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Influence of pyroligneous acid (PA) as a foliar nutrition on growth and yield parameters of green gram under sodic soil

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Abstract
A field experiment was carried out during Summer, 2021 at ADAC&RI, Tiruchirappalli to study the effect of foliar application of pyroligneous acid and reclamation of sodic soil using pyroligneous acid treated gypsum with an aim to increase the growth and yield of green gram under sodic soil conditions. The experimental trial comprised of ten treatments replicated thrice in a randomized block design. The treatment details are T_1 - Absolute Control with unprimed seeds, T_2 - Absolute Control with PA primed seeds (1:500), T_3 - Unprimed seeds + 50% GR alone, T_4 - PA primed seeds (1:500) + 50% GR alone, T_5 - PA primed seeds (1:500) + 50% GR treated with PA (1:5), T_6 - PA primed seeds (1:500) + 50% GR treated with PA (1:10), T_7 - T_5 + Foliar Spray with PA (1:300), T_8 - T_6 + Foliar Spray with PA (1:300), T_9 - T_5 + Foliar Spray with PA (1:400), T_{10} - T_6 + Foliar Spray with PA (1:400). The treatments T_3 to T_{10} received uniformly the recommended dose of of N, P_2O_5 and K_2O @ 25:50:25 kg/ha respectively. The Gypsum with or without PA was applied @ 50% gypsum requirement (3.2 t ha^{-1}) calculated for a pH of 8.9. Foliar application of PA at the rate of 1:300 and 1:400 were given at 30 DAS and 45 DAS coinciding with flowering and pod formation stage. A significant difference was observed in the plant height (50.4 cm), leaf area index (3.91), number of pods $plant^{-1}$ (38.4), number of grains pod^{-1} (12) and DMP (2576 kg ha^{-1}). The addition of 50% GR treated with PA @ 1:5 and 1:10 ratios resulted in an increase in available nutrients which ultimately enhanced the yield components and yield of green gram. The treatment T_{10} recorded the highest grain yield of 749 kg ha^{-1} followed by T_8 698 kg ha^{-1} which was 34% and 24% increase in yield over application of 50% GR alone (T_3). Therefore, incorporation of gypsum treated PA improved the effectiveness of slowly soluble gypsum in reclaiming sodic soils under garden land conditions which in turn resulted in higher growth and yield of green gram.

Keywords: foliar spray, green gram, gypsum, pyroligneous acid, seed priming

1. Introduction

To achieve food security for the ever growing population, it is necessary to focus on both the expansion of cultivable area under agriculture as well as increase in crop productivity. The possibility of increasing area under agriculture therefore exists in restoring the degraded lands. The potential yield of cultivable lands is drastically reduced due to soil sodicity. Sodic soils are characterized by high pH, high water soluble and exchangeable Na, low microbial activity, poor physical properties such as decrease in soil permeability, available water capacity and infiltration rates due to swelling and dispersion of clays as well as slaking of soil aggregates (Lauchli & Epstein, 1990) [8]. This has resulted in a significant reduction of productive lands. Thus, reclamation of salt affected soils is indispensable for increasing the area under cultivation and productivity. Gypsum is the commonly used amendment for removal of exchangeable Na from the soil exchange sites. However, ways and means to increase the sparingly soluble nature of gypsum becomes inevitable to improve the use efficiency of the applied gypsum. Pyroligneous acid (PA) also known as wood vinegar, an acidic (pH of 2-4) by-product of carbonation process has been used in the study with an aim to increase the solubility (Mun *et al.*, 2007) [11]. PA has been reported to possess multifunctional benefits in enhancing agricultural production (Lashari *et al*., 2013; Liu *et al*. 2018a; Simma *et al*. 2017) [6, 9, 18]. It is composed of organic acids, phenols, aldehydes, ketones and furan groups (Zhang *et al.*, 2013) [23]. It is used as a plant growth stimulator (Kulkarni *et al*., 2006; Mungkunkanchao *et al.*, 2013) [5, 12] and seed germination (Lei *et al*., 2018) [9], plant growth regulator (Apai and Thongdeethae, 2001) [1], biopesticide (Tiilikkala *et al*., 2010) [20] and soil amendment (Lashari *et al*., 2013) [6]. The acidic nature of PA may help in adjusting soil pH (Lashari *et al*., 2015) [7], improve nutrient availability (Lashari *et al*., 2013) [6], inhibit ammonium loss (Grewal *et al*.,

2018) [3] and improve the microbial activity in soil. Green gram being moderately tolerant to sodicity, was chosen as the test crop. It is commonly known as "mung" or "mung bean" and is the most important crop of South-East Asia particularly the Indian sub-continent. It is an excellent source of protein (24.3 %) and aminoacids such as riboflavin and thiamine. It plays an important role in maintaining and improving soil fertility through the root nodules by fixing atmospheric nitrogen in the soil. In general, seed germination and initial establishment is a major constraint in sodic soil. PA has been reported to be a stimulant for seed germination and seedling establishment in several crops, including rice (Staden *et al.*, 2006) [5]. Hence, this experiment was conducted to study the effect of pyroligneous acid as a seed primer as well as an amendment by treatment with gypsum in influencing its solubility to improve the productivity of green gram in sodic soil.

Materials and Methods

Experimental site

A field experiment was carried out at Anbil Dharmalingam Agricultural College and Research Institute farm, Tiruchirappalli. The experimental site is geographically located at 10°45´5.465" North latitude, 78°36' 1.227" East longitude and at an altitude of 85 meters above the mean sea level. The initial characteristics of the soil are listed below. (Table 1)

Experimental design and treatment details

The experiment was laid out in a Randomized Block Design with ten treatments replicated thrice. Green gram (VBN 2) variety was chosen as a test crop for the trial. The experimental field was thoroughly ploughed first with tractor drawn mould board ploughed to bring it to a fine tilth and allowed for natural oxidation. It was then leveled and 30 plots of uniform size (5m x 4m) with irrigation and drainage channels were formed. Calculated quantities of gypsum (50% gypsum requirement i.e., @ 3.2 t ha^{-1} based on initial soil pH) was treated with pyroligneous acid @ 1:5 and 1:10 ratios and the pyroligneous acid treated gypsum was allowed to react for a period of 15 days. At the end of 15 days, the pyroligneous acid treated gypsum was applied to the field at required quantities, 15 days prior to sowing as per the treatment schedule. This was followed by impounding with water which was maintained for 48 hours and then drained. Further, the green gram seeds were primed with PA @ 1:500 dilution (i.e.,1 part of pyroligneous acid diluted with 500 parts of distilled water) and dibbled on the sides of the ridges. This was followed by foliar application of PA at the rate of 1:300 and 1:400 (i.e.,1 part of pyroligneous acid diluted with 300 & 400 parts of distilled water) at 30 and 45 DAS coinciding with flowering and pod formation stage.

Observations

During the growing season five plants were tagged randomly from each plot for recording growth and yield parameters. Plant height was measured from base of the plant to its growing tip and was expressed in centimetres. Number of branches $plant^{-1}$ was recorded and expressed in numbers. Dry matter production was recorded by oven drying of samples at 65±5°C and expressed in kg ha^{-1}. Leaf area index was calculated using the formula given by Palanisamy and Gomez (1974). At harvest, yield attributes such as number of pods $plant^{-1}$, number of seeds pod^{-1}, pod length (cm), pod weight (g), test weight (g), grain yield (kg ha^{-1}) and haulm yield (kg ha^{-1}) were recorded.

Statistical analysis

The collected experimental data was statistically analyzed as suggested by Panse and Sukhatme (1967). The significant differences among the treatments were calculated at critical difference of 5 percent probability level.

Results and Discussion

Growth parameters

Foliar application of 1:400 PA along with 50 % GR treated with PA @1:10 ratio (T_{10}) significantly recorded taller plants (50.4 cm), a greater number of branches plant $^{-1}$ (5.1), higher leaf area index (3.91) and dry matter production (2576 kg ha^{-1}) and was followed by the treatment T_8 receiving foliar spray of 1:300 PA along with 50% GR treated with PA@ 1:5 dilution (Table 2). The lowest values for all the growth parameters were observed in the absolute control T_1. In the absence of fertilizer addition, seed priming with PA @ 1:500 dilution recorded significant increase in plant height, number of branches $plant^{-1}$ and DMP indicating the positive influence of PA in stimulating the growth of green gram. Besides, treatment of gypsum with varying dilutions of PA *viz.*, 1:5 and 1:10 along with seed priming did not have any significant influence in improving the growth parameters.

The plant height of green gram was measured at the termination of the experiment. Increase in plant height may be attributed to the presence of esters in PA resulting in an increase in chlorophyll which promotes photosynthesis (Rogelio, 2018) [17]. In general, PA application either as seed priming @ 1:500 or treating of gypsum (50% GR) with PA @ 1:5 or 1:10 dilution or as foliar spray at 1:300 or 1:400 dilution in combination with inorganic fertilizers was able to significantly enhance the plant height besides other growth parameters like number of branches $plant^{-1}$, LAI and DMP, when compared to unprimed seeds in combination with PA untreated gypsum application. PA addition in any form was found to increase plant height as it is an excellent plant growth regulator and hence can accelerate plant growth (Tsuzuki *et al.*, 2000; Payamara, 2011; Benzon and Lee, 2016) [21, 16, 2]. PA primed seeds @ 1:500 dilution along with application of gypsum treated with PA @ 1:10 dilution in combination with foliar spray of PA @ 1:400 dilution at flowering and pod formation stages recorded significantly higher values for all the growth parameters studied. This was followed by the treatment T_8 which received foliar spray of PA @ 1:300 dilution.

The significant increase in plant growth parameters may be attributed to the presence of esters such as methyl acetate and methyl formate present in the PA which would have triggered plant growth and development. (Grewal *et al.*, 2018) [3]. Moreover, addition of pyroligneous acid may have promoted the microbial growth near the rhizosphere region of soil. This increase in microbial activity may have resulted in enhanced bacterial and mycorrhizal symbiosis near the rhizosphere region (Narwal, 2000; Tsuzuki *et al.*, 1989) [13, 22] increasing the soil available N and P leading to increased photosynthetic rates thereby improving plant growth (Kaschuk *et al.*,2009) [4].

At harvest stage, the treatment receiving foliar spray of PA @ 1:400 along with 50 % GR treated with PA @ 1:10 ratio resulted in significantly higher DMP. Singh *et al.* (2009) [19] reported similar increase in leaf biomass due to application of

N, P, K fertilizers along with PA. On the other hand, the plant height was generally higher in treatments with foliar spray (1:400) with 50% GR treated with 1:10 PA and was followed by the treatment receiving foliar spray of PA @ 1:400 along with 50% GR treated with 1:5 PA. These treatments recorded the higher vegetative growth, higher leaf area and biomass than the treatments which did not receive foliar spray of PA. The absolute control recorded the lowest plant height, number of branches plant^{-1} and leaf area index which did not receive either RDF or PA as foliar spray and PA treated gypsum as amendment.

The study also revealed that seed priming with PA over unprimed seeds in combination with 50 % GR alone did not show any significant increase in all the growth parameters emphasizing / indicating the importance of gypsum application to sodic soils.

The leaf area index ranged from 2.15 in the absolute control with unprimed seeds (T_1) to 3.91 in the treatment involving PA as seed primer together with the treatment of gypsum and its foliar spray at higher dilutions (T_{10}).

The PA treatment with gypsum at lower dilution together with foliar spray either at 300- or 400-times dilution did not show any marked variation in the LAI while significantly higher LAI was recorded in the treatment (T_{10}) due to application of PA @ 1:10 dilution treated gypsum in combination with foliar spray at 400 times dilution when compared to foliar spray at 300 times dilution.

Yield attributes and yield

Yield attributes *viz*., number of pods plant^{-1} (38.4), number of seeds pod^{-1} (12), pod length (8.02 cm) and pod weight (0.64 g) were significantly higher with foliar spray of PA at 1:400 dilution combined with 50% GR treated with 1:10 PA (T_{10}) than the treatments which did not receive PA as foliar spray (Table 3). The test weight did not significantly showed any variation. This was followed by treatments T_8 and T_9 which received foliar spray of PA at 1:300 dilution + 50% GR treated with 1:10 PA and foliar spray of PA at 1:400 dilution + 50% GR treated with 1:5 PA, respectively. The absolute control (T_1) which did not receive any amendments recorded the lowest yield attributes and was found to differ significantly from the rest of the treatments. Tsuzuki *et al*., 2000 [21] reported that application of PA promoted plant height, increased ear number and yield of rice. Similar increase in fruit weight and fruit number of tomatoes was reported by Benzon and Lee (2016) [2] when PA was applied alone and/or its combination with conventional fertilizers over control. The increase in yield components such as the number of pods plant^{-1}, number of seeds pod^{-1}, pod length and pod weight can be attributed to the beneficial effects of PA which enhanced the yield attributes and yield of green gram. This could be due to the improved root system, plant growth, and flowering because of PA application either alone or in combination as seed primer, its treatment of gypsum or as foliar spray. The high sink stimulated photosynthesis could have increased the leaf biomass and delayed senescence resulting in increased yield of green gram (Paul and Peliny, 2003) [15].

The seed yield and haulm yield was significantly influenced by foliar spray of PA at 1:400 along with 50% GR treated at 1:10 dilution (T_{10}) than all other treatments compared. The treatment T_{10} recorded the higher seed yield and haulm yield of 749 kg ha^{-1} and 1705 kg ha^{-1} respectively. This was followed by T_8 and T_9 which received foliar spray of PA at 1:300 dilution 50% GR treated with 1:10 PA and foliar spray of PA at 1:400 dilution 50% GR treated with 1:5 PA, respectively. The absolute control (T_1) recorded the lowest grain yield and haulm yield of about 336 kg ha^{-1} and 871 kg ha^{-1}. Benzon and Lee (2016) [2] reported synergistic effect of conventional fertilizer and PA on each other. The acidic nature of PA mainly the acetic acid might have contributed to the dissolution of the sparingly soluble gypsum and the solubilization of inorganic nutrients to a more available form for plant uptake.

Table 1: Initial characteristics of experimental soil

S. No	Soil characteristics	Values
1.	Bulk density (Mg m^{-3})	1.38
2.	Particle density (Mg m^{-3})	2.47
3.	Pore space (%)	37.4
4.	Mechanical composition	
	Clay (%)	24.1
	Silt (%)	15.3
	Sand (%)	59.5
5.	Texture	Sandy clay loam
6.	pH (1:2.5)	8.9
7.	EC (dS m^{-1}) (1:2.5)	0.24
8.	Cation exchange capacity (cmol (p$^+$) kg^{-1})	22.8
9.	Organic carbon (%)	0.54
10.	Alkaline $KMnO_4$ - N (kg ha^{-1})	235.2
11.	Olsen – P (kg ha^{-1})	19.5
12.	Neutral N NH_4OAc – K (kg ha^{-1})	210.56

Table 2: Effect of pyroligneous acid on growth parameters of green gram under sodic soil

Treatments	Plant height (cm)	No. of branches plant^{-1}	LAI	DMP (kg ha^{-1})
T_1 - Absolute Control with unprimed seeds	28.6	2.75	2.15	1267
T_2 - Absolute Control with PA primed seeds (1:500)	31.3	3.09	2.40	1445
T_3 - Unprimed seeds + 50% GR alone	35.3	3.43	2.65	1602
T_4 - PA primed seeds (1:500) + 50% GR alone	36.2	3.52	2.80	1759
T_5 - PA primed seeds (1:500) + PA (1:5) treated 50% GR	39.0	3.86	2.94	1959
T_6 - PA primed seeds (1:500) + PA (1:10) treated 50% GR	41.1	3.97	3.08	2068
T_7 -T_5+ Foliar Spray with PA (1:300)	44.1	4.31	3.21	2131

T_8 -T_6+ Foliar Spray with PA (1:300)	47.8	4.76	3.64	2410
T_9 -T_5+ Foliar Spray with PA (1:400)	45.0	4.42	3.36	2240
T_{10} -T_6+ Foliar Spray with PA (1:400)	50.4	5.10	3.91	2576
SED	1.2	0.14	0.10	71
CD (P=0.05)	2.5	0.30	0.23	150

Table 3: Effect of pyroligneous acid on yield attributes and yield of green gram under sodic soil

Treatments	No. of pods plant^{-1}	No. of seeds pod^{-1}	Pod length (cm)	Pod weight (g)	Test weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1	17.0	6.7	6.00	0.26	3.70	336	871
T_2	20.0	7.5	6.30	0.31	3.77	402	975
T_3	23.9	8.3	6.60	0.36	3.83	448	1078
T_4	24.1	8.8	6.70	0.37	3.84	510	1166
T_5	27.5	9.3	7.00	0.43	3.86	569	1297
T_6	27.9	9.6	7.10	0.45	3.88	594	1376
T_7	31.0	9.9	7.40	0.51	3.89	619	1411
T_8	35.1	11.2	7.80	0.58	3.92	698	1598
T_9	32.0	10.4	7.50	0.52	3.90	646	1488
T_{10}	38.4	12	8.02	0.64	3.95	749	1705
SED	1.0	0.3	0.08	0.01	0.17	20	47
CD (P=0.05)	2.1	0.7	0.18	0.04	NS	43	100

Conclusions

The results of the study indicated that use of pyroligneous acid as a seed primer or its application with gypsum or as foliar spray either alone or its combination together with the recommended dose of inorganic fertilizer resulted in multiple benefits such as enhancing the germination, promoted plant height, number of branches plant^{-1}, LAI, DMP and yield components and yield of green gram in a sodic soil. This probably could be attributed to improved soil fertility through improved physical properties, nutrient supply, and its translocation in the plant. The study clearly suggests the potential benefits of pyroligneous acid in improving the yield of green gram in a sodic soil.

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