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Original Research Paper

Impact of pH regulants on growth, flowering, and color intensification of hydrangea (*Hydrangea macrophylla* Thunb.)

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ABSTRACT

An experiment was carried out to ascertain the effects of soil pH regulants on growth, flowering and color intensification of hydrangea cut flower under naturally ventilated polyhouse during 2022 to 2024, with seven treatments (g/m^2) *viz*., aluminium sulphate (60, 90 and 120) and lime (200, 250 and 300) replicated thrice in randomized block design. Results revealed that lime (300 g/m^2) exhibited maximum plant height (66.62 cm), plant spread (north-south) (65.65 cm), leaf length (22.98 cm), number of leaves (34.62), head diameter (29.49 cm) and stalk length (69.99 cm). Besides, maximum vase life (27.49 days), true blue colour (RHS colour: Purple violet group N82, strong purple A) and highest B:C ratio (4.08) was recorded with aluminium sulphate (120 g/m^2). Hence, treatment lime (300 g/m^2) is proved best for better growth, flowering and quality attributes, however, aluminium sulphate (120 g/m^2) was found best for colour intensification of hydrangea.

Key words: Aluminium sulphate, hydrangea, lime, pH regulants, quality

INTRODUCTION

Hydrangea, family Hydrangeaceae, is a novel cut flower crop, recently commercialized for cultivation as herbaceous perennial flower crop particularly in the cool and moist regions (Juhanja et al., 1998). The genus contains about 70-75 species with over 600 cultivars with somatic chromosome number is 2n=36, native to Honshu, the large Japanese Island (Bailey & Bailey, 1976).

Hydrangea is a spectacular temperate ornamental plant, occurring as shrubs, small trees, or climbers, commercially propagated through terminal cuttings and grows best in well-drained soil under semi-shade conditions with 70-80% relative humidity (Bailey, 1998). Hydrangea bloom from spring to the rainy season and are typically pruned after flowering to encourage new growth and subsequent flowering.

Ten million hydrangea plants being sold annually, accounting for 13.5 per cent ($ 91,265,000) of US annual shrub sales (Fulcher et al., 2021). In India, there is a huge potential for growing excellent quality hydrangeas particularly in the places experiencing cool climate like Kashmir, Himachal Pradesh, Nainital, Kalimpong, Darjeeling, Southern and Northern hills of Shillong, Sikkim and Ooty. It is commercially grown under protected cultivation makes excellent cut flowers besides pot plants, used in fresh and dried flower arrangements. In Europe, the hydrangea cut flowers are produced primarily for Easter and Mother's Day (Weiler, 1980).

The colour of hydrangeas will vary considerably due to the pH of the soil (Tilt, 2008). The blue hues are best in acid soil and the degree of blueness is controlled by the amount of available aluminium and the capacity of a particular variety to draw it up (Kikelly, 2006). The red and pinks enjoy an alkaline or neutral soil where aluminium is not actively absorbed, while the whites stay white but usually enjoy the same conditions as the reds and pinks. To encourage "bluing" of the flowers the acidity level of soil should be between 5.5-6.0 on the pH scale (Bailey, 1998). To initiate colour change from pink to blue, aluminium sulphate has to be applied several times at intervals till the desired colour is attained. Further, the sepals of Hydrangea possess an anthocyanin pigment that becomes blue upon reacting with aluminium. So, unless enough aluminium is present to react with all the anthocyanin completely, an intermediate colour will be produced instead of the desired clear blue colour.

Since there is no evident data on the impact of colour intensification of hydrangea by regulating the soil pH. The present investigation is therefore, carried out to study the effect of aluminium sulphate and lime on growth, flowering and colour intensification of hydrangea.

MATERIALS AND METHODS

The present investigation was carried out in the naturally ventilated polyhouse of Department of Floriculture and Landscape Architecture, College of Horticulture, Mudigere, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, India during 2022 to 2024, in randomized block design with three replications. The experimental area received a total annual rainfall of 1150 mm during 2022-23, which was mainly spread over during June to August. The average annual minimum and maximum temperature (12.35° and 33.11°C, respectively) and humidity (50.07 and 99.57%, respectively) was recorded. Treatments (g/m^2) *viz*., aluminium sulphate (60, 90 and 120), lime (200, 250 and 300) and control were applied in two splits as drench application at grand growth and bud initiation stage. The experiment was conducted year-round using the raised bed transplanting method, planted at 30 cm×45 cm in plots measuring 0.90 m×2.25 m. A recommended fertilizer dose of 80:30:50 g NPK per m² along with FYM at 25 t ha^{-1} was applied to ensure optimum crop growth. Both the years data were pooled and subjected to statistical analysis.

Estimation of anthocyanin (mg/100 g of fresh sepal weight)

To estimate the presence of anthocyanin pigment in sepals of hydrangea, paper chromatography method as described by Fuleki & Francis (1968) to detect the pigments present in sepals of hydrangea. The procedure involved extraction of the anthocyanins with ethanolic–HCL and measurement of colour at the wave length of maximum absorption (535 nm) by using spectrophotometer.

Reagents used are ethanol 95% and hydrochloric acid (HCl): 1.5 N HCl. Both reagents were mixed together in a proper concentration of (85:15) and then it was called ethanolic-HCl. To prepare Ethanol-HCl in the ratio of 85:15, the solution was separately prepared. About 950 mL of ethanol was taken and 150 mL of distilled water was added to make 95% ethanol solution. Then 62.5 mL of HCl was weighed and made up to 500 mL with distilled water to make 1.5 N HCl solutions. Prepared 1 litre ethanolic-HCl solution (850 mL of 95 % ethanol and 150 mL of 1.5 N HCl) and used for the extraction.

About 1-2 g of fresh fully colour developed sepal was collected from each treatment and weighed, later soaked in ethanolic-HCl solution and then crushed with pestle and mortar. The contents were transferred to 100 mL conical flask and kept at 4ºC overnight. The next day, it was filtered with Whatmann paper (No. 4). The volume was made up to (25 mL) and kept in dark for 2 hours. Then the absorbance was measured using spectrophotometer instrument at 535 nm.

$$\text{Total anthocyanin (mg/100 g)} = \frac{\text{OD (535 nm)} \times \text{vol. made up} \times \text{total vol.} \times 100}{\text{Weight of the sample} \times \text{aliquot vol.} \times 98.2}$$

RESULTS AND DISCUSSION

Effects on plant growth

The maximum plant growth *i.e.* plant height, plant spread, stem girth, leaf length and breadth, number of leaves and leaf area was recorded with the application of lime at 300 g at 270 days after planting, however, minimum plant growth parameters were recorded in aluminium sulphate at 120 g (Table 1 & 2). Adding lime created a more favorable pH range for plant nutrient uptake and overall growth. Wherein it improved the availability of essential nutrients like calcium in the soil and helped to mitigate the toxic effects of elements like aluminium. Hence, calcium is important for plant development, including cell elongation, which can contribute to increased plant height. Aluminium treated plants caused the root burn on plants contributing to plant stunting and phytotoxicity, as also reported by Havlin et al. (2013) and Pietsch et al. (2022) in hydrangea.

Effects on flowering

The higher dose of lime (300 g) recorded minimum days to flower bud initiation and first floret opening (Table 3), as lime is alkaline and when applied in higher concentrations it can significantly raise the pH of the soil contributing optimum pH, thus improve the

Table 1 : Effect of aluminium sulphate and lime on growth parameters of hydrangea

Treatment	Plant height (cm)			Plant spread (North-South) (cm)			Plant spread (East-West) (cm)			Stem girth (cm)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Control	52.48	60.36	56.42	55.21	62.36	58.78	53.28	60.24	56.76	3.6	3.82	3.71
AS 60 g/m^2	49.26	56.22	52.74	54.86	59.22	57.04	52..67	58.63	55.65	3.59	3.76	3.67
AS 90 g/m^2	47.34	53.94	50.64	52.45	57.61	55.03	49.35	53.92	51.49	3.58	3.74	3.66
AS 120 g/m^2	43.25	49.41	46.33	50.63	54.21	52.42	47.31	50.36	48.83	3.5	3.71	3.6
Lime 200 g/m^2	54.67	65.85	60.26	57.32	64.23	60.77	55.19	65.31	60.25	3.62	3.83	3.72
Lime 250 g/m^2	57.19	68.11	62.65	58.44	67.1	62.77	57.48	69.27	63.37	3.63	3.85	3.74
Lime 300 g/m^2	60.71	72.54	66.62	60.79	70.52	65.65	58.37	74.11	66.24	3.65	3.89	3.77
SEm±	0.65	0.8	1.45	0.86	0.77	1.63	0.78	1.08	0.93	0.05	0.06	0.05
CD at 5%	2.01	2.45	2.23	2.66	2.37	2.51	2.39	3.34	2.86	NS	NS	NS

AS: Aluminium sulphate

Table 2 : Effect of aluminium sulphate and lime on growth parameters of hydrangea

Treatment	Leaf length (cm)			Leaf breadth (cm)			Number of leaves			Leaf area (cm^2)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Control	21.1	22.2	21.65	17.45	18.64	18.04	24.34	28.32	26.33	3115.52	3426.31	3270.91
AS 60 g/m^2	20.82	21.33	21.07	16.82	17.87	17.34	22.67	26.74	24.7	2833.75	3018.59	2926.17
AS 90 g/m^2	20.41	20.67	20.54	15.47	17.62	16.54	20.76	24.16	22.46	2532.72	2824.62	2678.67
AS 120 g/m^2	19.22	20.14	19.68	14.34	16.33	15.33	19.12	22.34	20.73	2294.4	2412.37	2353.38
Lime 200 g/m^2	21.67	22.51	22.09	17.88	18.94	18.41	26.31	30.39	28.35	3393.99	3633.14	3513.56
Lime 250 g/m^2	22.24	23.35	22.79	18.12	19.26	18.69	28.83	34.54	31.68	3747.9	3928.63	3838.26
Lime 300 g/m^2	22.38	23.58	22.98	18.96	19.74	19.35	30.58	38.67	34.62	4036.56	4255.24	4145.9
SEm±	0.23	0.24	0.23	0.22	0.24	0.23	0.49	0.5	0.49	59.35	39.85	49.6
CD at 5%	0.7	0.74	0.72	0.68	0.74	0.71	1.51	1.53	1.52	182.88	122.8	152.84

AS: Aluminium sulphate

Table 3 : Effect of aluminium sulphate and lime on flowering parameters of hydrangea

Treatment	Flower bud initiation (days)			First floret opening (days)			Complete opening of inflorescence (days)			Duration of flowering (days)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Control	276.12	215.35	245.73	302.56	274.36	288.46	330.16	265.35	297.75	39.92	42.64	41.28
AS 60 g/m^2	269.39	195.84	232.61	291.39	255.21	273.3	308.49	242.63	275.56	36.32	39.62	37.97
AS 90 g/m^2	267.69	192.36	230.02	289.67	246.33	268	305.38	235.12	270.25	36.97	38.27	37.62
AS 120 g/m^2	264.57	185.54	225.05	286.52	240.39	263.45	300.26	226.48	526.74	37.52	38.1	37.81
Lime 200 g/m^2	260.48	208.21	234.34	290.48	268.1	279.29	315.35	261.21	288.28	39.56	44.36	41.96
Lime 250 g/m^2	257.14	204.33	230.73	287.14	262.98	275.06	318.1	263.56	290.83	47.53	47.82	47.67
Lime 300 g/m^2	251	198.92	224.96	281.34	254.27	267.8	311.29	257.28	284.28	48.94	50.57	49.75
SEm±	3.94	2.92	3.43	4.43	4.18	4.3	4.17	1.27	2.72	0.46	0.78	0.62
CD at 5%	12.13	8.99	10.56	NS	12.89	12.89	12.84	3.9	8.37	1.4	2.41	1.9

AS: Aluminium sulphate

availability of essential nutrients like calcium, magnesium, and phosphorus, which are important for flowering and overall plant growth. This high concentration of lime can provide plants with an abundance of these nutrients, encouraging the development of flower buds and days to flower bud opening. Landis (2019) in hydrangea also reported similar results. Minimum days to complete opening and bud formation to fully opened inflorescence were recorded in aluminium sulphate (120 g/m^2). These

Table 4 : Effect of aluminium sulphate and lime on quality and yield of hydrangea

Treatment	Diameter of inflorescence (cm)			Stalk length (cm)			No. of cut flower stems/plant			Vase life (days)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Control	20.00	22.63	21.31	57.48	60.38	58.93	6.00	6.00	6.00	15.16	17.35	16.25
AS 60 g/m^2	19.60	20.74	20.17	53.26	57.12	55.19	6.00	6.00	6.00	22.48	23.45	22.96
AS 90 g/m^2	17.90	18.42	18.16	50.34	54.26	52.30	6.00	5.80	5.90	24.34	25.18	24.76
AS 120 g/m^2	16.30	17.96	17.13	45.25	50.98	48.11	6.00	5.50	5.75	26.25	28.69	27.47
Lime 200 g/m^2	24.40	25.24	24.82	60.67	64.34	62.50	6.00	6.00	6.00	18.36	19.46	18.91
Lime 250 g/m^2	27.70	29.38	28.54	64.19	68.71	66.56	6.00	6.50	6.25	19.19	20.47	20.33
Lime 300 g/m^2	29.00	29.99	29.49	68.41	71.58	69.99	6.00	7.00	6.50	20.20	21.58	20.89
SEm±	0.36	0.25	0.30	1.22	1.10	1.16	0.11	0.12	0.08	0.40	0.41	0.40
CD at 5%	1.12	0.77	0.94	3.77	3.38	3.57	NS	0.37	0.25	1.22	1.27	1.24

AS: Aluminium sulphate

results are confirmed by Seydmohammadi et al. (2020) in lisianthus, Tigga & Fatmi (2021) in asiatic lily, Abdulhadi et al. (2022) in snapdragon. Duration of flowering was recorded maximum in lime (300 g).

Effects on flower quality and yield

The maximum inflorescence diameter and stalk length was recorded with drenching of lime (300 g/m^2) at grand growth stage (Table 4). Interestingly lime at higher doses, improve the availability of essential nutrients in the soil, these nutrients such as calcium and magnesium, are crucial for plant growth and development, including the formation of large and heavy flower heads. The results are in accordance with the findings of Bryson & Mills (2014) in hydrangea and Sultana et al. (2022) in lisianthus.

Maximum vase life was proved to be best in aluminium sulphate (120 g/m^2). The indeed reason is higher dose of aluminum can lower the pH of sepal (4.12) can help prevent the growth of bacteria and fungi in the flower, reducing the risk microbial decay and wilting, which can extend vase life. Besides, higher dose aluminum treated plants produced thicker and quality sepals, contributing to reduce water loss through transpiration by the sepals. Therefore, sepals can retain moisture and nutrients for a longer period, enhancing their freshness and longevity in hydrangea (Landis & Whipker, 2017; Opena et al., 2017).

Effects on soil and sepal pH

On testing soil pH, resulted in higher (7.84) pH after each treatment under lime (300 g/m^2) and lowest (4.23) pH in aluminium sulphate (120 g/m^2) after imposing 15 days of treatment (Table 5). Drenching aluminum sulfate to a medium, can release acidic aluminum ions (Al^{3+}), these ions can lower the pH of the medium by increasing its acidity in hydrangea (Ito et al., 2019; Yoshida et al., 2021).

Analysis of sepal pH found highest (7.23) in lime (300 g/m^2) and lowest (4.12 pH) in aluminium

Table 5 : Effect of aluminium sulphate and lime on pH of soil, sepal and anthocyanin content of hydrangea

Treatment	Soil pH			Sepal pH			Anthocyanin (mg/100 g)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Control	6.57	6.96	6.76	5.92	5.9	5.91	336	336.1	336.05
AS 60 g/m^2	5.2	5.22	5.21	4.5	4.54	4.52	461.64	463	462.32
AS 90 g/m^2	4.54	4.7	4.62	4.25	4.35	4.3	576.36	576.38	576.37
AS 120 g/m^2	3.9	4.5	4.23	4.04	4.2	4.12	714.74	715	714.87
Lime 200 g/m^2	7.2	7.14	7.17	6.8	6.6	6.7	424	423.56	423.78
Lime 250 g/m^2	7.4	7.38	7.39	6.9	6.8	6.85	587	586.12	586.56
Lime 300 g/m^2	7.9	7.78	7.84	7.3	7.16	7.23	713.83	711.83	712.83
SEm±	0.1	0.08	0.09	0.1	0.06	0.08	7.4	7.5	7.45
CD at 5%	0.3	0.26	0.28	0.3	0.2	0.25	22.96	22.98	22.97

AS: Aluminium sulphate

Table 6 : Effect of aluminium sulphate and lime on colour intensification of hydrangea

Treatment	Flower colour (RHS chart)
Control	Red purple group 68 - Strong purplish pink B
AS 60 g/m^2	Violet group N87 - Brillant purple C
AS 90 g/m^2	Violet blue group 93 - Strong violet C
AS 120 g/m^2	Purple violet group N82 - Strong purple A
Lime 200 g/m^2	Red purple group N66 - Deep purplish pink D
Lime 250 g/m^2	Red purple group 68 - Strong purplish pink B
Lime 300 g/m^2	Red purple group 64 - Strong purplish red C

AS: Aluminium sulphate

Table 7 : Effect of aluminium sulphate and lime on flower colour as per RHS chart of hydrangea

Treatment	Initial flower colour	Final flower colour change
Control	Light pink	Light pink
AS 60 g/m^2	Light pink	Light blue
AS 90 g/m^2	Light pink	Blue hue
AS 120 g/m^2	Light pink	Dark blue
Lime 200 g/m^2	Light pink	Pink hue
Lime 250 g/m^2	Light pink	Dark pink
Lime 300 g/m^2	Light pink	Bluish pink

AS: Aluminium sulphate

sulphate (120 g/m^2). The reason validated as lime is alkaline and raises the pH of the growth medium, plants have mechanisms for transporting ions and nutrients from the root system to various parts of the plant, when plants absorb water and nutrients from this medium, the pH of their internal tissues including sepals, can be influenced by the pH of the medium. Similar results were also reported by Oyama (2015) and Yoshida et al. (2021) in hydrangea.

Effects on flower colour intensification

The results pertaining to flower colour intensification of hydrangea is presented in Table 5, 6 and 7. Anthocyanin content was ranged from 336.05 to 714.87 mg/100 g of sepal, wherein aluminium sulphate (120 g/m^2) recorded significantly higher anthocyanin content (714.87 mg/100 g of sepal weight) because of higher delphinidin content caused by higher dose of aluminium in combination with acidic pH produce

Table 8 : Effect of aluminium sulphate and lime on economics of hydrangea cut flower production

Treatment	Total cost of cultivation (Rs.)	Cut flower yield	Price/cut flower stem (Rs.)	Gross return (Rs.)	Net returns (Rs.)	B:C ratio
Control	6,67,233	28,800	110	30,80,000	24,12,766	4.61
AS 60 g/m^2	6,89,733	28,800	120	33,60,000	27,00,266	4.87
AS 90 g/m^2	7,00,983	28,800	140	39,20,000	32,49,016	5.59
AS 120 g/m^2	7,12,233	28,800	150	42,00,000	34,87,767	5.89
Lime 200 g/m^2	6,76,233	28,800	120	33,60,000	24,03,767	4.96
Lime 250 g/m^2	6,78,453	28,800	130	36,40,000	29,61,547	5.36
Lime 300 g/m^2	6,80,733	28,800	110	31,68,000	26,79,267	4.68

AS: Aluminium sulphate

Fig. 1 : Effect of soil pH regulants on colour intensification of hydrangea

dark blue colour. Whereas, lime produce cyanidin pigments ranged from 423.78 to 712.83/100 g of sepal due to neutral to alkaline pH of media and sepal in combination with absence of aluminium leading to pink colour sepals with lower anthocyanin content compared to aluminium treatments in hydrangea (Yashaswini et al., 2024; Yuan et al., 2023).

Flower colour intensification was main objective of the study remarked the initial flower colour as light pink in all the treatments. These were changed to final flower colour as blue hues in aluminium treated plants, because on drenching aluminium sulphate, caused increase level of water soluble Al^{3+} in soil and these were generally available and absorbed by the roots, leading to acidic condition of soil (<5.0 pH). Once absorbed, the Al ions are transported into sepals where they form complexes with anthocyanin, resulting in blue sepal colour. Hence, on increasing the dose of aluminium, sepal colour is dramatically intensified to produce desired dark blue sepals at aluminium sulphate (120 g/m^2). Whereas, lime treated plants produced dark pink sepals due to absence of aluminium ions in combination with alkaline condition of soil (>6.5 pH) in hydrangea (Chen et al., 2015; Pietsch et al., 2022).

Flower colour varied significantly in hydrangea by applying soil pH regulants, flower colour varied from light pink to dark blue hue according to treatments imposed. The best accepted flower colour code as per RHS chart was in aluminium sulphate (120 g/m^2) (Purple violet group N82 - Strong purple A) as dark blue hue due to combination of acidic soil pH with presence of aluminium and least accepted flower colour code as per RHS chart was in control (Red purple group 68-Strong purplish pink B) due to light and dull flower colour (Fig. 1). Meanwhile, most accepted flower colour code was recorded in lime (250 g/m^2) with colour code being dark pink (Red purple group 68-Strong purplish pink B) due to increase in dosage of lime leading alkaline condition to soil pH.

Effects on economics

Aluminium sulphate (120 g/m^2) recorded maximum gross returns, net returns and B:C ratio of Rs. 42,00,000, Rs. 34,87,767 and 5.89, respectively for cut flower colour intensification of hydrangea (Table 8), which might be due to increased price of flower stalk owing to best colour and quality blooms acceptability compared to other treatments, which in turn increased B:C ratio. Similar results were obtained by Nataraj et al. (2018) in anthurium; Anand et al. (2021) in bird of paradise and Kavya et al. (2022).

CONCLUSION

Among different doses of aluminium sulphate and lime, lime (300 g/m^2) proved better plant growth parameters such as plant height, plant spread, leaf length and number of leaves per plant. However, aluminium sulphate (120 g/m^2) proved to be highly accepted with best quality blooms exhibited true blue hue (Purple violet group N82-Strong purple A), maximum anthocyanin content (delphinidin) (714.87 mg/100 g of fresh sepal) in combination with acidic sepal pH (4.12), vase life (27.47 days) and highest B:C ratio (5.89). Hence, aluminium sulphate (120 g/m^2) is best treatment for colour intensification of hydrangea cut flower.

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