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Lanthanum Induced Seed Germination Rate, Seedling Growth and Dry Matter Production of Soybean [*Glycine max* (L.) Merr.]

Radhe Shyam[1,2,*] **and N.C. Aery**[1]

[1]**Laboratory of Geobotany and Biogeochemistry, Department of Botany, University College of Science, Mohanlal Sukhadia University, Udaipur-313001 (Rajasthan) India**
[2]**Department of Botany, Leeladevi Parasmal Sancheti Kanya Mahavidyalaya, Vidyawadi (Khimel)-306115, Station-Rani, Dist- Pali (Rajasthan) India**

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Corresponding Author Email: radheshyamgodara@gmail.com

Abstract

A solution culture experiment was conducted to study the effect of different levels (0.1, 0.5, 2.5, 12.5 and 62.5 µg ml^{-1}) of La^{3+} provided as $La.N_3O_9.6H_2O$ on seed germination, seedling growth, dry matter production (shoot-root relative yield) and grade of growth inhibition of soybean [*Glycine max* (L.) Merr.]. La^{3+} at low levels (0.1-0.5 µg ml^{-1}) significantly increased the rate of seed germination, seedling growth, dry matter production and decreased the grade of growth inhibition of soybean seedlings. Higher concentration (12.5 and 62.5 µg ml^{-1}) of La^{3+} proved to be toxic for seedling growth and dry matter production. At higher levels of La^{3+} (62.5 µg ml^{-1}) root length was drastically affected than shoot length. Though germination speed was affected, ultimate germination was always 100%. Results of the study indicate that low levels of La^{3+} are beneficial for the soybean plants.

Keywords
La^{3+}, Seed germination, Shoot-Root length, Relative yield, Soybean.

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1. INTRODUCTION

Rare earth elements (REEs) include 17 elements of the 6th Period of the III group in the Periodic system with Scandium (21) and Yttrium (39) and 15 elements of lanthanide series with atomic number 57-71 [1]. Generally, 15 lanthanides (REEs) have been divided into two groups (i) Light rare earth elements (LREEs) (ii) Heavy rare earth elements (HREEs) [2]. La and Ce belong to the group of LREEs, because of their atomic mass lower than 153 amu. These REEs are lithophile elements, frequently occur together in rare earth minerals and have similarities in ionic radii and physical/ chemical properties [3].

Lanthanum (La) and Cerium (Ce) are two important elements of commercial REEs micro fertilizer and have been observed to be potentially beneficial for plant growth in trace amounts [4, 5]. These are widely used in China since 1970s as micro fertilizer in chloride and nitrate form to improve plant growth and yield [1].

There are contradictory results regarding the influence of REEs on plant growth and development. Results of early studies indicate that REEs have positive, negative and nil effect on plant growth. For example, REEs enhanced the speed of seed germination and growth (shoot-root length) of agricultural crops such as rice, wheat, barley and vegetable crops [6,7].

REEs (5 and 10 ppm) increased the leaf area, seedling length, dry matter accumulation and stimulate the growth of root system of soybean plants in hydroponics culture experiments [8]. However, REEs as $(REE)_xO_y$ decreased root length of rice plants [9]. Mixture of REEs nitrate and La^{3+} decreased the seed germination of *Triticum durum* Desf. as compared to control [10]. La^{3+} and Nd^{3+} inhibited the elongation of oat coleoptile section [11]. A general requirement by crop plants for lanthanum has not yet been established.

Soybean is an important economic crop plant in the world for seed oil content and protein content [12]. Keeping these facts in mind, studies were undertaken to investigate the effect of La^{3+} on seedling growth (shoot-root length), dry matter production (shoot-root relative yield) and grade of growth inhibition (shoot-root) of soybean.

2. MATERIAL AND METHODS

2.1. Experimental plant material, culture solution and growth conditions

A solution culture experiment was set up during the month of June under laboratory conditions (Room temperature 37.1±1ºC) with a photoperiod of 7 hours day^{-1} and light intensity of 3600 Lux. Twelve seeds of certified variety Pratap Soya-1 of *Glycine max* (L.) Merr. (Obtained from RCA/MPUAT, Udaipur) were selected for uniformity and placed in each Petri dish with filter paper rinsed with freshly prepared La^{3+} solution. A randomized block factorial design with five concentrations of La^{3+} (0.1, 0.5, 2.5, 12.5 and 62.5 µg ml^{-1}) was used. La^{3+} as $La.N_3O_9.6H_2O$ (A.R.Grade) was applied in triplicate. The different concentrations of La^{3+} were prepared separately by taking corresponding amount of (calculated on the basis of their molecular weights) chemical/ liter of water. Control sets contained only distilled water. A fix amount (10 ml) of La^{3+} solution and distilled water (For control group) with glass pipette (BOROSIL) was poured in each Petri dish to saturate the filter paper. After the start of seed germination, the speed of seed germination was noted after everyone hour and percent germination were calculated.

2.2. Seedling growth and weight measurements

After 7 days of treatment, plants were harvested and washed with double distilled water and shoot-root length was measured. Shoot and root were cut apart and fresh weight was noted. The harvested plant samples were dried at 80°C in an oven for 48 hours and weighed for dry weight of shoots and roots.

2.3. Grade of growth inhibition (GGI)

The grade of growth inhibition (GGI) of the seedlings (shoot-root) was calculated by applying the formula as described in Aery [13].

GGI = (Dry weight of control plant - Dry weight of treated plant/ Dry weight of control plant) ×100

2.4. Statistical analysis

All the experiments were conducted with a minimum of 3 replicates per treatment and results were statistically analyzed for variance (ANOVA) using SPSS version 17 (SPSS, Chicago, USA). The significance of differences among means was carried out using Duncan's multiple range test (DMRT) at $p<0.05$. The results are shown as mean ± SD of three replicates.

3. RESULTS AND DISCUSSION

La^{3+} showed a positive influence on the speed of seed germination, early seedling growth (shoot-root length), dry matter (shoot-root relative yield) and grade of growth inhibition of soybean plant [*Glycine max* (L.) Merr.]. Results on the effect of La^{3+} on seed germination are shown in Figure 1. Seed germination started after 10 hours in La^{3+} treated seeds (0.1-62.5 µg ml^{-1}) and after 11 hours in untreated seeds (control group). After 10 hours, at higher concentrations of La^{3+} (62.5 µg ml^{-1}) maximum speed of seed germination was observed. More than 50% germination was achieved at lower applied La^{3+} concentrations (0.1-12.5 µg ml^{-1}) after a period of 11 hours, but at higher level of La^{3+} (62.5 µg ml^{-1}) it was attained after a period of 16 hours.

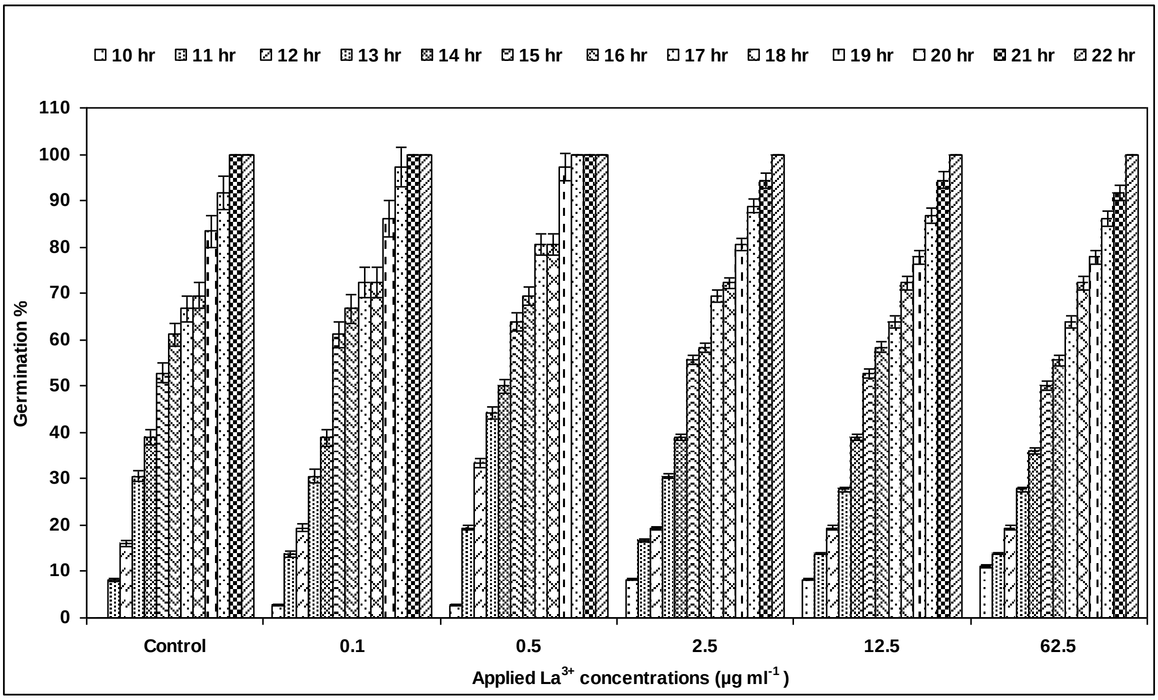

Figure 1. Effect of different concentrations of lanthanum as lanthanum nitrate on seed germination of *Glycine max* (L.) Merr. Each column represents the percentage (%) of seed germination. Bar on each column represent the Standard Deviation (±SD) of replicates from mean value.

Lower applied La^{3+} concentrations (0.1-2.5 µg ml^{-1}) increased the speed of seed germination and the maximum increment in speed of seed germination was observed at 0.5 µg ml^{-1} level of La^{3+}. The increment in speed of seed germination may be due to enhanced activities of SOD, CAT and POD and decreased production rate of O_2^- and peroxidation of lipid membrane [14] or an increase in the amylase activity and rate of seed respiration [15] under the treatment of La^{3+}. Chao *et al.,* [16] reported that lanthanum enhanced the permeability of seeds which was favorable for entry of water and O_2 in the cells of the seeds and increased the rate of respiration *vis* a *vis* speed of seed germination [17].

In almost all treatments except the higher ones (2.5-62.5 µg ml^{-1}) a slight decrease in the speed of seed germination was observed after a period of 19 hours. At lower concentrations of La^{3+} (0.1-0.5 µg ml^{-1}) 100% germination was achieved after a period of 21 hours, but at higher level of La^{3+} (12.5-62.5 µg ml^{-1}) it was obtained after a period of 22 hours. It seems that the higher level of La^{3+} damaged the structure of seed membrane, resulting in the water retention ability of seed membrane *vis* a *vis* a decrease in the speed of seed germination [7]. Similar results have been reported on the effect of Ni [18], Ce [7], W and Mo [19].

Liu, [20] reported that REEs at low level (<100 mgL^{-1}) stimulate the seed germination but at higher level (>500 mgL^{-1}) restrained the speed of seed germination of sunflower.

The results of present study indicate that low levels of La^{3+} (0.1-2.5 µg ml^{-1}) had promotory effect on seedling growth (shoot-root length) and relative yield (shoot-root) of test plant (Figure 2 and 3). Maximum increment in seedling growth (shoot-root length) and relative yield was observed at the 0.5 µg ml^{-1} level of La^{3+} which was 15.90%, 53.48% for shoot and root length and 118.51%, 142.85% for shoot and root relative yield of test plant, respectively, over the control.

Hong *et al.,* [14] reported that lanthanum plays a key role in the germination of aged rice seeds. They observed that La^{3+} as La $(NO_3)_3$ (at 500 µg/g) increased the rate of seed germination, germination index, vigor index and seedling dry weight of aged rice seeds over the control, (except with 100 µg/g level of lanthanum nitrate) but at higher level (600-700 µg/g) a gradual decrement in various indices was observed and suggested that lanthanum salts be used for seed pretreatment before sowing. Low concentrations (0.1-2.5 µg g^{-1}) of Ce^{3+} have also been observed to be beneficial for the cowpea plants [21].

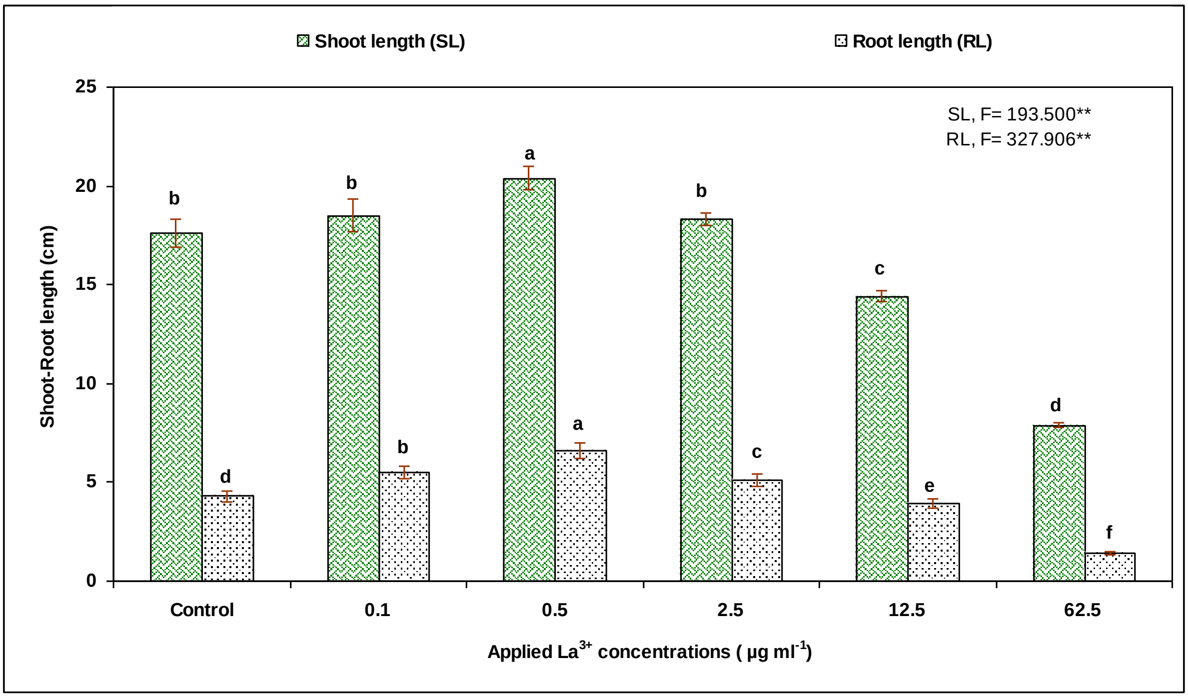

Figure 2. Effect of different concentrations of lanthanum as lanthanum nitrate on seedling growth (shoot-root length) of *Glycine max* (L.) Merr. after 7 days of seed germination. Bar on each column represent the Standard Deviation (±SD) of replicates from mean value. Same letter on the columns of shoot and root length parameter are statistically not significantly different (p<0.05) using Duncan's multiple range test.

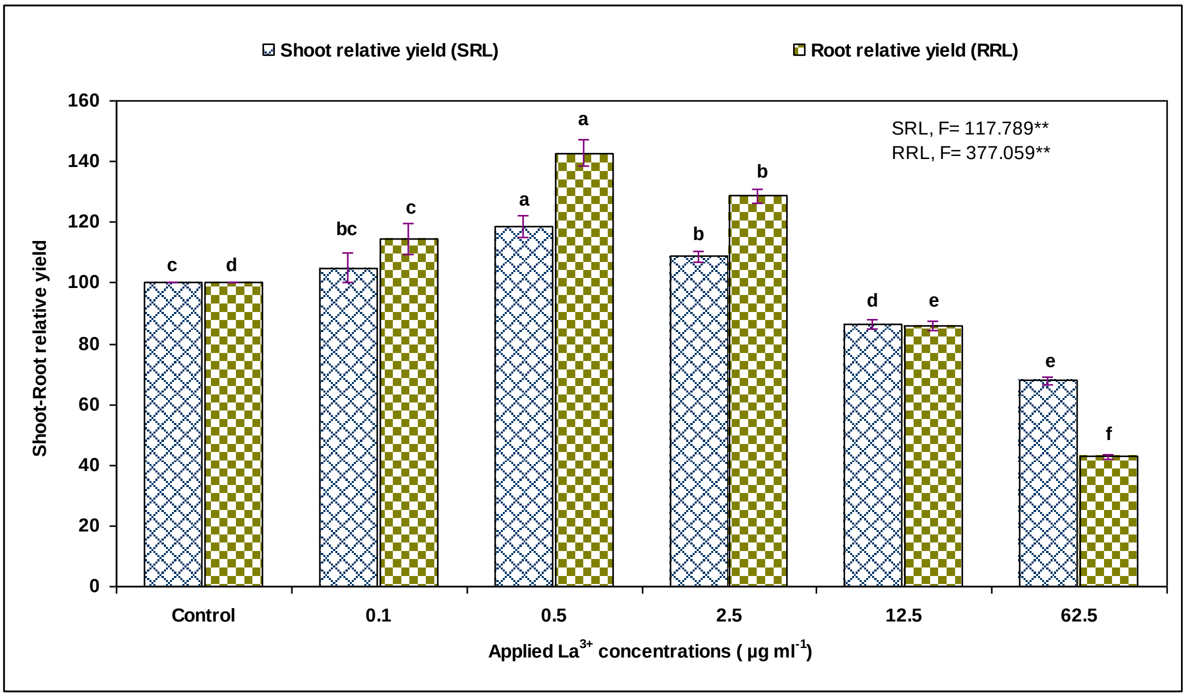

Figure 3. Effect of different concentrations of lanthanum as lanthanum nitrate on shoot-root relative yield (Dry matter) of *Glycine max* (L.) Merr. after 7 days of seed germination. Same letter on the columns of shoot and root relative yield parameter are statistically not significantly different (p<0.05) using Duncan's multiple range test. Bar on each column represent the Standard Deviation (±SD) of replicates from mean value.

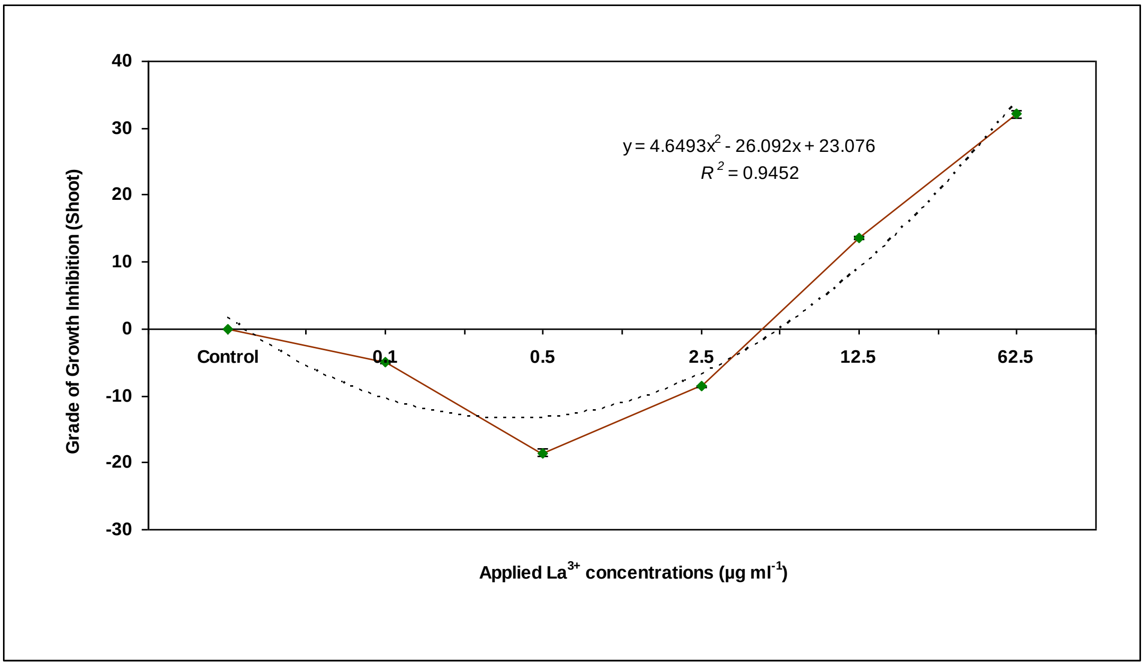

Figure 4. Effect of different concentrations of lanthanum as lanthanum nitrate on grade of growth inhibition (shoot) of *Glycine max* (L.) Merr. after 7 days of seed germination. Bar on each line represent the Standard Deviation (±SD) of replicates from mean value.

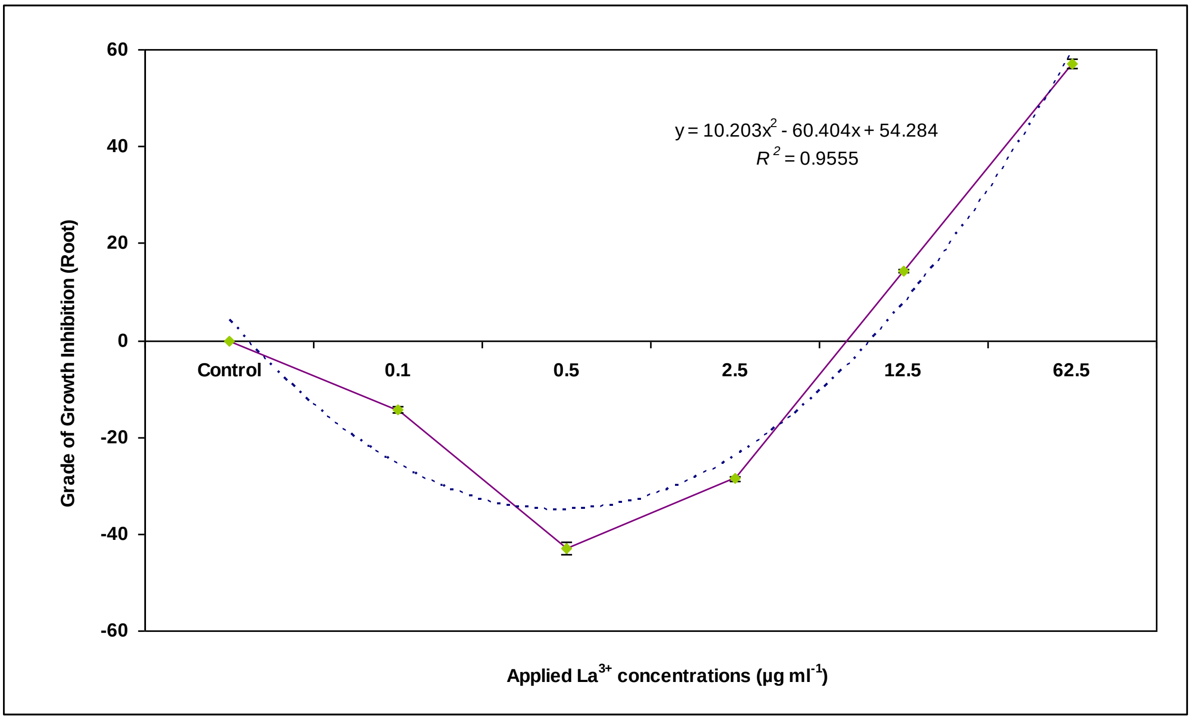

Figure 5. Effect of different concentrations of lanthanum as lanthanum nitrate on grade of growth inhibition (root) of *Glycine max* (L.) Merr. after 7 days of seed germination. Bar on each line represent the Standard Deviation (±SD) of replicates from mean value.

Sun et al., [22] reported that optimum concentration of REEs (5 or 10 mg/L) increase the plant length, leaf area and dry matter of young soybean plant but higher level of REEs (500 mg/L) significantly inhibited the growth and killed the test plant.

Lanthanum (La^{3+}) ions as lanthanum chloride ($LaCl_3$) in Hoagland nutrient solution at 20 mg/L, increased the seedling growth, dry weights (Root 42.3%, Stem 41.2% and leaf 56.2% respectively, over the control) of tobacco plants in water culture experiments at suitable level of La^{3+} (20 mg/L) in *vivo* but inhibited them at the higher level (≥50mg/L) [23].

Li *et al.,* [24] reported that La^{3+} at lower concentrations (200 mg. L^{-1}) increased the shoot-root length, fresh weight and plasma membrane H^+-ATPase activities of *Casuarina equesetifolia* seedlings under acid rain stress (pH 4.5) when the seeds were soaked for 8 hrs in $LaCl_3$ solution. However, higher level (300-400 mg. L^{-1}) inhibited the plant growth (seedling growth) and plasma membrane Ca^{2+}-ATPase activity.

He and Loh, [25] suggested that REEs increased the sensitivity of cell to plant growth regulators and might affected the sensitivity of cell through their effect on the membrane fluidity and membrane binding of hormones.

In the present studies at higher level (beyond 12.5 µg ml^{-1}) a gradual decrement in seedling growth (shoot-root length) and shoot-root relative yield (dry matter) was observed. Higher levels of La^{3+} (12.5-62.5 µg ml^{-1}) retarded the seedling growth and shoot-root relative yield of soybean plant (Figure 2 and 3). Maximum decrement in seedling growth and relative yield (55.11 % for shoot length and 67.44% for root length; 67.89% for shoot and 42.85% for root relative yield, respectively, over the control) was observed at the 62.5 µg ml^{-1} La^{3+} level.

At the higher level of La^{3+} (62.5 µg ml^{-1}) growth inhibition caused by La^{3+} can be attributed to the loss of cellular turgor, due to higher accumulation of La^{3+} in cell which inhibit cell enlargement and reduced the extensibility of the cell wall [26,27] or it might be due to inhibition of mitotic activity in the meristematic zone [28]. La in colloidal form inhibits cell division in root tips and finally decreases the root elongation of barley [29].

Hu *et al.,* [30] reported that La (≥0.75g La Kg^{-1} soil and ≥0.05g La Kg^{-1} soil) significantly (P≤0.5) decreased the shoot-root dry weight of maize seedlings as compared to control. At the higher level of La^{3+} (62.5 µg ml^{-1}) root tips become black, thick and root growth (length) was drastically affected than shoot growth (length) and this concentration proved to be highly toxic for soybean seedlings. Roots have been considered as a sensitive biomarker of lanthanum stress [30].

La^{3+} also affects the grade of growth inhibition (shoot-root) of test plant (Figure 4 and 5). Minimum grade of growth inhibition for shoot was observed to be 18.5 (at 0.5 µg ml^{-1} La^{3+}) with curve showing parabolic path. Similarly, minimum GGI for root (42.85 at 0.5 µg ml^{-1} La^{3+}) also shows parabolic path ($y=10.20x^2-60.40x+54.28$; $R^2=0.95$).

Beyond this level a gradual enhancement in GGI was observed. At higher level of La^{3+} (62.5 µg ml^{-1}) it was observed to be highest for both parameters (32.09 for shoot and 57.14 for root). Kumar and Aery [19] have also reported that in cowpea W at lower levels decrease the grade of growth inhibition and increase it at higher levels.

4. CONCLUSION

La^{3+} has been proved to be beneficial for seed germination and growth of soybean. Low levels of La^{3+} (0.5 µg ml^{-1}) increased the rate of seed germination, seedling growth (shoot-root length) and relative yield (shoot-root dry matter) but decreased the grade of growth inhibition. Higher levels of La^{3+} (62.5 µg ml^{-1}) suppressed the plant growth and relative yield and increased the grade of growth inhibition.

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