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ACCUMULATION AND DISTRIBUTION OF DRY MASS AND NITROGEN IN SORGHUM PLANTS GROWN AT DIFFERENT NUTRITIONAL LEVEL

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Abstract

A pot experiment was carried out to determine the accumulation and distribution of dry mass and nitrogen in sorghum depending on the nutritional level. The plants were grown on eight levels of nutrition – $N_0P_0K_0$, $N_0P_{200}K_{200}$, $N_{600}P_0K_0$, $N_{200}P_{200}K_{200}$, $N_{400}P_{200}K_{200}$, $N_{600}P_{200}K_{200}$, $N_{800}P_{200}K_{200}$, $N_{600}P_{400}K_{400}$. The different levels of nutrients were created by applying of NH_4NO_3, $Ca(H_2PO_4)_2$ and KCl dissolved in water. It was established that plants accumulated higher aboveground dry biomass and nitrogen at $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ levels. The fertilization 600 mg $N.kg^{-1}$ soil increased the grain nitrogen concentration both applied alone and in combination with two levels of phosphorus and potassium $P_{200}K_{200}$ and $P_{400}K_{400}$. The fertilization levels decreased the harvest index of sorghum compared to the control plants. The nitrogen harvest index changed from 47.8% at $N_{800}P_{200}K_{200}$ to 59.7% at $N_{200}P_{200}K_{200}$. Nitrogen harvest index at $N_{800}P_{200}K_{200}$ fertilization had the lowest value 47.8% of all studied levels.

***Key words**: dry mass, nitrogen, accumulation, sorghum.*

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is one of the five major crops in the world (Shehzad et al., 2009). It can be used as food (grain), feed (grain and biomass), fuel (ethanol production), fiber (paper), fermentation (methane production) and organic by-products (Fernandes et al., 2013). In the European Union, the production is mainly concentrated in France, Italy and Spain and the total consumption of 850,000 tons in Europe exceeds production (Ivanov, 2006). In Bulgaria the production of grain sorghum has increased in recent years and sorghum is one of the top ten grown crops in the country (Bulgarian Ministry of Agriculture and Foods, Agrostatistics, 2016).

Sorghum is a multipurpose crop belonging to the Poaceae family, which are C_4 carbon cycle plants with high photosynthetic efficiency and productivity (Tari et al., 2012). The modern varieties are hybrids with high productivity potential appropriate for application of intensive forage grain production technologies (Kertikov, 2007; Kikindonov et al., 2008).

Nitrogen, phosphorus, potassium and water are considered as the major limiting factors in crop growth, development and finally economic yield (Enchev & Kikindonov, 2015). Proper nitrogen nutrition is critical to meet crop needs and indicate considerable opportunities for improving nitrogen use efficiency (Murrel, 2011). Many agricultural soils have a limited ability to supply available nitrogen for target yields and nitrogen is the most limiting nutrient for cereal crops, including sorghum production (Gerik et al., 2014).

Nutrient uptake of sorghum precedes dry matter accumulation because nutrients are required for growth and dry matter accumulation (Soleymani et al, 2011). The level of mineral nutrition has greater effect on growth and yield of cereals plants (Raun & Johnson, 1999).

The studies of sorghum genotypes in this connection are limited. For better fertilizer management the study about the effects of different levels of nitrogen, phosphorus and potassium on the growth and nutrient uptake of sorghum is very crucial.

The objective of this research was to investigate the effect of different nutritional levels on the accumulation and distribution of dry mass and nitrogen in sorghum plants.

MATERIALS AND METHODS

The effect of different levels of mineral nutrition on the accumulation and distribution of dry mass and nitrogen of sorghum plants was studied in a pot experiment under conditions of growing installation. The experimental design consisted of eight levels of mineral nutrition and four replications of each variant. The studied treatments of soil nutritional levels were: $N_0P_0K_0$, $N_0P_{200}K_{200}$, $N_{200}P_{200}K_{200}$, $N_{400}P_{200}K_{200}$, $N_{600}P_{200}K_{200}$, $N_{800}P_{200}K_{200}$, $N_{600}P_0K_0$ and $N_{600}P_{400}K_{400}$. The levels of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in the soil were created by adding of NH_4NO_3, $Ca(H_2PO_4)_2$ and KCl dissolved in a water.

Three plants per pot of hybrid EC Alize were grown under optimal water regime in plastic pots of 10 L. Each pot contained 15 kg air-dry soil. The main agrochemical characteristics of the soil before sowing of the sorghum were: pH_{H2O} = 7.80 (slightly alkaline reaction); content of mineral nitrogen 27.6 mg $Nmin.kg^{-1}$ soil; content of available phosphorus (Egner-Ream) 158 mg $P_2O_5.kg^{-1}$; and content of exchangeable potassium 210 mg $K_2O.kg^{-1}$.

These results showed low supply of the soil with mineral nitrogen and good soil supply with available phosphorus and potassium. A good water regime was maintained in the pots during the vegetation of the sorghum plants.

The aboveground biomass was collected from the plants under all the treatments in a full maturity phase. The harvested samples were separated in a grain and stover (stems + leaves + chaff). The dry weight of grain and stover was determined after drying for 48 hours at 60°C. The sub-samples of 0.5 g ground and dry plant material were mineralized using a wet digestion by H_2SO_4 and H_2O_2 as a catalyst (Mineev, 2001).

The concentration of nitrogen in plant samples were determined by colorimetric methods and potassium concentration was analyzed by the flame photometer model PFP-7 (Tomov et al, 2009). The content of accumulated nitrogen was obtained by multiplying the dry mass of sorghum grain and stover by the concentration of nitrogen in each plant part.

The differences in the accumulation and distribution of dry mass and nitrogen into sorghum plants among all levels of mineral nutritional were calculated by using the overall analysis of variance (ANOVA). Duncan's Multiple Range Test (Duncan, 1955) at $p < 0.05$ was used in order to determine the difference among the means.

RESULTS AND DISCUSSIONS

The average grain yield of all studied nutritional levels was 56.3 $g.pot^{-1}$ and the obtained average stover yield was 84.0 $g.pot^{-1}$ (Table 1). Unfertilized plants showed the lowest productivity of grain and stover in maturity. The grain and stover yields of sorghum significantly increased at all variants with applied nitrogen in rates from N_{200} to N_{800}, compared to the yield of the controlplants $N_0P_0K_0$. The increase was by 64.0% - 108.6% for the grain yield and by 82.0% - 144.0% for the stover, respectively.

Table 1. Productivity of grain and stover of sorghum plants depending on nutritional level, $g.pot^{-1}$

Nutritional level	Grain	% to $N_0P_0K_0$	Stover	% to $N_0P_0K_0$
$N_0P_0K_0$	35.0 ^{f*}	100.0	45.1 ^{e}	100.0
$N_0P_{200}K_{200}$	39.2 ^{f}	112.0	51.9 ^{e}	115.1
$N_{200}P_{200}K_{200}$	57.4 ^{d}	164.0	82.1 ^{d}	182.0
$N_{400}P_{200}K_{200}$	68.5 ^{bc}	195.7	102.7 ^{b}	227.6
$N_{600}P_{200}K_{200}$	73.0 ^{a}	208.6	110.0 ^{a}	244.0
$N_{800}P_{200}K_{200}$	47.0 ^{e}	134.3	80.1 ^{d}	177.6
$N_{600}P_0K_0$	61.1 ^{c}	174.6	93.1 ^{c}	206.5
$N_{600}P_{400}K_{400}$	69.1 ^{ab}	197.1	107.0 ^{ab}	237.3
Average	*56.3*		*84.0*	

*Values in each column followed by the same letters are not significantly different at p<0.05 according to Duncan's multiple range test.

Sorghum plants accumulated the highest quantity of dry above-ground mass when grown at $N_{600}P_{200}K_{200}$ level. The phosphorus-potassium-only fertilization $N_0P_{200}K_{200}$ had a slight effect on the grain and straw yields, and in this variant the sorghum productivity was not significantly different from that of the $N_0P_0K_0$control.The combination of applied phosphorus-potassium $P_{200}K_{200}$ with increasing nitrogen levels from N_{200} to N_{600} resulted in a proven increase of sorghum productivity along with an increase of nitrogen application up to N_{600} level. The exclusion of phosphorus and potassium fertilization and the cultivation of sorghum under N_{600} nitrogen fertilization had a negative effect on the accumulation of dry above-ground biomass at maturity. The productivity of plantsat this nutritional level $N_{600}P_0K_0$ decreased by 11.9 $g.pot^{-1}$ for grain and 16.9 $g.pot^{-1}$ for the stover, compared to the corresponding yields of the triple combination $N_{600}P_{200}K_{200}$ variant. Growing of sorghum at the elevated phosphorus-potassium level $P_{400}K_{400}$ combined with N_{600} did not affect the amount of dry above-ground biomass in maturity. The grain and stover yields of this variant $N_{600}P_{400}K_{400}$ were similar to those obtained with the $N_{600}P_{200}K_{200}$ fertilization.

Table 2. Total productivity of sorghum plants depending on nutritional level, g.pot^{-1}

Nutritional level	Grain+Stover	% to $N_0P_0K_0$
$N_0P_0K_0$	80.1 ^{g*}	100.0
$N_0P_{200}K_{200}$	91.1 ^{f}	113.7
$N_{200}P_{200}K_{200}$	139.5 ^{d}	174.2
$N_{400}P_{200}K_{200}$	171.2 ^{b}	213.7
$N_{600}P_{200}K_{200}$	183.0 ^{a}	228.5
$N_{800}P_{200}K_{200}$	127.1 ^{e}	158.7
$N_{600}P_0K_0$	154.2 ^{c}	192.5
$N_{600}P_{400}K_{400}$	176.0 ^{ab}	219.7
Average	*140.3*	

*Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.

Hybrid EC Alize demonstrated higher productivity of above-ground dry mass in maturity when grown at levels N_{200} - N_{800} (Table 2). The increasing of grain and stover yields of these variants significantly increased by13.7% - 128.5% in comparison with the productivity of unfertilized control plants. Sorghum showed higher total productivity in maturity when grown at $N_{600}P_{200}K_{200}$, $N_{600}P_{400}K_{400}$ and $N_{400}P_{200}K_{200}$ fertilization levels. The high N_{800} level combined with $P_{200}K_{200}$ let to formation of 55.9 g less dry mass per pot, compared to total accumulated above-ground dry mass of plants grown at $N_{600}P_{200}K_{200}$ level.

Mineral nutrition had a significant effect on the percentage of nitrogen of the sorghum grain and stover in maturity (Table 3). The nitrogen concentration of grain was 1.88% N on average, and its values changed in a range 1.65% N - 2.14% N. The sorghum stover contained an average of 1.05% N and its values varied from 0.84% to 1.30% N depending on the fertilization level.

Growing the sorghum without addition of nitrogen ($N_0P_0K_0$ and $N_0P_{200}K_{200}$) resulted in obtaining a grain with the lowest nitrogen concentration of 1.65%-1.69%. Our results corresponded to studies on the effect of nitrogen on the concentration of nitrogen in sorghum grain of other authors (dos Santos et al., 2014). Low nitrogen rate N_{200} in combination with $P_{200}K_{200}$ and as well as application of only phosphorus-potassium fertilization $N_0P_{200}K_{200}$ demonstrated not significant effect on the nitrogen concentration of sorghum stover compared to the control. The nitrogen concentration of the stover of these three variants $N_0P_0K_0$, $N_0P_{200}K_{200}$ and $N_{200}P_{200}K_{200}$ showed lower values of 0.84%-0.90% nitrogen.

Grain nitrogen concentration of the sorghum plants proven increased in parallel with the applied nitrogen in amount of 200, 400, 600 и 800 mg N.kg soil^{-1} when the nitrogen level was combined with $P_{200}K_{200}$. The effect of nitrogen fertilization alone $N_{600}P_0K_0$ on the percentage of grain nitrogen was unproven compared to the $N_{600}P_{200}K_{200}$ and $N_{800}P_{200}K_{200}$ variants. The highest grain nitrogen concentration (2.14% N) was established when sorghum grown at 600 mg N.kg soil^{-1} combined with a higher $P_{400}K_{400}$ level. In this triple combination, nitrogen concentration of grain exceeded by 29.7% the grain nitrogen concentration of unfertilized plants.

Table 3. Concentration of nitrogen of grain and straw of sorghum plants depending on nutritional level, N %

Nutritional level	Grain, % N	% to $N_0P_0K_0$	Stover, % N	% to $N_0P_0K_0$
$N_0P_0K_0$	1.65 ^{f*}	100.0	0.90 ^{ef}	100.0
$N_0P_{200}K_{200}$	1.69 ^{f}	102.4	0.87 ^{f}	96.9
$N_{200}P_{200}K_{200}$	1.77 ^{e}	107.3	0.84 ^{f}	93.2
$N_{400}P_{200}K_{200}$	1.83 ^{d}	110.9	0.99 ^{de}	110.0
$N_{600}P_{200}K_{200}$	1.97 ^{c}	119.4	1.22 ^{ab}	135.7
$N_{800}P_{200}K_{200}$	2.03 ^{b}	123.0	1.30 ^{a}	144.6
$N_{600}P_0K_0$	1.99 ^{bc}	120.6	1.10 ^{cd}	122.1
$N_{600}P_{400}K_{400}$	2.14 ^{a}	129.7	1.18 ^{bc}	131.4
Average	*1.88*		*1.05*	

*Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.

The nitrogen N_{400}, N_{600} and N_{800} levels positively affected the concentration of stover nitrogen, with an increase of 10.0%- 44.6%, compared to that of the untreated control (Table 3). The results showed higher nitrogen concentrations of stover (1.30%N) at a high nitrogen $N_{800}P_{200}K_{200}$ variant, but the difference with $N_{600}P_{200}K_{200}$fertilization was not mathematically proven. The doubled

$P_{400}K_{400}$level combined with N_{600} did not significantly change the percentage of stover nitrogen, compared to its valueof sorghum plants grown at $N_{600}P_{200}K_{200}$ level. The stover nitrogen concentration of only nitrogen fertilized plants $N_{600}P_0K_0$ was 1.10% N. The data showed similar values of the N percentage of stover at plants cultivated at $N_{600}P_0K_0$ and $N_{600}P_{400}K_{400}$ levels and no proven effect of $P_{400}K_{400}$ fertilization.

Table 4. Accumulated nitrogen of grain and stover of sorghum depending on nutritional level, g $N.pot^{-1}$

Nutritional level	Grain g $N.pot^{-1}$	% to $N_0P_0K_0$	Stover g $N.pot^{-1}$	% to $N_0P_0K_0$
$N_0P_0K_0$	0.58 ^{e*}	100.0	0.41 ^{e}	100.0
$N_0P_{200}K_{200}$	0.66 ^{e}	114.3	0.45 ^{e}	110.4
$N_{200}P_{200}K_{200}$	1.02 ^{c}	175.1	0.69 ^{d}	167.3
$N_{400}P_{200}K_{200}$	1.25 ^{b}	216.2	1.01 ^{c}	247.1
$N_{600}P_{200}K_{200}$	1.44 ^{a}	247.9	1.34 ^{a}	327.7
$N_{800}P_{200}K_{200}$	0.95 ^{d}	164.5	1.04 ^{c}	253.8
$N_{600}P_0K_0$	1.22 ^{b}	209.6	1.02 ^{c}	248.7
$N_{600}P_{400}K_{400}$	1.48 ^{a}	254.6	1.26 ^{b}	308.2
Average	*1.07*		*0.90*	

*Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.

The accumulated nitrogen of the above-ground plant parts of sorghum in maturity widely varied depending on the level of mineral nutrition (Table 4). The average nitrogen uptake of sorghum grain was 1.07 g $N.pot^{-1}$ and the average stover nitrogen uptake was 0.90 g $N.pot^{-1}$. Plants with nitrogen fertilization accumulated more grain nitrogen and nitrogen of the vegetative above-ground dry mass, compared to control plants and only phosphorus-potassium fertilized plants. Sorghum accumulated the highest amount of grain nitrogen at N_{600} level combined with phosphorus-potassium $P_{200}K_{200}$ or $P_{400}K_{400}$ levels. The absorbed grain nitrogen of sorghum grown at $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ levels was 1.44 g $N.pot^{-1}$and 1.48 g $N.pot^{-1}$, respectively. These values exceeded the nitrogen taken up of control plants by 147.9% and 154.6%, respectively. Application of nitrogen alone in a rate N_{600} proven reduced the quantity of grain nitrogen in maturity compared to the $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ combinations. It was not established the significant effect of alone nitrogen fertilization $N_{600}P_0K_0$ and triple combination $N_{400}P_{200}K_{200}$ on the accumulated nitrogen of the grain. Sorghum plants grown at $N_{200}P_{200}K_{200}$ and $N_{800}P_{200}K_{200}$ levels distinguished by a lower grain yield and quantity of grain nitrogen among the nitrogen-fertilized variants. Applied mineral nitrogen in rates N_{200}, N_{400}, N_{600} and N_{800} significantly increased the amount of nitrogen accumulated in the sorghum straw. The increase was by 67.3%-208.2% in regard to the non-fertilized control. Plants grown at $N_{200}P_{200}K_{200}$ level accumulated the lowest stover nitrogen among all trails with nitrogen input. Sorghum stover contented more nitrogen (1.34 g $N.pot^{-1}$-1.26 g $N.pot^{-1}$) as a result of $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ fertilization levels. The accumulated nitrogen in the straw had similar values (1.01 g $N.pot^{-1}$-1.04 g $N.pot^{-1}$) when sorghum plants grown at $N_{400}P_{200}K_{200}$, $N_{800}P_{200}K_{200}$, $N_{600}P_0K_0$ levels.

Sorghum accumulated small quantity (0.98 g $N.pot^{-1}$-1.12 g $N.pot^{-1}$)of above-ground nitrogen at variants without added nitrogen (Table 5). Nitrogen fertilization significantly increased the total amount of nitrogen in maturity. The total uptake of nitrogen in above-ground plant parts was higher from 73.6% ($N_{200}P_{200}K_{200}$) to 183.8% ($N_{600}P_{200}K_{200}$) in comparison with unfertilized control plants. The results demonstrated higher accumulation of nitrogen in maturity when plants grown at the triple $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ combinations.

Table 5. Total accumulated nitrogen of sorghum grain + stover depending on nutritional level, g $N.pot^{-1}$

Nutritional level	Total N, g $N.pot^{-1}$	% to $N_0P_0K_0$
$N_0P_0K_0$	0.98 ^{e*}	100.0
$N_0P_{200}K_{200}$	1.12 ^{e}	113.8
$N_{200}P_{200}K_{200}$	1.70 ^{d}	173.6
$N_{400}P_{200}K_{200}$	2.27 ^{b}	231.3
$N_{600}P_{200}K_{200}$	2.78 ^{a}	283.8
$N_{800}P_{200}K_{200}$	2.00 ^{c}	203.6
$N_{600}P_0K_0$	2.24 ^{b}	228.1
$N_{600}P_{400}K_{400}$	2.74 ^{a}	279.6
Average	*1.98*	

*Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.

The grain of the EU Alize sorghum hybrid represented 40.5% on average of the total above-ground biomass in maturity (Table 6).The portion of grain nitrogen from the total accumulated nitrogen of plants was 55.1%. The harvest index of sorghum plants varied from 47.8% to 59.7% and the nitrogen harvest index changed in range 47.8%-59.7% depending on the level of mineral nutrition. The highest values of harvest index were obtained at the unfertilized control plants and plants grown at lower levels of mineral nutrition. The harvest index of sorghum received elevated N_{600} and N_{800}levels proven decreased by 9.0%-15.5% compared to that at $N_0P_0K_0$ control. No significant differences were found in the harvest index of plants grown at $N_{600}P_{200}K_{200}$, $N_{800}P_{200}K_{200}$, $N_{600}P_0K_0$ and $N_{600}P_{400}K_{400}$ fertilization. The obtained harvest indexes of these levels were in a range 37.0%-39.9%.

Table 6. Harvest index HI and nitrogen harvest index NHI of sorghum depending on nutritional level, %

Nutritional level	HI	% to $N_0P_0K_0$	NHI	% to $N_0P_0K_0$
$N_0P_0K_0$	43.8 [a*]	100.0	58.7 [a]	100.0
$N_0P_{200}K_{200}$	43.0 [a]	98.1	59.4 [a]	101.1
$N_{200}P_{200}K_{200}$	41.2 [a]	94.0	59.7 [a]	101.7
$N_{400}P_{200}K_{200}$	40.1 [ab]	91.5	55.3 [ab]	94.2
$N_{600}P_{200}K_{200}$	39.9 [b]	91.1	51.7 [c]	88.1
$N_{800}P_{200}K_{200}$	37.0 [b]	84.5	47.8 [d]	81.5
$N_{600}P_0K_0$	39.6 [b]	90.5	54.4 [bc]	92.7
$N_{600}P_{400}K_{400}$	39.2 [b]	89.5	53.9 [c]	91.8
Average	*40.5*		*55.1*	

*Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.

The nitrogen harvest index showed the highest values when the sorghum plants grown without nitrogen fertilization and under low N_{200} level. The obtained result of NHI of variants $N_0P_0K_0$, $N_0P_{200}K_{200}$ and $N_{200}P_{200}K_{200}$ were similar 58.7%-59.7%. The differences in the nitrogen harvest index of these variants and the variants with nitrogen application N_{600} were mathematically proven. Our results showed strong negative effect of higher N_{800} level on the proportion of grain nitrogen from total above-ground nitrogen in maturity. The nitrogen harvest index of plants cultivated at $N_{800}P_{200}K_{200}$ was down up to 47.8% and NHI had the lowest value of all studied levels.

CONCLUSIONS

Sorghum hybrid EC Alize showed high response to the soil nitrogen level. The plants accumulated higher above-ground dry biomass and nitrogen at $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ levels. High N_{800} level combined with $P_{200}K_{200}$ significantly decreased the grain and stover yield compared to the productivity of above-ground dry mass of plants grown at lower N_{200}, N_{400} and N_{600} levels. The productivity of plants with applied N_{600}alone decreased grain and stover yields by 16.3% and 15.4%, respectively, compared to the corresponding yields of the triple $N_{600}P_{200}K_{200}$ combination.

Mineral nutrition had a significant effect on the nitrogen concentration of sorghum plants with changes in ranges 1.65% N - 2.14% N and 0.84% N - 1.30% N for grain and stover, respectively. The fertilization 600 mg $N.kg^{-1}$ soil increased the grain nitrogen concentration both applied alone and in combination with $P_{200}K_{200}$ and $P_{400}K_{400}$ levels. The highest grain nitrogen 2.14% was established in sorghum plants grown at 600 mg N.kg $soil^{-1}$ combined with a higher $P_{400}K_{400}$ level.

Sorghum accumulated the most grain nitrogen at N_{600} level combined with $P_{200}K_{200}$ or $P_{400}K_{400}$ levels. Application of N_{600} alone proven reduced the quantity of grain nitrogen in maturity compared to the $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ combinations. Higher accumulation of total nitrogen was established of plants grown at the triple $N_{600}P_{200}K_{200}$ and $N_{600}P_{400}K_{400}$ combinations.

The harvest index varied from 47.8 to 59.7% and the nitrogen harvest index changed in range 47.8 - 59.7% depending on the level of mineral nutrition. The fertilization levels decreased the harvest index of sorghum compared to the control plants. It was proven a strong negative effect of the higher nitrogen level on the nitrogen harvest index of sorghum. Nitrogen harvest index at $N_{800}P_{200}K_{200}$ fertilization had the lowest value 47.8% of all studied levels.

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