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Standardizing the Hydrogel Application Rates and Foliar Nutrition for Enhancing Yield of Lentil (*Lens culinaris*)

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Abstract: Lentil (*Lens culinaris*) is an important winter season annual legume crop known for its highly valued seed in human and animal nutrition owing to its high lysine and tryptophan content. Shortage of water during the crop growth period has become the major impediment for cultivation of pulses in rice fallow in particular. Under such conditions, the application of hydrogel can be a potential alternative to improve photosynthetic efficiency, assimilate partitioning, and increase growth and yield. A field experiment was conducted from November to February during 2015–16 to 2017–18 on clay loam soil that was medium in fertility and acidic in reaction (pH 5.4) at Central Agricultural University, Imphal, Manipur. The experiment was laid out in split plot design with three replications. There were three hydrogel levels in total in the main plot and foliar nutrition with five different nutrient sprays in sub-plots, together comprising 15 treatment combinations. The data pooled over three years, 2015–2018, revealed that application of hydrogel at 5 kg/ha before sowing recorded a significantly greater number of pods per plant (38.0) and seed yield (1032.1 kg/ha) over the control. Foliar application of nutrients over flower initiation and pod development had a positive effect on increasing the number of pods per plant eventually enhanced the seed yield of lentil. Foliar application of either 0.5% NPK or salicylic acid 75 ppm spray at flower initiation and pod development stages recorded significantly more pods per plant over other nutrient treatments. Further, the yield attributed improved because of elevated growth in plant. Significantly maximum seed yield (956 kg/ha) recorded in the NPK spray of 0.5% remained on par with salicylic acid 75 ppm (939 kg/ha) over the rest of the treatments.

Keywords: hydrogel; rainfed agriculture; foliar nutrition; lentil; moisture conservation

1. Introduction

Rainfed agriculture has a protruding role to play in India's agriculture and economy. India ranks first among the rainfed countries in the world in terms of area, however, it counts the lowest in yields (around 1 ton/ha) [1]. Rainfed areas are home to the majority of rural poor and marginal farmers, who come across multiple risks and uncertainties relating to bio-physical and socio-economic conditions resulting in poverty, malnutrition, water scarcity, severe land degradation, lower yields, low investments, and poor physical and social infrastructure.

Rainfed agriculture supports four out of every ten Indians, and comprises 60% to 70% of total cropped area (85 million hectare), 48% of the area under food crops, and 68% of the area under non-food crops [2]. More than 75% of pulses, 66% of oilseeds, and 45% of cereals are grown under rainfed conditions [1]. Though the maximum area is under rainfed, negligence is shown towards its upliftment. Despite this systematic neglect, yields of coarse grains, oilseeds, and pulses are increasing faster under rainfed than in irrigated.

Drought is the major environmental stress in dryland areas of many countries of the world [3], and often affects the crop simultaneously with heat stress and perplexing effects on crop productivity [4]. For an improved production in dryland/rainfed ecosystems, a larger percentage of the precipitation must be stored in soil and the stored water must be used more efficiently to exploit its full potential. The most serious problem for the failure in yielding potential of the second crop like lentil after the rice harvest is soil moisture deficit [2]. The heat and temperature extremities in the crop growth stages (especially flowering and pod development) during moisture stress are the major factors affects the lentil productivity owing to flower drop and seed filling [5]. These anomalous weather conditions have posed new generation problems like nutrient management in rainfed areas [5]. The nitrogen deficiency induces a reduction in photosynthetic activities in plants, which hastens the senescence of leaves, which are very important for promoting the pod development in succeeding stages, which depends on carbon and nitrogen accumulation. Supply of nitrogen via soil may incur higher costs besides lower absorption capacity by roots in dry conditions [5]. Thus, supplying nutrients through foliar application in a lower concentration through bio-regulators helps in nutrient acquisition by acting as chemical catalyst in plants for enhancing physiological and reproductive efficiencies [6]. Thus, foliar application of water soluble nutrients in addition to efficient nutrient management (macro and micronutrients) not only helps in amending the nutrient deficiency, but also helps in reducing the heat stress.

Super absorbent polymers like hydrogel may have great potential in the renewal and reclamation of soil [7,8] and help in storing water available for plant growth and development [9,10] by delaying the permanent wilting point, thereby minimizing the irrigation requirement of the crop [1,11]. This also adds to the enhancement of the soil enzymes acid and alkaline phosphatase, dehydrogenase, protease, and urease, which are the indicatives of the rich microflora in the sandy soils [1,12]. Incorporation of polymer into soil helped in stabilizing the agriculture production [13], reducing the effect of drought stress [14]. The proven facts about hydrogel application were recorded in different crops like sunflower [15] and aerobic rice [16]. Drilling hydrogel (2.5 kg/ha) along with foliar application of either NPK (0.5%) or salicylic acid (75 ppm) helps in increasing the yield of lentil [5]. Thus, hydrogels have pronounced prospective in areas under limited opportunity for irrigation and can increase the water use potential during crop establishment stages, besides improving soil physical-chemical properties [17,18].

Lentil (*Lens culinaris*) is an important winter season annual legume predominantly grown in rainfed conditions, known for its high lysine and tryptophan content. Consumption with cereals like wheat or rice provides a balance in essential amino acids supplements. The crop has great significance in cereal-based cropping systems, rainfed areas in particular, as its cultivation improves soil nitrogen

(fix 0 to 190 kg/ha) [19], as well as carbon and organic matter status, thus providing sustainability in production systems. A shortage of water during the crop growth period in winter crops like lentil has become the major impediment for the cultivation of pulses [20]. Under such conditions, application of hydrogel and foliar nutrition through bio-regulators and nutrient sprays can be a potential alternative to improve photosynthetic efficiency, assimilate partitioning, and increase growth and yield. Therefore, an investigation was conducted to enhance the nutrient and water use efficiency of lentil through hydrogel and foliar nutrition on the growth and yield of lentil under restricted irrigation conditions.

2. Results and Discussion

2.1. Effect of Hydrogel Application on Growth and Yield Components

Analysis of variance revealed significant differences for hydrogel and nutrition treatments for all the traits studied. Year-to-year variations were not significant for these two treatments, but interaction effect of Y*H and Y*N was significant for most of the traits. The interaction effect of H*N and Y*H*N was not significant for all the traits, indicating that the effects of hydrogel and nutrition treatments are independent of each other (Table 1).

The data pooled over three years, 2015–16, 2016–17, and 2017–18, revealed that the application of hydrogel 5 kg/ha before sowing recorded a significantly greater number of pods per plant (37.94) and seed yield (1032.1 kg/ha), which was 22.2 and 51.1 percent higher, respectively, over the control (Tables 2 and 3), whereas it recorded as 13.1 and 17.8 percent higher for the number of pods and seed yield, respectively, over 2.5 kg/ha hydrogel application. Similarly, haulm yield at 5 kg/ha hydrogel application recorded a 39.7% and 6.4% increase over other the two treatments (Table 3). Similar findings of yield improvement were recorded with other crops like wheat [11,21], aerobic rice [15], pearl millet [22–24], wheat [11], and groundnut [25]. The water conservation by hydrogel creates a buffered environment, reducing the effect of the periodical drought and reducing the losses of moisture from soil [12] in the early crop phone phase in the lentil plant. Thus, super absorbent polymers (hydrogel) lead to an improvement in plant growth by increasing the water holding capacity in soils [26], contributing towards increasing the yield of lentil [6].

Table 1. Analysis of variance for plant growth and yield related characters under different treatment combinations involving hydrogel and nutrition.

EFFECT	DF	SY	HY	HI	Plant Height (cm)	PPP	Branches
Year (Y)	2	391,299	8,606,849	2230	461	1378	11.97
Rep (Y)	6	4129	50,960	12	11	10	0.17
Hydrogel (H)	2	1,345,976**	4,601,977**	43*	186**	542**	2.25**
Y × H	4	144,840**	1,027,835**	63**	19*	28*	0.32
Error (H)	12	5509	45,586	10	6	7	0.10
Nutrition (N)	4	369,092**	523,739**	65**	74**	344**	1.89**
Y × N	8	33,511**	39,811	23**	4**	16	0.39**
H × N	8	2361	22,369	3	5	6	0.21
Y × H × N	16	3151	31,894	7	3	4	0.08
Residual	72	2323	26,056	5	4	10	0.13
Total	134	45,715	271,347	44	17	48	0.41

DF: degrees of freedom; SY: seed yield (kg/ha); HY: haulm yield (kg/ha); HI: harvest index (%); PPP: pods per plant.

* Significant at 1% probability level. ** Significant at 5% probability level

Foliar application of nutrients during flower initiation and pod development had a positive effect on increasing the number of pods per plant, and eventually enhanced the seed yield of lentil (Table 2). Foliar application of 0.5% NPK at flower initiation and pod development stages recorded a significantly greater number of pods per plant (37.4) and was on par with salicylic acid 75 ppm, and superior over treatments with Thiourea 500 ppm, 2% urea, and water spray (Table 2). The higher seed yield (956 kg/ha) recorded in 0.5% NPK spray was on par with salicylic acid 75 ppm (939 kg/ha) and superior

over the rest of the treatments. The percent increase in seed yield was to the tune of 43.8% over water spray. A similar yield improvement using hydrogel in lentil was reported in the work of [15]. The foliar spray of 0.5% NPK, salicylic acid 75 ppm, and thiourea 500 ppm increased the dark fixation of CO₂ in embryonic tissues of the plant, which has diverse biological expressions [26,27]. Its beneficial effect might be owing to the delayed senescence of both vegetative and reproductive organs, as thiourea displays cytokinin-like activity, particularly on delaying senescence [28]. These regulators increase the photosynthetic activities of plants, which in turn increase the active leaf surface during the grain filling period [28,29], facilitating the best partitioning of the source and sink and creating the congenial atmosphere in plants for enhancing the yield [5,15].

Table 2. Seed yield and number of pods per plant of lentil as influenced by different levels of hydrogel and foliar nutrition.

Treatment	No. of Pods Per Plant				Seed Yield (kg/ha)			
	2015–16	2016–17	2017–18	Average	2015–16	2016–17	2017–18	Average
H ₀ : 0 kg/ha	35.94	25.73	31.61	31.10	727.7	678.3	654.4	686.8
H ₁ : 2.5 kg/ha	38.29	29.21	33.16	33.56	886.7	778.0	964.2	876.3
H ₂ : 5 kg/ha	45.17	31.25	37.41	37.94	1110.1	818.0	1168.4	1032.1
SEM (±)	0.43	0.82	0.68	0.38	9.8	24.0	20.7	11.04
C.D (p = 0.05)	1.67	3.22	2.68	1.18	38.3	94.4	81.3	34.09
N ₁ : Water spray	33.90	20.24	30.18	28.11	694.1	459.2	841.8	665.0
N ₂ : 2% urea	39.79	29.27	34.36	34.47	913.1	791.9	901.9	869.0
N ₃ : Thiourea 500 ppm	40.78	30.49	34.36	35.21	926.4	836.1	928.1	896.9
N ₄ : Salicylic acid 75 ppm	41.78	31.11	34.58	35.82	993.6	842.6	981.3	939.2
N ₅ : NPK 0.5% spray	42.76	32.56	36.84	37.39	1013.5	860.7	991.8	955.4
SEM (±)	1.27	1.22	0.59	0.62	15.2	20.2	11.5	9.82
C.D (p = 0.05)	3.70	3.60	1.72	1.75	44.5	59.1	33.6	26.18

H: hydrogel; N: foliar nutrition; SEM: standard error of mean; CD: critical difference.

Table 3. Plant height and haulm yield (kg/ha) of lentil as influenced by different levels of hydrogel and foliar nutrition.

Treatment	Plant Height (cm)				Haulm Yield (kg/ha)			
	2015–16	2016–17	2017–18	Average	2015–16	2016–17	2017–18	Average
H ₀ : 0 kg/ha	26.35	21.45	24.91	24.24	1278.3	2045.5	1257.5	1527.1
H ₁ : 2.5 kg/ha	27.41	22.63	27.05	25.70	1407.0	2368.2	2240.3	2005.2
H ₂ : 5 kg/ha	31.35	23.15	30.28	28.26	1573.0	2441.0	2388.1	2134.0
SEM (±)	0.65	0.70	0.47	0.35	43.4	53.5	62.3	31.8
C.D (p = 0.05)	2.55	2.74	1.86	1.09	170.5	156.5	181.7	98.1
N ₁ : Water spray	24.52	19.87	25.62	23.34	1244.4	1940.2	1796.9	1660.5
N ₂ : 2% urea	28.42	22.36	26.93	25.90	1396.0	2329.9	1859.6	1861.8
N ₃ : Thiourea 500 ppm	28.91	22.91	27.67	26.50	1427.7	2337.3	2026.0	1930.3
N ₄ : Salicylic acid 75 ppm	29.81	23.33	27.51	26.89	1521.2	2376.8	2055.7	1984.6
N ₅ : 19:19:19 0.5% spray	30.18	23.58	29.33	27.70	1507.8	2440.1	2071.5	2006.5
SEM (±)	0.78	0.82	0.27	0.39	44.1	53.5	62.3	31.1
C.D (p = 0.05)	2.28	2.39	0.79	1.09	128.7	156.2	181.7	87.6

H: hydrogel; N: foliar nutrition; SEM: standard error of mean; CD: critical difference.

Improvement in crop height in pearl millet with application of hydrogel (23) was the result of the retentive ability of moisture, which helps in enhancing the availability of nutrients. This has helped to increase the meristematic activity, expansion, and elongation of the cells, ultimately leading to increased crop height [30,31]. The increase in the moisture percentage was recorded with an increase in the dose of hydrogel ranging from 15%–25% during different crop intervals (Table 4), indicating the availability of the moisture for crop growth during the critical stage of the crop, which helped in improving the growth and development of the crop. Similar conclusions were well documented by different researchers in aerobic rice crop in upper 0–15 cm depth [15] sandy soils, which promoted the moisture retaining ability [31–34], increasing the crop ability to promote growth and yield attributes, ultimately increasing the yield of crops. Hydrogel treated plots yield more lentil compared with non-hydrogel plots in the present investigation. Our investigations are in accordance with the several findings in aerobic rice, soybean, tomato, and other crops [14,34,35].

Table 4. Moisture % in the soil during crop growth stages (average data of three years).

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS
H ₀ : 0 kg/ha	19.47	18.62	22.39	24.80	22.60	14.22
H ₁ : 2.5 kg/ha	23.11	23.48	23.11	25.82	23.14	17.07
H ₂ : 5 kg/ha	24.89	25.12	25.88	25.95	23.63	22.75
Mean	22.49	22.41	23.79	25.52	23.12	18.02
N ₁ : Water spray	22.71	22.09	23.52	25.70	23.36	17.18
N ₂ : 2% urea	22.48	22.49	23.55	25.04	22.18	16.04
N ₃ : Thiourea 50 ppm	21.55	22.52	22.96	25.21	23.41	17.67
N ₄ : Salicylic acid 75 ppm	21.85	21.43	23.71	25.46	22.91	18.47
N ₅ : NPK 0.5% spray	23.87	23.50	25.23	26.22	23.74	19.92
Mean	22.49	22.41	23.79	25.52	23.12	18.02

DAS: days after sowing; H: hydrogel N: foliar nutrition; 20–60 DAS: vegetative stage; 60–80 DAS: pre-flowering and pod initiation stages; 80–100 DAS: pod development stage; 100–120 DAS: maturity stage.

The higher cost of cultivation was recorded with the application of 5 kg hydrogel per hectare (₹34,537/ha) owing to the higher cost of hydrogel and foliar application of NPK (₹32,045). The highest net returns (₹18,636/ha) and B/C (1.54) ratio were recorded with the application of 5 kg hydrogel per ha, followed by application of 2.5 kg hydrogel. There was a monetary benefit of ₹17,712/ha with the use of hydrogel of 5 kg and ₹6276 per hectare with 2.5 kg hydrogel [5]. The highest net returns were recorded with the foliar application of 0.5% NPK (19:19:19) spray (₹13,106/ha) and salicylic acid 75 ppm (₹13,033/ha) (Table 5). The increase in returns is the result of the higher yield with respective treatment, and the spray of NPK @ 0.5% [5] and salicylic acid 75 ppm spray [16,27,28] improved nutrient supply to the leaf by foliar absorption, which might have delayed the senescence of leaves and allowed greater assimilation and carbon remobilization to the vegetative and economic plant parts, which improved the production of a greater number of pods, ultimately increasing yield.

Table 5. Economics of lentil as influenced by the application of hydrogel and foliar nutrition (average data of three years).

Treatments	Cost of Cultivation	Gross Returns (₹/ha)	Net Returns (₹/ha)	B/C Ratio
H ₀ : 0 kg/ha	28,841	29,764	924	1.03
H ₁ : 2.5 kg/ha	31,591	43,951	12,360	1.39
H ₂ : 5 kg/ha	34,537	53,173	18,636	1.54
Mean	31,656	42,296	10,640	1.32
N ₁ : Water spray	30,890	38,331	7441	1.24
N ₂ : 2% urea	31,409	41,052	9643	1.31
N ₃ : Thiourea 50 ppm	32,295	42,273	9978	1.31
N ₄ : Salicylic acid 75 ppm	31,642	44,674	13,033	1.41
N ₅ : NPK 0.5% spray	32,045	45,151	13,106	1.41
Mean	31,656	42,296	10,640	1.34

H: hydrogel; N: foliar nutrition.

2.2. Additive Main effects and Multiplicative Interaction (AMMI) Analysis

AMMI analysis represents a potential tool that can be used to deepen the understanding of factors involved in the manifestation of the treatment × environment interaction (TEI). The AMMI method is used for three main purposes [36]. The first is model diagnoses. AMMI is more appropriate in the analysis of yield trials, because it provides an analytical tool of diagnosing other models as sub cases when these are better for particular datasets. Secondly, AMMI clarifies the G × E interaction and it summarizes patterns and relationships of treatments and environments [37]. The third use is to improve the accuracy of yield estimates.

AMMI analysis of three hydrogels and five nutrient treatment combinations tested over three years for seed yield is presented in Table 6. The analysis indicated a significant influence of year, treatments, and year*treatment interactions, where treatments had a maximum influence (68.4%), followed by the year*treatment interaction (14.7%) and year (12.8%) on seed yield, indicating differences among treatment combinations and the possibility of selecting a reliable treatment to enhance nutrient and water use efficiency in lentil. Year and year*treatment interaction explained approximately 27% of the variation, indicating that environment has a significant influence on the performance of treatments, which in turn affects seed yield. As the year*treatment interaction (YTI) is significant, we can study the stability of treatments over different years. The AMMI model further partitioned YTI into different interaction principal component axes (IPCA). These ordination techniques using Golob's F statistic identified two IPCAs, that is, IPCA1 and IPCA2, to be significant for seed yield, which together explained 100% of the variation in YTI.

Table 6. Additive Main effects and Multiplicative Interaction (AMMI) analysis of variance for seed yield for different treatment combinations involving hydrogel and nutrition.

	Df	Sum Sq	Mean Sq	F Value	% Contribution
Year (Y)	2	782,989	391,495***	94.84	12.78
Rep (Y)	6	24,769	4128	1.49	0.40
Treatment (T)	14	4,188,054	299,147***	107.91	68.36
Y*T	28	898,125	32,076***	11.57	14.66
IPCA1	15	797,823	53,188***	19.19	88.83
IPCA2	13	100,302	7716**	2.78	11.17
Residuals	84	232,864	2772		3.80

IPCA: interaction principal component. ***—Significant at 0.1% probability level. **—Significant at 5% probability level. *—Significant at 1% probability level

AMMI biplots were constructed for seed yield to study the main effects and interactions, and are presented in Figure 1. AMMI biplots of the additive main effects or mean seed yield shown along the X-axis and Y-axis represent the first IPCA or multiplicative interaction. If the main effects have an IPCA score close to zero, this indicates negligible interaction effects, and when a treatment and an environment have the same sign on the IPCA axis, their interaction is positive; if different, their interaction is negative. Treatments are more scattered than years, indicating that variability owing to treatment is higher than that owing to seasonal difference, which is in complete agreement with the analysis of variance (ANOVA). Treatments that are characterized by means greater than the grand mean and an IPCA score of nearly zero are considered as generally adaptable to all environments, whereas treatments with a high mean performance and large value of IPCA score are considered as having specific adaptability to environments. Treatments with lower absolute IPCA1 scores will have a low GE interaction effect and such treatments are regarded as highly stable. Treatments that are located farthest on the X-axis are high yielders, whereas those on the Y-axis genotypes whose IPCA1 scores are closer to zero are more stable. The results revealed that treatments H_1N_4 and H_1N_5 with nearly zero IPCA1 scores are very stable, whereas treatment H_2N_1 is unstable with high IPCA1 scores and is more likely to be influenced by seasonal/environmental effects. Treatment H_2N_5 , which is farthest on the X-axis, is a high yielder, followed by treatment H_2N_4 , whereas treatment H_0N_1 is a low yielder.

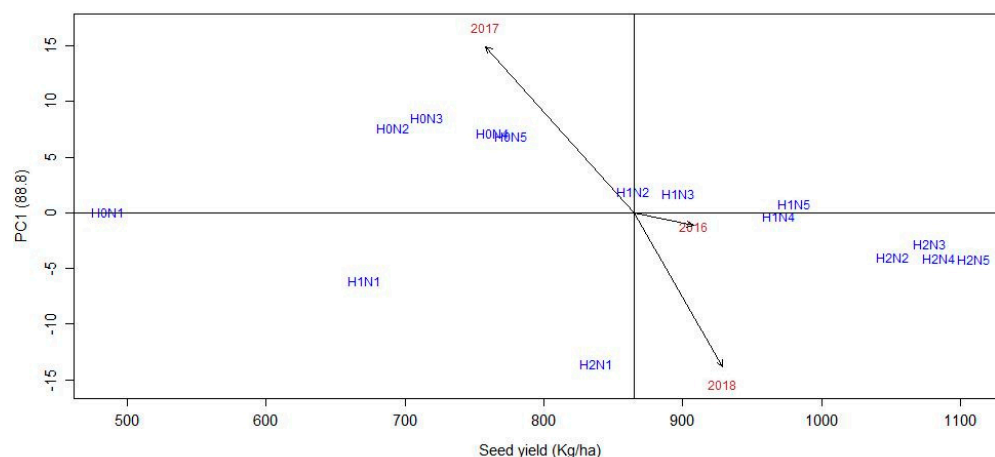


Figure 1. AMMI analysis biplots of (a) first interaction principal component axis (IPCA1) vs. seed yield (SY).

The AMMI model indicated complex YTI, which makes graphical interpretation of modules difficult, so it is essential to use alternative procedures to interpret YTI, such as AMMI parameters [38]. The proposed modified AMMI stability index (MASI) considers all significant IPCAs to rank treatments on the basis of stability [39]. MASI was calculated for seed yield using output from the AMMI model, and the results are presented in Table 7. Treatment H_0N_1 , followed by H_1N_4 and H_1N_5 , had low MASI values, and hence were identified as more stable. Treatments H_2N_5 , followed by H_2N_4 and H_2N_3 , had very high seed yield. Considering the stability of treatments and their mean seed yield together (SSI), treatment H_1N_4 and H_1N_5 had high stability and high seed yield followed by treatment H_2N_3 , as indicated by their low SSI values.

Table 7. Ranking of hydrogel and nutrition treatment combinations on the basis of yield and stability.

Treatment	SY	MASI	rMASI	rSY	SSI
H_0N_1	486.25	0.25	1	15	16
H_0N_2	691.81	6.80	13	13	26
H_0N_3	715.90	7.59	14	12	26
H_0N_4	763.40	6.37	12	11	23
H_0N_5	776.49	6.11	11	10	21
H_1N_1	671.02	5.43	10	14	24
H_1N_2	864.10	1.82	5	8	13
H_1N_3	896.62	1.67	4	7	11
H_1N_4	969.43	0.36	2	6	8
H_1N_5	980.35	0.81	3	5	8
H_2N_1	837.65	12.03	15	9	24
H_2N_2	1051.24	3.58	7	4	11
H_2N_3	1078.18	2.53	6	3	9
H_2N_4	1084.29	3.61	8	2	10
H_2N_5	1109.33	3.71	9	1	10

rSY: rank of seed yield; MASI: modified AMMI stability index; rMASI: rank of MASI; SSI: genotype selection index; SY: seed yield.

3. Materials and Methods

3.1. Plant Material and Preparation

A field experiment was conducted during the winter seasons of 2015–16, 2016–17, and 2017–18 on clay loam soil with 46.4% sand, 12.6% silt, and 39.1% clay and medium in fertility (285.38, 324, and 16.32 kg/ha available nitrogen, potassium, and sulphur, respectively), except phosphorus (18.78 kg/ha), with 1.45% organic carbon content and being low and acidic in reaction (pH 5.4), at CAU research farm,

Andro, Imphal East, Central Agricultural University, Imphal, Manipur. The topography was sloping to gently sloping, with the slope varying from 3% to 5%. The soil in Manipur belongs to the order Inceptisols showing not much horizonation. The bulk density of the surface layer was 1.38 Mg/m³ and the water holding capacity of the soil was 42.2%.

Pusa hydrogel is a carboxymethyl cellulose-based polymer gel produced by M/s Earth Internationals under the trade name of Varidhar G1 (cost ₹1100/ kg). Physically, it appears to be a loose and granular formulation that is white to light yellowish in colour. When the hydrogel comes in contact with atmospheric moisture, it tries to form clumps, losing its free flowing characteristic, affecting the normal functioning of the polymer. Thus, necessary precautions were taken to avoid any kind of moisture contamination during hydrogel application.

The experiment was laid out in split plot design with three hydrogel treatments in the main plot (0, 2.5 kg/ha, and 5.0 kg/ha) and foliar nutrition (water sprays, 2% urea sprays (cost ₹10.5/kg), thiourea spray at 500 ppm (cost ₹180/kg), salicylic acid at 75 ppm (cost ₹430/kg), and NPK 0.5% (19:19:19 water soluble complex fertilizer) (cost ₹930/kg) at 0.5%) in the sub-plots with three replications. The field plots of size 5.0 m × 2.5 m were separated from each other using 0.5 m distance and 1.0 m distance between replications. The soil in a ratio of 1:10 was mixed well with hydrogel for uniform distribution in the field. Hydrogel was drilled in the soil before lentil sowing in earmarked strips, subsequently followed by foliar spray of nutrient solutions at critical stages, that is, flower initiation and pod development. The seeds were sown keeping 22.5 cm row spacing using 40 kg seeds/ha on the 26th, 21st, and 24th November during 2015–16, 2016–17, and 2017–18, respectively. The crop was irrigated immediately after sowing during all the years. The recommended dose of fertilizer (20 kg N, 17.5 kg P, 16 kg K/ha, 20 kg S, and 5 kg Zn) was drilled in the soil at the time of sowing and seeds were treated with rhizobium and phosphate solubilizing bacteria (PSB) at 10 g/kg. The crop did not experience any biotic stress during its growth period. The weather parameters were recorded and tabulated in all three seasons of experimentation along with the distribution of rainfall in Manipur (Figures 2 and 3). Observations on growth and yield attributes were recorded at different intervals and analysis of variance (ANOVA) for three years pooled data was analyzed using R software.

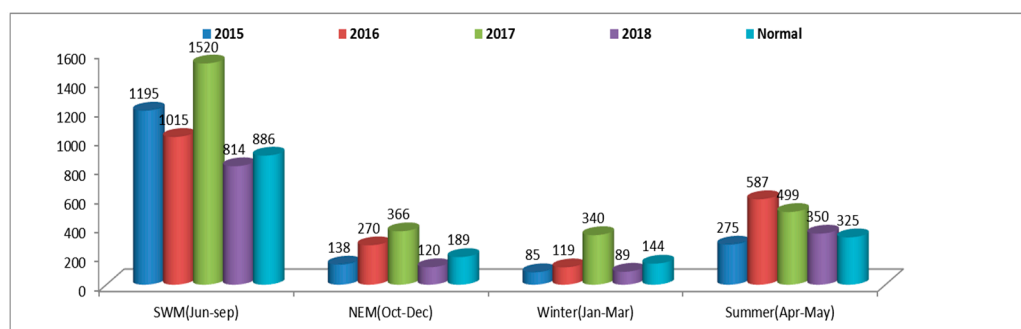


Figure 2. Rainfall during the cropping seasons from 2015–2018 with normal rainfall of Manipur. SWM—South West Monsoon; NEM—North East Monsoon.

The weather data were collected from the 45th to 52nd and 1st to 17th weeks. All the crop husbandry practices from field preparation to harvest of the crop were carried out utilizing the moisture received from rains. The weather was appropriate and, though the lesser amount of rainfall received was well distributed during different growth stages to support the growth of the crop, during the winter season of 2015–16 and 2016–17; it received slightly higher than normal which did not affect to carrying out the field activities in the crop. The third year 2017–18 had water scarcity owing to the significantly lower number of rainy days with lower rainfall during the crop growth. The weather conditions without extremes supported the study of the treatment interactions over the years/seasons, which were studied in the present investigation. However, the required management practices were attended without affecting the crop. The maximum and minimum temperature ranged from 10 °C

to 24 °C, with the number of rainy days ranging from 9 to 28 over the three years. The crop was maintained in healthy condition with appropriate plant protection management.

Observations were recorded at harvest and soil moisture content was recorded at 0–15 cm soil depth and determined using the gravimetric method, starting from the sowing of the crop and continuing up to its maturity in appropriate intervals of 20 days. The economics of the treatments was carried out on the basis of prevailing market prices of inputs, outputs including labour wages, transport, and marketing charges existing during the season of the experiment, which were adopted by the farmers of Manipur. Gross returns were calculated based on the seed and stover yields of the crop and minimum support price (₹45/kg of lentil seed; ₹0.25/kg of stover) during the respective crop seasons. Net returns were calculated by subtracting the cost of cultivation from gross returns. The benefit/cost ratio was calculated by dividing the net returns with the cost of cultivation.

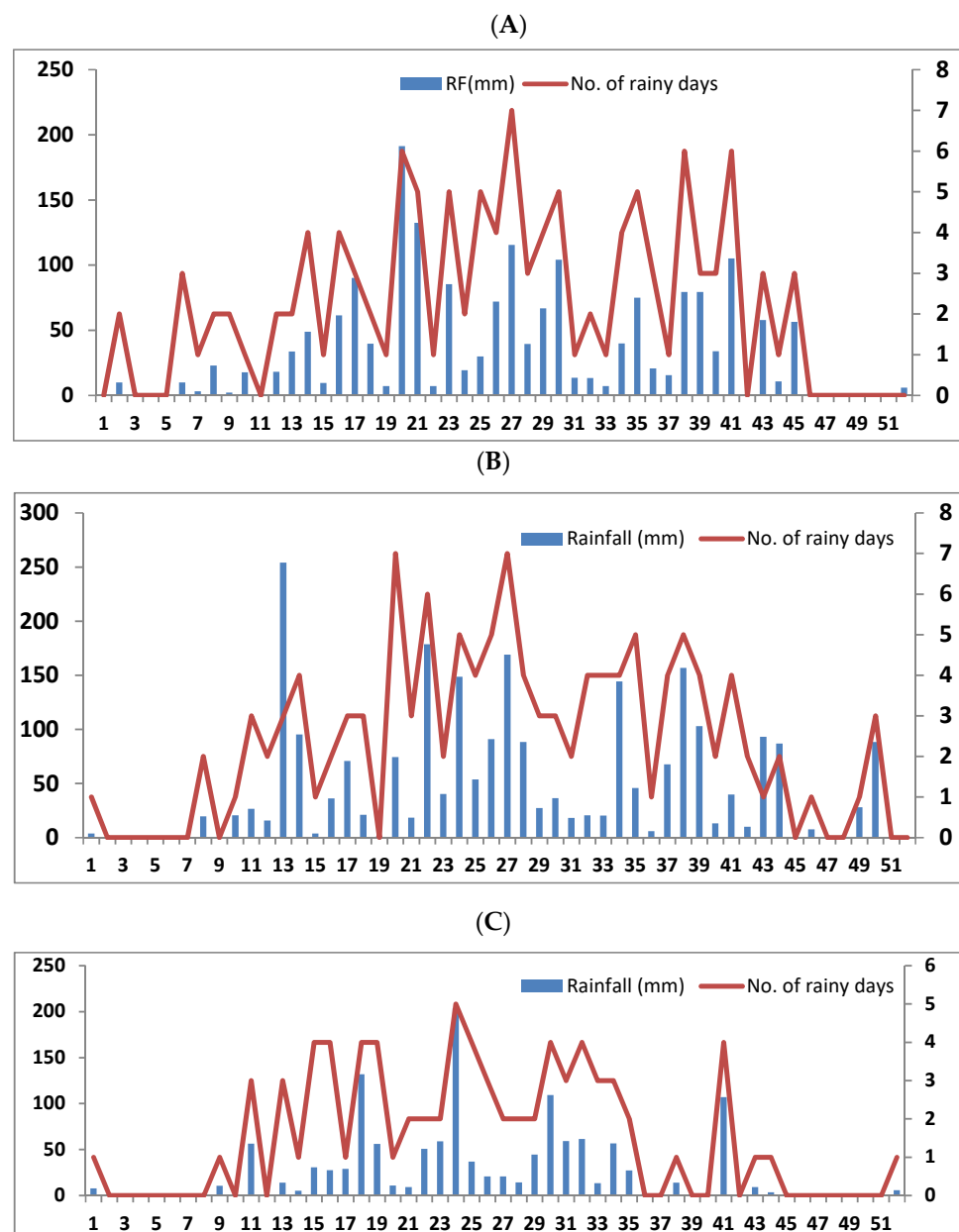


Figure 3. Rainfall (RF) distribution during (A) 2016, (B) 2017, and (C) 2018 in Manipur in standard weeks.

3.2. AMMI Analysis

The yield data from different hydrogel treatments evaluated over consecutive years from 2015–16, 2016–17, and 2017–18 were subjected to AMMI analysis, which is a combination of analysis of variance and multiplication effect analysis. Briefly, analysis of variance is used to partition variance into three components: module deviation from grand mean, environment deviations from grand mean, and module \times environment (ME) deviation from grand mean. Subsequently, the multiplication effect analysis is used to partition ME deviations into different interaction principal component axes (IPCA). R package was used to perform this analysis. AMMI analysis was performed in R [39] using package ‘agricolae’ [40,41].

3.3. Modified AMMI Stability Index (MASI)

The modified AMMI stability Index (MASI) was calculated as described by authors in research papers [39,40,42] using the package ‘ammistability’ [42].

$$MASI = \sqrt{\sum_{n=1}^{N'} PC_n^2 \times \theta_n^2}$$

where PC_n are the scores of nth IPC; and θ_n is the percentage sum of squares explained by the nth principal component interaction effect. Smaller MASI scores indicate a more stable genotype across environments.

3.4. Simultaneous Selection Index for Yield and Stability (SSI)

Stability alone cannot be the sole criteria for module selection, because most stable modules may not be the best performer with respect to management of stem rot. SSI, which takes into consideration both the performance of modules and stability, was used [43] to select stable and best performing modules. SSI was calculated using the following formula:

$$SSI = RASV + SY$$

where RASV is the rank of AMMI stability value and RY is the rank of mean yield of genotypes (SY) across environments. YSI incorporates both mean yield and stability in a single criterion. A low value of this parameter shows desirable genotypes with high yield and stability.

4. Conclusions

Three years of consecutive study reveal that the application of hydrogel 2.5–5.0 kg/ha before lentil sowing and subsequent foliar nutrition either through NPK at 0.5% or salicylic acid 75 ppm during flower initiation and pod development was found to be effective for increasing the seed yield and economics of lentil. Hence, hydrogel along with foliar application of either 0.5% NPK or salicylic acid 75 ppm based on the availability may become a practically and economically feasible option in water-scarce areas for enhancing the agricultural productivity by achieving sustainability in production.

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