

Effects of Low Dose Gamma Radiation on the Root Growth of Soybean Cultivars

Youngman Yoon¹⁾, Hyung In Cho¹⁾, Sunghee Chang¹⁾, NamBum Kim¹⁾, Jae-Sung Kim²⁾, Jeong-Gyu Kim¹⁾

¹⁾Korea University, Seoul, 136-701, ²⁾Korea Atomic Energy Institute, Taejeon, 303-353

ABSTRACTS : γ -Radiation at very low doses frequently has a stimulating or hormetic effect on the growth of organism. Effects of low dose γ -ray irradiation on the root growth of soybean cultivars were investigated and hormetic effects by environmental conditions were compared with the occurrence of increased economic yield, seeds of cultivars were irradiated with the dose of 0.5~20Gy and cultivated in growth chamber controlling temperature, humidity, light, greenhouse and field respectively. To understand hormetic effect on root growth of cultivars and the difference of hormetic effect by cultivation environment, harvested root of soybean cultivars were scanned with image file, and root surface area, root length, root average diameter etc. were examined by WinRhizo program. Also, dry weight of cultivars was examined. Root growth and dry weight of soybean cultivars showed apparently hormetic effect at cultivation of growth chamber condition. In field experiment executed for whole life cycle, yields of pea were not different significantly in each γ -ray irradiated cultivars but weight of one hundred peas increased in whole γ -ray irradiated cultivars. Increment of yield was assumed to be induced through shortening of maturing stage caused by γ -ray hormesis in early growth stage.

Key words: Hormesis, γ -Radiation, Soybean, Root growth

INTRODUCTION

Hormesis was defined as stimulative effect by low dose of agent in positive aspect on organism. Southam and Ehrlich¹⁾ used hormesis in research for the effect of extract of western red-cedar heartwood on certain wood decaying fungi firstly. Until now, it has been thought that hormesis stimulated organism in more response for the changes of environmental factor. This response included repair and defence mechanism, priority for available use-efficiency of energy.

Hormesis by radiation has been researched through ⁶⁰Co, and ¹³⁷Cs that radiate pure γ -ray since 1960s, but hormesis by radiation had variability and low reproducibility in experiment data. Results of Luckey²⁾ and Simon³⁾ admitted hormesis of radiation in irradiated plant through application for various plants.

Occurrence of hormesis was observed as accelerated germination, development, growth, ripening, increased yield in plant, and many researchers reported for appearance of hormesis in cereal crops such as potato⁴⁾, maize⁵⁾, barley⁶⁾, and many vegetables such as radish⁷⁾, lettuce⁸⁾, pepper⁹⁾, cucumber¹⁰⁾.

But, most of researches for hormesis in crop plant were dealt with in the aspect of increase of crop yield and nutrient

content such as protein, amino acids, carbohydrates and vitamine. Hormesis mechanism remained as hypothesis, or was supported with only a little indirective proof. Moreover, in spite of the variety of hormetic effect by environment factor, a few report studied effect of environmental factor on hormesis of radiation.

Therefore, in this study, we evaluated effect of environmental conditions on appearance of hormesis by γ -ray irradiation, examined hormetic effect on root growth for soybean cultivars that was reported hormetic effect for ripening, increase of yield etc..

MATERIALS AND METHODS

Materials

To examine the effect of hormesis of γ -radiation on root growth of plant, Seeds of soybean were irradiated as 0.5, 1, 2, 4, 8, 12, 16, 20Gy by ⁶⁰Co irradiation system supplemented in Korea Atomic Energy Institute. Irradiated dose was measured by Frincke dosimeter.

Cultivations

To understand hormetic effect on root growth of cultivars

and the difference of hormetic effect by cultivation environment, Irradiated seeds of soybean were sowed at pot in growth chamber, greenhouse and experiment field of Korea university, and cultivated for 22 days, 35 days respectively. Also, to observe hormetic effect during whole life cycle of soybean, irradiated soybean seeds were cultivated in experiment field of Korea Atomic Energy Institute.

Measurements of root growth

The plant were prudently harvested by washing with tap water, harvested plant roots were spreaded out in transparent plastic box charged with water, root image were scanned at scanner (AGFA; Snapscan1236). The saved root image in computer was analyzed by image analysis program (WinRhizo V4.0B). Root length, root surface area, root average diameter and root volume were measured.

Results and discussion

Form of the response-to-dose function by γ -radiation at soybean cultivars cultivated in growth chamber.

To investigate hormetic effect of low dose γ -ray on the root growth of soybean cultivars and to compare hormetic effect by environmental condition, Seeds irradiated with 0.5 to 20Gy and control were cultivated in growth chamber. Changes of root growth by γ -ray irradiation showed at table 1, and to investigate minutely hormetic effect in root growth, we showed distribution of root surface area, root length, and root volume for root diameter size such as fig. 1, fig. 2, fig.3.

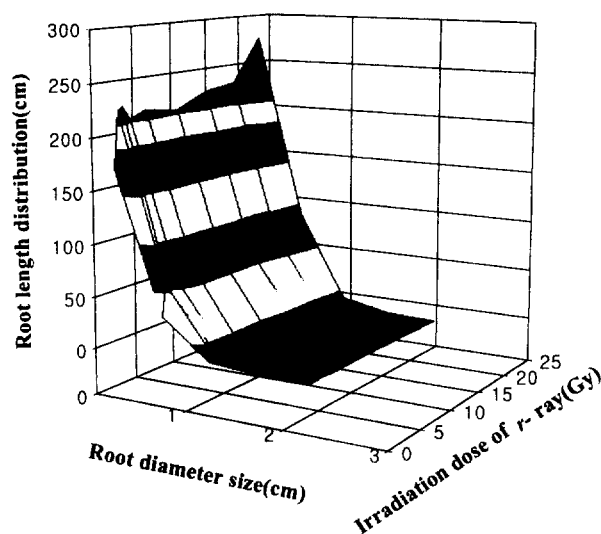


Fig. 1. Change of total root length distribution by γ -ray irradiation at soybean cultivars cultivated in growth chamber according to root diameter size.

Responses such as total root length, root average diameter, root volume by γ -ray irradiation was significantly different in comparison with non irradiated cultivars. Except for root surface area, root growth of γ -ray irradiated soy bean cultivars increased, and root growth continuously increased, as irradiation dose increased to 20Gy. Shamsi⁽¹¹⁾ investigated effect of low dose γ radiation on the growth and yield of two cultivars of broad bean, he reported that the french cultivar showed a greater degree of sensitivity to higher dose γ radiation than did the Egyptian in green house condition that light and temperature were well controlled. Therefore, the environment confined in growth chamber resulted in hormetic effect apparently.

Table 1. Effect of γ -ray irradiation on root growth of soybean cultivars cultivated in growth chamber

Dose of γ -ray (Gy)	Duration of cultivation	Root growth			
		Root total length (cm)	Root surface area (cm ²)	Root average diameter (mm)	Root volume (cm ³)
0	22 days	221(1.00) [†] b [*]	30(1.00) a	0.436(1.00) c	0.34(1.00) b
0.5		308(1.39) ab	45(1.51) a	0.473(1.09) abc	0.55(1.62) ab
1		304(1.38) ab	34(1.41) a	0.452(1.04) bc	0.49(1.44) ab
2		299(1.35) ab	46(1.53) a	0.503(1.15) a	0.59(1.73) ab
4		313(1.42) ab	48(1.59) a	0.486(1.11) ab	0.60(1.77) ab
8		304(1.38) ab	46(1.53) a	0.488(1.12) ab	0.58(1.70) ab
12		320(1.45) ab	50(1.64) a	0.500(1.14) ab	0.63(1.85) ab
16		331(1.50) ab	51(1.69) a	0.487(1.12) ab	0.64(1.90) ab
20		389(1.76) a	59(1.94) a	0.484(1.11) ab	0.72(2.13) a

^{*}Any two means having a common letter are not significantly different in the 5% level of significance.

[†]Figures given in parentheses are values of ratio for control

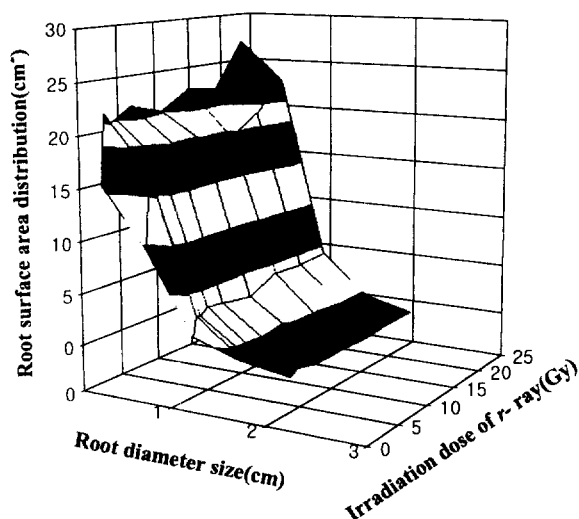


Fig. 2. Change of total root surface area distribution by γ -ray irradiation at soybean cultivars cultivated in growth chamber according to root diameter size.

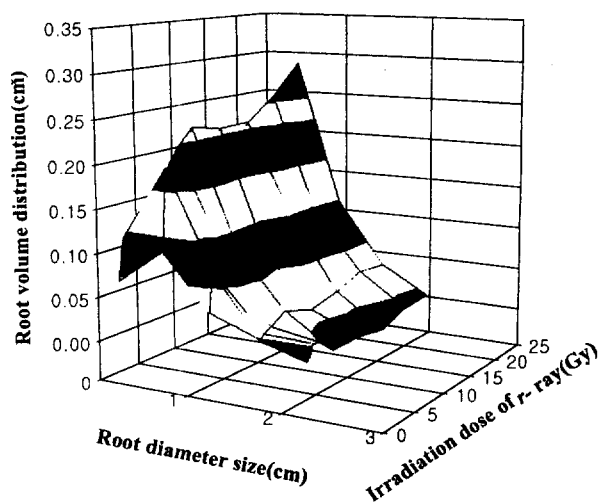


Fig. 3. Change of total root volume distribution by γ -ray irradiation at soybean cultivars cultivated in growth chamber according to root diameter size.

Form of the response-to-dose function by γ -radiation at soybean cultivars cultivated in greenhouse.

In cultivars cultivated at greenhouse, Changes of root growth by γ -ray irradiation showed at table 2. Soy bean cultivars irradiated with 0.5 to 20Gy were harvested in 22 days and 35 days respectively, the results showed difference in hormetic effect for root growth according to cultivation time. After 22 days root total length, root surface area increased broadly, but after 35 days total root growth decreased in 16Gy irradiation significantly.

Form of the response-to-dose function by γ -radiation at soybean cultivars cultivated in field condition.

In cultivars cultivated at field condition, changes of root growth by γ -ray irradiation showed at table 3. Soy bean cultivars irradiated with 0.5 to 20Gy were harvested in 22 days and 50 days respectively. Hormetic effect occurred to different form according to cultivation time. In the very early stage of growth, total root length and root surface area of irradiated cultivar increased broadly, and were different significantly in the 5% level compared with those of non-irradiated cultivars. But after 50 days, root total length were least in cultivars irradiated with 16Gy, and root surface area, root average diameter and root volume did not show difference statistically. Therefore it was thought that hormetic effect occurred differently according to growth stages, emergence of hormesis was apparent in the early stage of growth.

Effect of γ -irradiation on growth of soybean cultivars cultivated in different cultivation environment.

Table 4 showed the response form of dry weights of soybean cultivars by environment condition and growth stage at the γ -ray irradiation of soybean seeds. Root growth data mentioned above and dry weight data showed broadly apparent hormetic effect at cultivars cultivated in growth chamber condition, and in the greenhouse and field condition hormetic effect emerged sharply or was not admitted significantly. Also, soybean cultivars showed different growth rates by cultivation condition, Growth rate of soybean cultivated in growth chamber was most rapid in shoot length and fresh weight, growth stage of cultivars could not compare absolutely by only cultivation time. but, as cultivation time increased, hormetic effect for root growth and biomass was weakened. This result might be due to cultivation condition. During cultivation, environment condition of growth chamber including light, day and night temperature, humidity was maintained regularly, but greenhouse and field condition were irregular due to change of weather condition. Especially field condition might be most variable. Lowell¹²⁾ researched for hormesis in corn seed, he pointed out some problem that the experiment must be performed under absolutely constant conditions in order to obtain reproducible results. But it was considered that research in variable condition was important in the aspect of field application.

Table 2. Effect of γ -ray irradiation on root growth of soybean cultivars cultivated in green house

Dose of γ -ray (Gy)	Duration of cultivation	Root growth			
		Root total length	Root surface area	Root average diameter	Root volume
		(cm)	(cm ²)	(mm)	(cm ³)
0	22 days	368(1.00) [†] ab [*]	53(1.00) b	0.464(1.00) a	0.62(1.00) a
0.5		353(0.96) b	56(1.07) ab	0.515(1.11) a	0.74(1.20) a
1		416(1.13) ab	63(1.20) ab	0.486(1.05) a	0.79(1.28) a
2		541(1.47) a	83(1.57) a	0.493(1.06) a	1.03(1.66) a
4		390(1.06) ab	56(1.06) ab	0.459(0.99) a	0.64(1.04) a
8		372(1.01) ab	55(1.05) ab	0.479(1.03) a	0.67(1.08) a
12		477(1.29) ab	77(1.46) ab	0.521(1.12) a	1.01(1.64) a
16		430(1.17) ab	96(1.31) ab	0.512(1.10) a	0.90(1.45) a
20		422(1.15) ab	67(1.27) ab	0.511(1.10) a	0.87(1.41) a
0	35 days	864(1.00) ab	139(1.00) a	0.518(1.00) b	1.82(1.00) a
0.5		909(1.05) a	145(1.04) a	0.512(0.99) b	1.88(1.03) a
1		861(0.99) ab	142(1.02) a	0.532(1.03) ab	1.91(1.05) a
2		860(0.99) ab	137(0.98) a	0.520(1.01) b	1.82(1.00) a
4		871(1.01) ab	144(1.03) a	0.530(1.03) ab	1.92(1.05) a
8		828(0.96) ab	138(0.99) a	0.537(1.04) ab	1.86(1.02) a
12		787(0.91) abc	138(0.99) a	0.562(1.09) a	1.95(1.07) a
16		673(0.78) c	108(0.78) b	0.513(0.99) b	1.40(0.77) b
20		747(0.87) bc	123(0.89) ab	0.532(1.03) ab	1.65(0.91) ab

*Any two means having a common letter are not significantly different in the 5% level of significance

[†]Figures given in parentheses are values of ratio for control

Table 3. Effect of γ -ray irradiation on root growth of soybean cultivars cultivated in field

Dose of γ -ray (Gy)	Duration of cultivation	Root growth			
		Root total length	Root surface area	Root average diameter	Root volume
		(cm)	(cm ²)	(mm)	(cm ³)
0	22 days	39(1.00) [†] b [*]	7(1.00) b	0.580(1.00) a	0.102(1.00) a
0.5		52(1.31) b	8(1.15) ab	0.507(0.87) abc	0.102(1.00) a
1		75(1.89) ab	13(1.87) ab	0.567(0.98) ab	0.187(1.83) a
2		73(1.84) ab	13(1.85) ab	0.560(0.96) ab	0.187(1.83) a
4		106(2.69) a	15(2.20) ab	0.463(0.80) c	0.180(1.77) a
8		73(1.85) ab	11(1.69) ab	0.519(0.89) abc	0.155(1.52) a
12		96(2.43) ab	13(1.86) ab	0.437(0.75) c	0.143(1.40) a
16		105(2.66) a	16(2.21) a	0.480(0.83) bc	0.184(1.80) a
20		79(2.01) ab	13(1.85) ab	0.523(0.90) abc	0.172(1.68) a
0	50 days	639(1.00) ab	131(1.00) a	0.664(1.00) a	2.18(1.00) a
0.5		815(1.28) a	173(1.33) a	0.685(1.03) a	3.00(1.38) a
1		735(1.15) ab	152(1.16) a	0.660(0.99) a	2.57(1.18) a
2		586(0.92) ab	122(0.93) a	0.667(1.01) a	2.05(0.94) a
4		813(1.27) a	161(1.23) a	0.638(0.96) a	2.58(1.18) a
8		771(1.21) ab	160(1.23) a	0.647(0.97) a	2.76(1.27) a
12		638(1.00) ab	134(1.03) a	0.667(1.01) a	2.34(1.08) a
16		468(0.73) b	100(0.76) a	0.679(1.02) a	1.74(0.80) a
20		518(0.81) ab	112(0.86) a	0.704(1.06) a	2.01(0.92) a

*Any two means having a common letter are not significantly different in the 5% level of significance.

[†]Figures given in parentheses are values of ratio for control

Table 4. Effect of γ -ray irradiation on dry weights of soybean cultivars cultivated in different environment condition

Dose of γ -ray (Gy)	Cultivation situation (Duration of cultivation)				
	Chamber (22 days)	Green house (22days)	Green house (35days)	Field (22days)	Field (35days)
	g				
0	0.297(1.00) [†] b [*]	0.318(1.00) ab	0.833(1.00) a	0.243(1.00) a	1.557(1.00) a
0.5	0.283(0.95) b	0.316(0.99) ab	0.865(1.04) a	0.173(0.71) a	1.011(0.65) ab
1	0.486(1.64) a	0.296(0.93) ab	0.854(1.03) a	0.308(1.27) a	0.925(0.59) ab
2	0.325(1.10) ab	0.387(1.22) a	0.924(1.11) a	0.202(0.83) a	0.918(0.59) ab
4	0.301(1.01) b	0.223(0.70) b	0.970(1.17) a	0.257(1.06) a	1.150(0.74) ab
8	0.285(0.96) b	0.261(0.82) b	0.884(1.06) a	0.280(1.15) a	1.045(0.67) ab
12	0.332(1.12) ab	0.343(1.08) ab	0.920(1.10) a	0.251(1.03) a	1.008(0.65) ab
16	0.376(1.27) ab	0.250(0.79) b	0.744(0.89) a	0.284(1.17) a	1.272(0.82) ab
20	0.308(1.04) b	0.254(0.80) b	0.874(0.93) a	0.288(1.19) a	0.711(0.46) b

*Any two means having a common letter are not significantly different in the 5% level of significance

[†]Figures given in parentheses are values of ratio for control

Table 5. Effect of γ -irradiation on root growth and yield of soybean cultivars cultivated in field for whole life cycle.

Dose of γ -ray (Gy)	Duration of cultivation	Root growth				
		Root total length (cm)	Root surface area (cm ²)	Root average diameter (mm)	Root volume (cm ³)	
0		448(1.00) [†] bcd [*]	98(1.00) bc	0.729(1.00) bc	1.77(1.00) c	
0.5		464(1.04) abcd	102(1.04) abc	0.713(0.98) c	1.84(1.04) bc	
1		431(0.96) cd	107(1.08) abc	0.803(1.10) a	2.15(1.22) a	
2	middle vegetative stage	531(1.19) ab	113(1.15) ab	0.693(0.95) c	1.94(1.10) abc	
4		536(1.20) a	116(1.18) a	0.701(0.96) c	2.04(1.15) ab	
8		405(0.91) cd	96(0.97) c	0.767(1.05) ab	1.82(1.03) bc	
12		479(1.07) abc	105(1.07) abc	0.711(0.97) c	1.85(1.05) bc	
16		378(0.84) d	81(0.82) d	0.690(0.95) c	1.40(0.79) d	
20		509(1.14) ab	112(1.14) ab	0.716(0.98) c	2.00(1.13) abc	
0		1,203(1.00) a	332(1.00) a	0.919(1.00) ab	7.62(1.00) a	
0.5		1,021(0.85) abc	281(0.84) b	0.909(0.99) abc	6.34(0.83) b	
1		889(0.74) bcd	245(0.74) bc	0.986(0.97) abc	5.50(0.72) bc	
2	flowering stage	836(0.70) d	241(0.72) bc	0.942(1.02) a	5.69(0.75) bc	
4		1,017(0.85) abc	278(0.84) b	0.897(0.98) abc	6.26(0.82) b	
8		1,099(0.91) a	278(0.84) b	0.841(0.92) c	5.77(0.76) bc	
12		1,085(0.88) ab	283(0.85) ab	0.878(0.96) abc	6.19(0.81) b	
16		833(0.69) cd	219(0.66) c	0.859(0.93) bc	4.70(0.62) c	
20		786(0.65) d	223(0.67) c	0.983(1.02) ab	5.24(0.69) bc	
0			436(1.00) ab	260(1.00) ab	2.097(1.00) ab	10.74(1.00) ab
0.5			377(0.60) c	220(0.68) b	2.302(1.09) a	9.23(0.77) ab
1	pod maturing stage	355(0.85) bc	215(0.80) b	1.853(0.89) bc	8.72(0.75) b	
2		317(1.20) a	184(1.17) a	1.902(0.93) bc	12.62(1.14) a	
4		306(1.06) ab	178(1.00) ab	1.879(0.90) bc	10.53(0.95) ab	
8		283(0.76) bc	173(0.77) b	1.993(0.97) bc	8.65(0.78) b	
12		272(0.60) c	170(0.67) b	2.234(1.05) a	8.70(0.73) b	
16		234(0.79) bc	162(0.78) b	2.031(0.95) abc	8.98(0.77) ab	
20		219(0.79) bc	153(0.72) b	1.822(0.87) c	7.87(0.64) b	

*Any two means having a common letter are not significantly different in the 5% level of significance

[†]Figures given in parentheses are values of ratio for control

Effect of γ -irradiation on root growth and yield of soybean cultivars cultivated in field for whole growth stage.

Occurrence of hormesis in field during whole growth stage and change of yield showed at table 5, fig. 4 and fig. 5. Hormetic effects of γ -ray irradiation on root growth had a variable trend in each growth stage, but in the middle of vegetative stage, 4Gy, 12Gy and 20Gy irradiation showed stimulating effect at root length and root surface area. In flowering stage and pod maturing stage, root growth gradually decreased at γ -ray irradiated cultivars. Especially, decrease of root growth in pod maturing stage meant of degradation and deterioration of root after flowering stage, and it was considered that rapid degradation and deterioration was due to early maturation of pod.

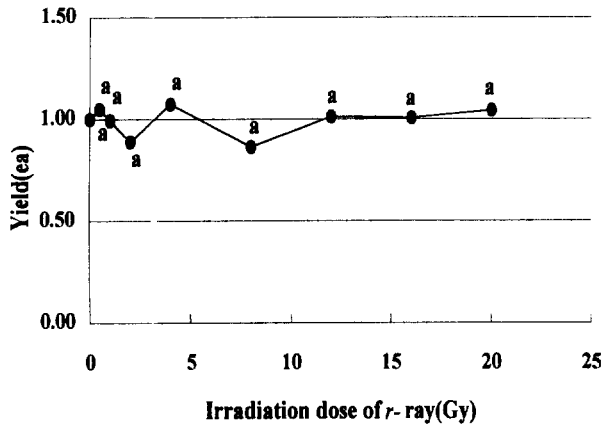


Fig. 4. The Changes of Yield by γ -ray irradiation at soybean cultivars cultivated in field(Any two means having a common letter are not significantly different in the 5%level of significance).

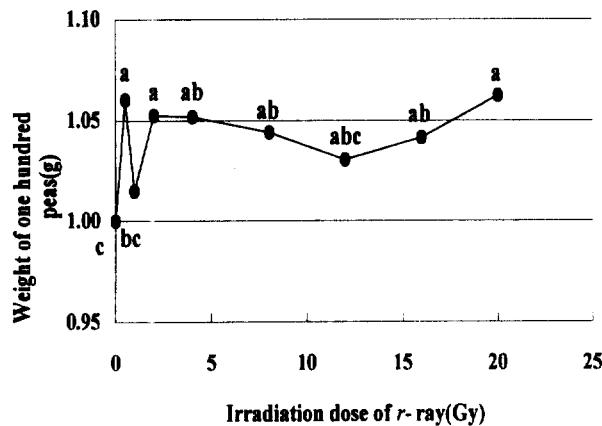


Fig. 5. The Changes of dry weight of one hundred peas by γ -ray irradiation at soybean cultivars cultivated in field(Any two means having a common letter are not significantly different in the 5%level of significance).

Yields of pea were not different significantly in each γ -ray irradiated cultivars such as fig. 5, but Weight of one hundred peas increased in whole γ -ray irradiated cultivars. This results showed that quality of peas was risen irrespective of root growth comparing with above result. Therefore, rise of pea quality was supposed to be induced through stimulation of growth in early growth stage and shortening of maturing stage. The similar result was reported by Kim¹³⁾ *et al.* that yield of soy bean increased 35% in 2.0Gy irradiation.

SUMMARY

This study was conducted to examine the root growth responses and yield of soybean cultivars by γ -ray irradiation, to investigate the hormesis effect by environmental condition with the goal of developing an ability to predict the occurrence of increased economic yield. Seeds of cultivars were irradiated with the dose of 0.5–20Gy and cultivated in growth chamber that control temperature, humidity, and light, greenhouse and field respectively. To comprehend hormetic effect for whole growth stage, field application was executed.

After harvesting, roots of cultivars were scanned with scanner, total root length, root surface area, root diameter and root volume were examined through scanned root image by WinRhizo root image analyzing program that was based on fractal theory.

In growth chamber condition, responses such as total root length, root average diameter, root volume by γ -ray irradiation was significantly different in comparison of control. Except for root surface area, root growth of γ -ray irradiated soy bean cultivars increased, and root growth continuously increased, as irradiation dose increased to 20Gy. In cultivars cultivated at green house condition, Soy bean cultivars irradiated with 0.5 to 20Gy showed difference in hormetic effect for root growth according to cultivation time in which were 22 days and 35 days respectively. After 22 days root total length, root surface area increased broadly, but after 35 days total root growth decreased in 16Gy irradiation significantly. Also, in cultivars cultivated at field condition, hormetic effect occurred to different form according to cultivation time, it was assumed that hormetic effect occurred differently according to growth stages, emergence of hormesis was apparent in the early stage of growth.

Root growth data and dry weight data showed broadly apparent hormetic effect at cultivars cultivated in growth

chamber condition, and in the green house and field condition, hormetic effect emerged sharply or was not admitted significantly. In field experiment practiced for whole growth stage, yields of pea were not different significantly in each γ -ray irradiated cultivars, but weight of one hundred peas increased in whole γ -ray irradiated cultivars. Rise of quality that was observed assumed to be induced through stimulation of growth in early growth stage and shortening of maturing stage.

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