = b_0 + b_1X - b_2X^2 + e \quad \text{when } b, b_1, b_2 > 0$$

where Y means a dependent variable, X – an operand, and regression rates was marked with b. On the figure 2 there is also hormesis phenomenon but a model has a form of quadratic function as a letter U described by the equation:

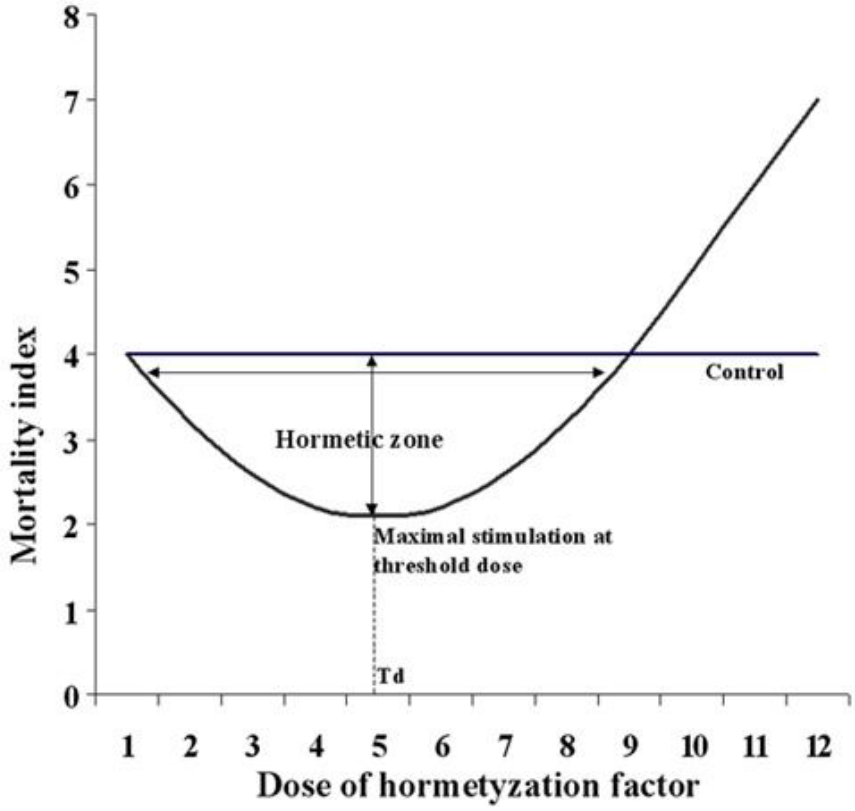
$$Y = b_0 - b_1X + b_2X^2 + e \quad \text{when } b_0, b_{1,} b_2 > 0$$

Figure 1. The curve of upturned U-type of hormesis phenomenon resulting from increase in productivity with use of a suitable dose of hormetization factor



Source: Own elaboration based on [8].

Figure 2. The curve of U-type of hormesis phenomenon resulting from improvement in wholesomeness with use of a suitable dose of hormetization factor



Source: Own elaboration based on [8].

Hormesis phenomenon also occurs in case, when its course can be described with use of Gompertz's function or logistic function. However, in this paper it was limited to the most popular quadratic functions [8].

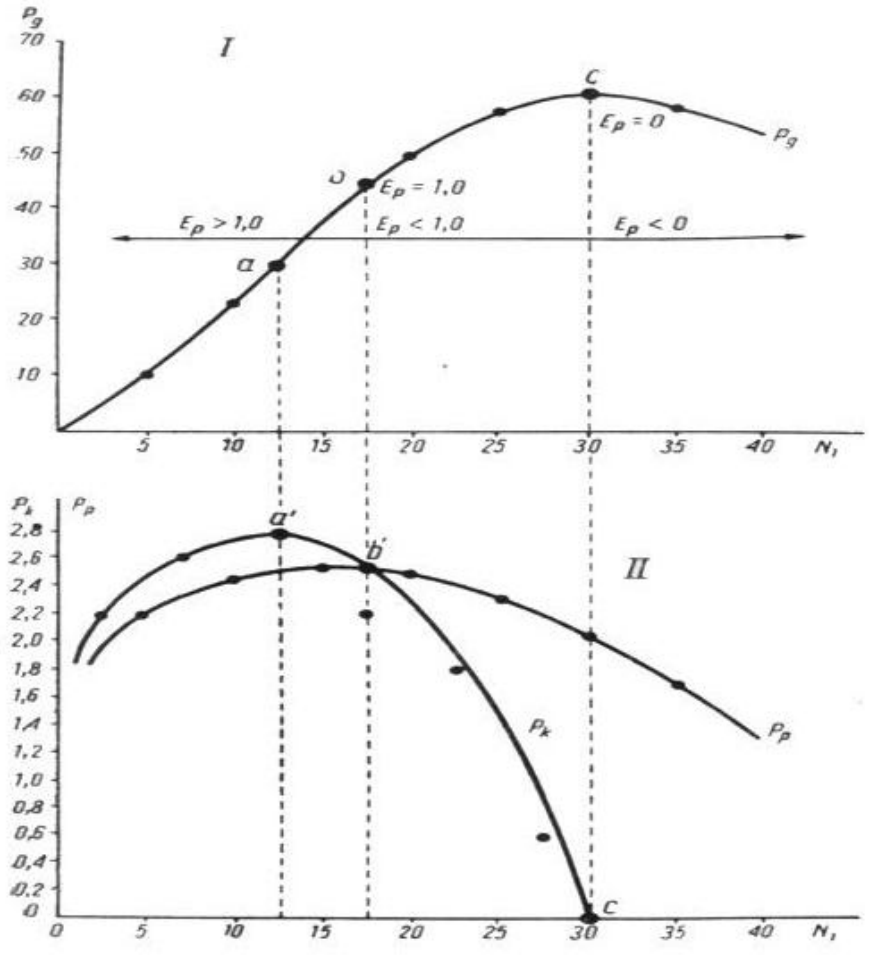
This paper is a kind of return to sources of law of diminishing returns, which were observed and described by J. A. Turogot over 250 years ago. In spite of a huge number of years of functioning and describing of the law of diminishing

returns, just now – in the XXI century – there is a possibility to get to its roots. It is possible thanks to achievements of many people, who over 100 years carried scientific researches. Until now hormesis phenomenon was described mostly in toxicology and that is why this field of science is a pioneer of researches on it. Publications connected with hormesis phenomenon can be also found in radiation chemistry. It is assumed that one of the most lethal effects on living organisms – ionizing radiation – in small doses has a favourable influence on many living organisms.

Slight concern is focused on agriculture, as one of economic field, which every day and on massive scale uses hormesis phenomenon. Analysis of results of agricultural experiments contributes new cognitive elements connected with functioning of hormesis phenomenon.

In the previous paper there was presented the law of diminishing returns (diminishing input efficiency). Economy has developed this law, enriching it additionally in an issue of marginal and average product (fig. 3). On this basis, areas of rational and irrational production were determined. A rule of rational farming demands that production achieved thanks to additional input should be higher than additional input into this production. As it is shown on the figure 3, a curve of Pg is approximately an accurate representation of the curve of hormesis phenomenon described on the figure 1. Actually these curves are almost identical. The difference comes down to the fact that the curve of production has mostly a value expression (expressed in money) whereas the hormesis curve is represented with natural values (kg, dt, t). However, it does not change the essence.

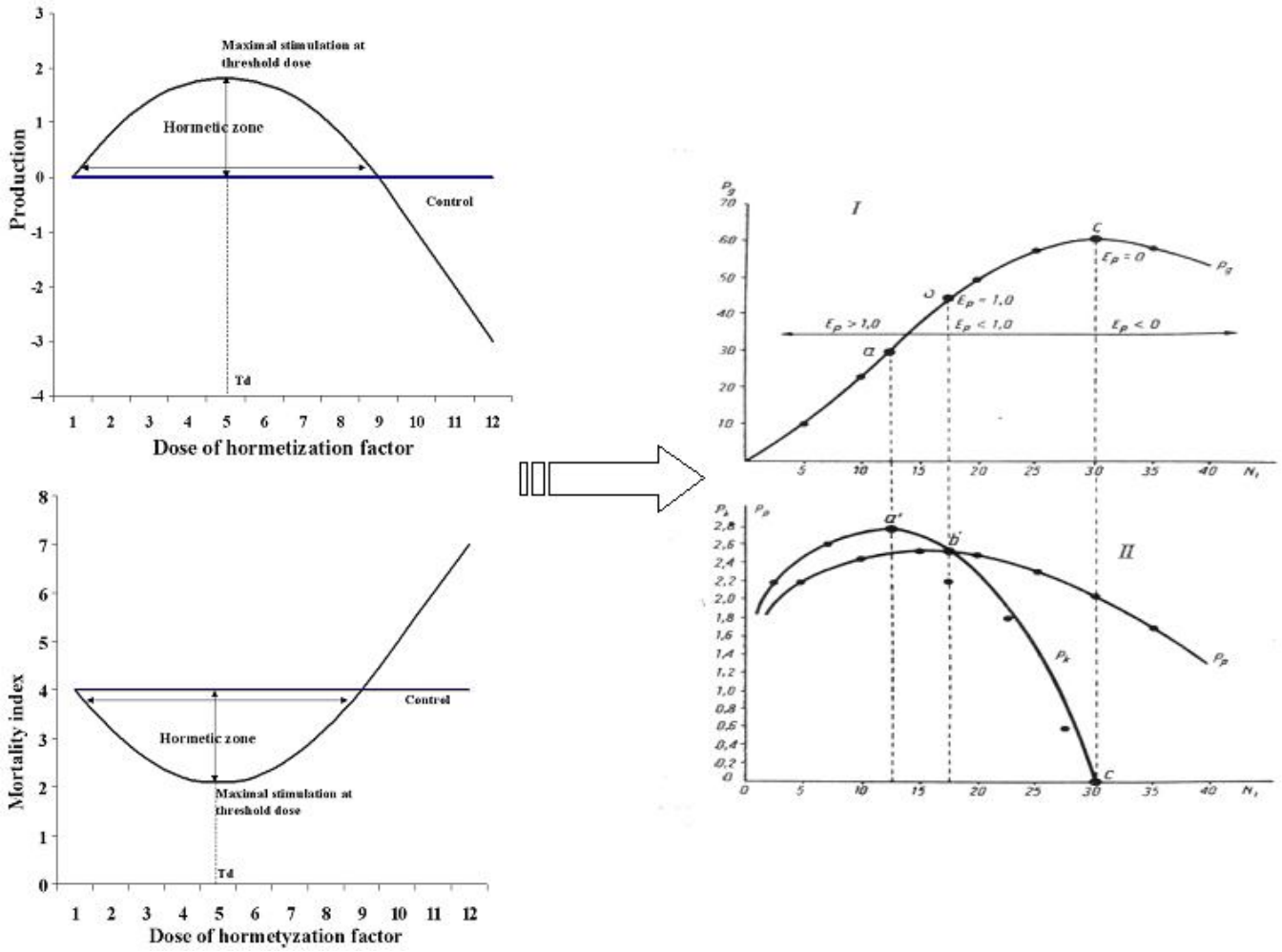
Figure 3. Relationships between input (N) and total product (P_g), marginal product (P_k) and average product (P_p)



Source: [28].

In case of response of organism illustrated on the figure 2, the curve in form of U-letter is not an economic representation of additional input. In this case, a transformation of effect expressed in natural units into money units will take place, which is presented on the figure 4. That is why it is not important whether hormesis phenomenon is represented in form of the upturned U-type curve, whether the U-type curve. Achieved effects can be easily transformed into improvement in productivity (fig. 4). For a farmer it is essential that there will be a growth of production. Lowering of unit costs will take place as effect, production intensity will improve, efficiency and profitability of farming will rise.

Figure 4. Transformation of hormesis phenomenon in case of representation of production effects in money units



Source: Own elaboration based on [28]

It should be realized that a level of production and its intensity could not be determined on the basis of quantity threshold of hormesis presented on the figures 1 and 2. Relations between additional input and additional production are presented on the figure 5. Production threshold is in this case with the input N7. If we assume that the curve P shows volume of production achieved thanks to using additional dose of hormetization factor, so the point of rational production will not be the input N4 but the input N3. In order to explain this, data presented on the figure 5 should be analyzed. If it is assumed that levels of input and production are vector quantity, it will results from the figure that increase in input form the level N1 to the level N2

$$Dn1 < Dp1$$

further increase in input from the level N3 to N4 will result that

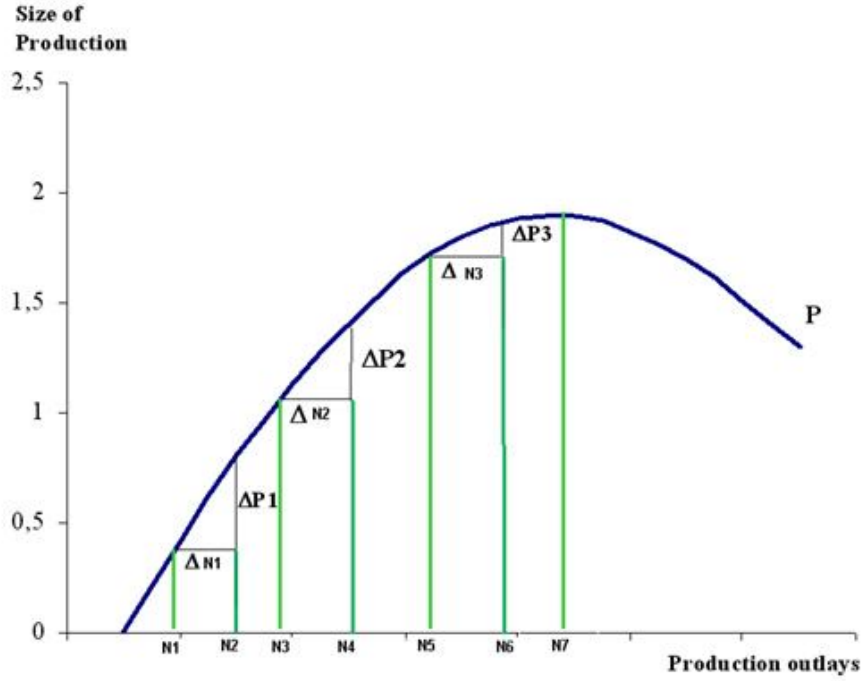
$$Dn2 = Dp2$$

further rise in input is pointless because after exceeding this point

$$Dn3 > Dp3$$

which means that value of input used for additional production is higher than achieved production.

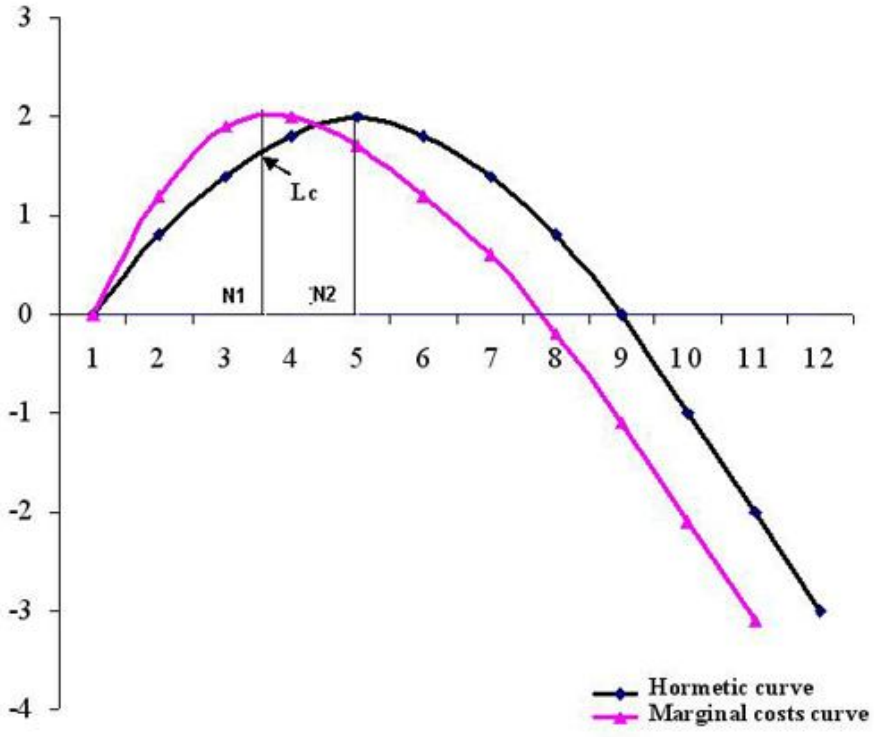
Figure 5. The point of occurrence of marginal cost with using additional input (Dn) for achieving additional production (D p)



Source: Own elaboration.

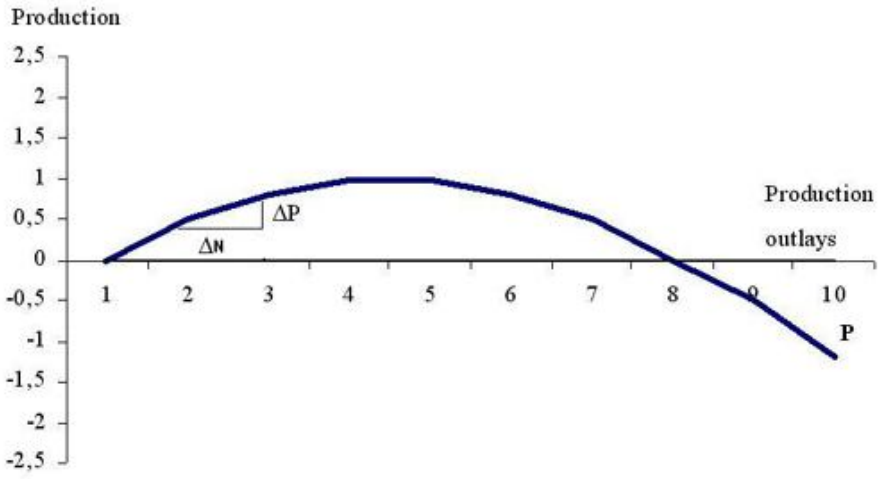
Phase shift of the hormesis curve towards the marginal cost curve takes place in this case. The marginal cost curve is shifted to the left towards the hormesis curve (figure 6). A shape of the hormesis curve conditions size of shifting. The more oblate this curve is, the more to the left the marginal cost curve is shifted. In some cases, it can happen that occurrence of hormesis phenomenon is so slight, that this fact will no influence on economic effect (figure 7). In this situation, in spite of occurrence of hormesis phenomenon, increase in production achieved thanks to use of hormetization factor will be so slight, that its use in economic practice misses a goal. Engagement of additional input in order to achieve little increase of additional production is economically unfounded, because DN > DP.

Figure 6. Phase shift of the marginal cost curve and the hormesis curve. Production threshold occurs in this case with a dose N2, and economic threshold with a lower dose – N1



Source: Own elaboration.

Figure 6. Influence of shape of the hormesis curve on efficiency of additional producing input



Source: Own elaboration.

Similar situation occurs in farm practice. In experiments with fertilizers, use of additional fertilizer component – for example increase in quantity of potassium fertilizer with a constant dose of nitrogenous and phosphorus fertilizers – causes small increase in yielding in comparison with a control object, in which fertilization was not used.

In should be kept in mind, that this relation is conditioned by prices of a unit of additional input and a price if additional product. A low price of a unit of additional input or a high price of a unit of additional product – regardless of how much the hormesis curve is oblate – will cause that use of additional input will be economically profitable. On the other hand, a high price of a unit of additional input and a low price of a unit of additional product will cause that use of additional input will not be economically profitable. That is why results achieved in experiments should be always transformed into money units (see figure 3 and figure 5). Examination of obtained results in this context will reveal their usefulness in farm practice.

SUMMARY

Presented data do not raise doubts that the law of diminishing returns is a result of hormesis phenomenon. While this law explains issues of transformation of input into final products, hormesis phenomenon explains anomalies occur in farm practice described in the first part of the paper. Taking into account hormetization factors in case of the law of diminishing returns on the one hand and expanding of the hormesis law with elements of economic is a method, which will allow efficient use of these laws in practice. It will be a base for precise determination of doses of hormetization substances guarantying maximal production obtainment. Analyze of results of experiments allow to state that elements of heavy metals included in soil can influence in significant way on yielding of cultivated plants. This factor is an element, which should be considered in chemical and agricultural researches. Soil classification existing to date should be expanded with content of heavy metals in particular soils. Moreover, in cultivated soils there can be peculiar substances for particular kind of soil, different than formerly determined, which cause hormesis phenomenon. That is why soil analyze should be expanded with content of trace elements as important factor of yielding.

Finding out favourable influence of substances, which were considered as toxic, is a fact difficult to accept. On the other hand, its existence cannot be doubted because this approach explains numerous issues passed over in agriculture and farming economics before.

Scientifics researches on hormesis phenomenon existing to date led to determination of production threshold. The next phase after it is determination of economic threshold, which is a marginal cost of used hormetization factors. Economic threshold is shifted in phase towards production threshold and occurs with a lower dose of hormetization factor than production threshold.

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FOOTNOTES

[1] From the initiative of Polish delegation.

[2] 1 ppm responds a dose of 1 $mg \cdot kg^{-1}$.

Stanisław Szarek
Department of Economics and Agribusiness Organization,
University of Podlasie, Siedlce, Poland
B. Prusa 12, 08-110 Siedlce, Poland
email: szarek@ap.siedlce.pl

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