



Article

Options for Intensification of Cropping System in Coastal Saline Ecosystem: Inclusion of Grain Legumes in Rice-Based Cropping System

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Abstract: The coastal saline zone of West Bengal in India is the home to millions of the world's poorest and most vulnerable people. Due to a gradual increase in salt accumulation on soils of the coastal saline zone of West Bengal in India from winter to summer days, cultivation of the second crop in the winter season becomes possible in a limited area. To address these issues, field experiments were conducted in rainy and winter seasons of 2016–17 and 2017–18 at the farmer's field of the coastal saline zone (CSZ) of West Bengal, India. The experiment was carried out to study the system productivity, nutrient uptake, and profitability vis-à-vis salinity dynamics of the crops in rice-pulse-based cropping systems under different land elevations (medium upland and medium lowland). The experiment was conducted in a strip-split plot design having horizontal factors namely, Factor A: Six dates of sowing of rice at an interval of one week (2nd week of June to 3rd week of July), Factor B: Two land situations (medium upland and medium lowland) and Two Cropping Systems (Rice-*Lathyrus* and Rice-Lentil) as vertical factor, replicated four times. The results suggest that irrespective of land situation, early sown rice (15 June to 21 June) produces higher dry matter and grain yield compared to late sown crops. This early sowing of rice also facilitated the better performance of subsequent *lathyrus* and lentil, by avoiding the worst situation of the salinity build-up and drought stress later in the winter. Moreover, significantly higher productions were obtained from medium-lowland situations for both the cropping systems. Sowing date has also significantly influenced macro-nutrient uptake (NPK) by rice and pulse grains. It may be concluded that early sowing of rice may be a potential option for intensification of rice-pulse-based cropping systems under CSZ of West Bengal, India.

Keywords: rice; coastal saline; pulses; cropping system; *lathyrus*; lentil



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1. Introduction

The expansion of agricultural land in the coastal saline belt of West Bengal, India, is impeded by several physical, socioeconomic, and chemical factors [1]. The farmland in this region, excluding the homestead upland, is typically categorized as medium low-, medium up-, and lowlands, with the latter medium low- and lowlands often experiencing inundation due to floods and poor drainage [2]. The saline shallow water table and its salinity levels are highly dynamic, and this seasonal variation significantly influences surface soil salinity levels [1]. During the winter to summer months, the upward capillary movement of saline groundwater results in frequent salt deposition in the topsoil layer [3].

Farmers in the coastal zone predominantly follow traditional rice-based monocropping systems to meet their own needs, often disregarding cost-effectiveness, agroecological suitability, and sustainability [4]. The implementation of judicious farmland management practices increases the augmentation of overall productivity, thereby elevating agricultural profitability while ensuring the sustained health of the soil. Therefore, it is often crucial to rely on pre-existing rice-based cropping systems to improve their productivity in terms of sustainability and profitability. Seasonal soil salinity and moisture shortage dynamics are key biophysical constraints that determine the cropping pattern for this agroecosystem [5]. In the coastal saline zone, the crop sowing window started when the monsoon season arrived with sufficient freshwater, desalinizing the surface soil and facilitating the growth of wet-season rice (*Kharif*) without salinity issues. However, in the *rabi* season, the lack of cultivable water and the upsurging of soil salinity to the top layer of the soil limit the possibility of second crops to a very restricted area.

Therefore, there is an urgent need to refine predominant agro-technologies by adopting sustainable rice-based cropping systems. The flexibility of the cropping window is essential for adjusting to seasonal salt dynamics and climatic challenges, focusing on judicious nutrient application, selecting suitable rice varieties, and following *rabi* crops [6]. The sowing date is crucial for optimizing crop production and adapting to climate change. Early sowing and transplanting allow *Kharif* (rainy) rice to exploit more solar radiation under non-waterlogged conditions, leading to higher photosynthetic activity and better nutrient accumulation. Delayed sowing beyond the optimal window can negatively impact crop yield [7,8]. Rice is one of the few crops that can be successfully grown in salt-affected soils, despite its sensitivity to salinity [5]. This is due to its growing ecology under flooded conditions, which partially desalinizes the soil and decreases the effect of salinity [9].

Optimizing the sowing time of rice under varied land situations is a vital strategy for exploiting residual soil moisture and avoiding late-season salinity for subsequent pulse crops, which in turn promotes the expansion of cultivable land and intensifies the cropping system of CSZ. Increasing the cropping intensity of CSZ is necessary to ensure good incomes for farmers through additional crops, using residual soil moisture or minimal irrigation in the post-monsoon season. The integration of pulses into rice fallow periods offers a promising strategy for diversifying cropping systems, promoting sustainable production practices, and expanding the total area dedicated to pulse cultivation [10]. Legumes are critically important for soil enrichment and for addressing malnutrition, particularly in developing countries [11]. Though India is the largest producer (around 25% of global production and 33% of the world area), consumer (27%), and importer (around 14%) of pulses, the average yield of pulses in India is at 789 kg/ha, which is quite low as compared to the average requirement of 1.0 t/ha to make pulse production internationally competitive [12]. So, there is an urgent need for area expansion for pulse crops to boost its production and productivity. *Lathyrus* (*Lathyrus sativus* L.) is a vital leguminous pulse crop cultivated predominantly during winter [13]. Its rapid growth, high yield potential, and remarkable adaptability to saline and moisture-stress conditions make it an ideal candidate for integration as a catch crop within the existing cropping systems [7]. On the other hand, lentil (*Lens culinaris* Medikus) is another important leguminous pulse crop of the winter season. Nationally, it occupies about 1.80 million ha with a production of 1.10 million tonnes [14]. The CSZ region faces challenges in achieving optimal lentil yields due to a confluence of factors. Weather variability disrupts sowing schedules, and limited land availability following the late harvest of rainy season rice restricts timely planting, leading to lower lentil production [15].

Keeping these facts in mind, a multisession (rainy and winter seasons of 2017–18 and 2018–19), field experiment was planned in the coastal saline zone (CSZ) of West Bengal. The specific objectives of this study were to (i) to study the feasibility of incorporating different winter pulses into the rice-based cropping system in the salt-affected coastal zone of West Bengal; (ii) to determine the system productivity of the crops in rice–pulse-based cropping systems under different land elevations (medium lowland and medium upland);

(iii) to study the nutrient uptake by all the crops in sequence and any physicochemical changes, including the nutrient balance of the soil under the proposed intensified systems of cropping; and, finally, (iv) to analyze and compare the economics of crop production for the cropping patterns under consideration.

2. Materials and Methods

2.1. Site Description

Field experiments were conducted for two years (2016–2018) on a farmer's field in Rangabelia, which comes under the Gosaba block, South-24 Parganas, West Bengal, India (22.15° N, 88.83° E) (see Figure S1). The agro-climatic condition of the experimental site is mostly influenced by the Bay of Bengal which is nearly 35 km away from the experimental site. The average annual rainfall varies between 1378 and 2485 mm, the lion's share of which occurs between June and September. The amount, frequency, and intensity of heavy rains are likely to occur in the month of July followed by August. The various meteorological data during the crop growth period were recorded at the Automatic weather station [(EM50 Data Collection System, Decagon Inc., Berlin, Germany) located near the study area (21.92503° N and 88.80815° E)] (Figure 1). The mean temperature during the experimental years fluctuated between 13.6 and 31.6° C which is quite congenial with the long-term average air temperature. The monthly mean maximum relative humidity (85, 98, and 96%) was observed in the months of December, July, and September in 2016, 2017, and 2018 respectively. The value of the minimum relative humidity (52%) was the lowest in November 2016, whereas, in 2017 and 2018, the lowest relative humidity (49% and 51% respectively) was found in March and April respectively. The rainfall was distributed throughout the experimental period, but the highest monthly rainfall was received in July 2017 (905 mm). The two-year average rainfall during the experimental period was recorded as 212 mm. The average solar radiation of the experimental years was $16 \text{ MJ/m}^2/\text{day}$ was recorded. The soils of the area fall under the lower deltaic physiographic unit and have been developed on alluvium with shallow groundwater (at 2 m depth) [16]. The composite samples of 0–15, 15–30, 30–50, 50–80, and 80–120 cm depth were randomly collected from five places in the experimental field. The soil samples thus obtained were used in various physical and chemical analyses, and the results obtained have been presented in Table 1. During the experimental period, the deposition of surface water across different land situations was also presented in Figure S2a,b.

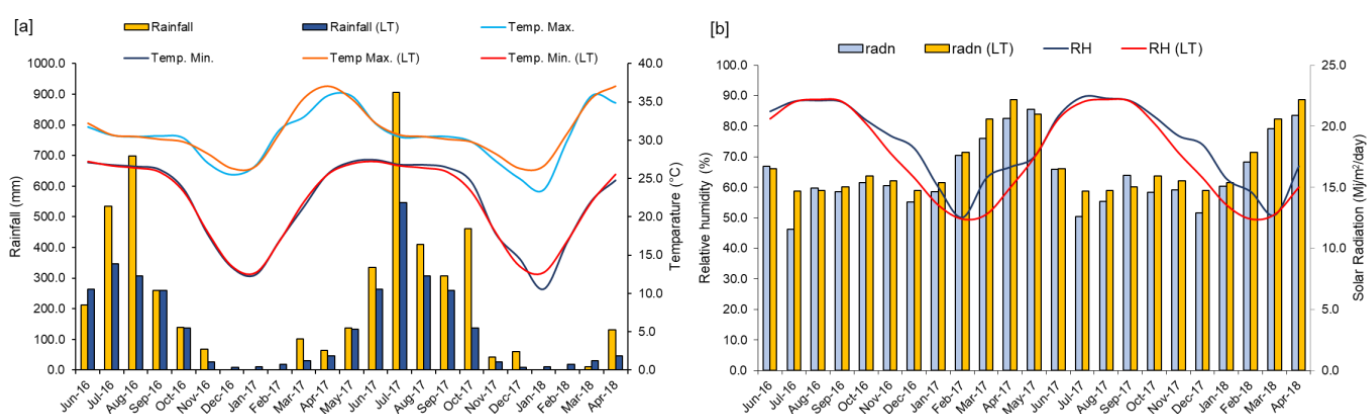


Figure 1. (a) Average monthly maximum and minimum [Temp. Max. $^{\circ}$ C; Temp. Min. $^{\circ}$ C]; air temperature; total monthly rainfall (mm); (b) average monthly relative humidity RH (LT) %; and solar radiation [$\text{MJ m}^2/\text{day}$], for the experimental site (Gosaba, West Bengal) during the experimental period (2016–2018).

Table 1. Summary of physical and chemical soil parameters of the experimental site (before starting of *kharif* season experiment in 2016).

Soil Depth (cm)	Clay (%)	Silt (%)	Sand (%)	OC (%)	N (kg/ha)	P ₂ O ₅ (kg/ha)	K ₂ O (kg/ha)	BD (g/cm ³)	EC _{1:5} (dS/m)	pH
Medium upland condition										
0–15	45.2	28.0	26.8	0.50	125.44	14.34	445.20	1.530	0.22	5.45
15–30	46.8	28.4	24.8	0.41	150.52	19.12	404.90	1.480	0.27	5.65
30–50	47.6	29.5	22.9	0.29	125.44	28.68	493.70	1.450	0.27	5.75
50–80	49.1	29.1	21.8	0.23	113.07	23.90	415.40	1.430	0.29	5.70
80–120	53.2	26.0	20.8	0.21	103.65	22.65	398.31	1.410	0.31	5.70
Medium-lowland condition										
0–15	47.9	27.6	24.5	0.51	137.98	23.90	465.35	1.510	0.13	5.65
15–30	48.1	28.7	23.2	0.46	175.61	9.56	406.05	1.450	0.24	6.05
30–50	48.3	28.3	23.4	0.44	175.61	28.68	466.80	1.430	0.25	5.62
50–80	50.5	29.5	20.0	0.38	112.89	19.12	474.80	1.410	0.29	5.52
80–120	55.3	26.6	18.1	0.32	111.3	21.21	469.31	1.390	0.29	5.52

2.2. Experimental Design and Treatment Details

Field experiments spanning multiple seasons and environments were conducted during the monsoon (June–October) and winter (November–April) seasons over two consecutive years (2016–2017 and 2017–2018). These experiments employed a strip-split plot design with the following factors: the horizontal factors (Factor A) included six sowing dates for rice (cv. *CR1017*, a high-yielding, salinity- and disease-resistant cultivar), spaced one week apart from 15 June to 19 July; the vertical factors (Factor B) included two land situations (medium upland and medium lowland) and two cropping systems (Rice–*Lathyrus* and Rice–*Lentil*). The total number of treatment combinations for each cropping system was twenty-four replicated four times and randomized as per statistical norms [17]. The experiment comprised of total 98 plots, and each plot measured 20 m² (5 m by 4 m). Rice seedlings, aged 22 days, were manually transplanted according to their respective planting dates, maintaining a spacing of 20 cm by 15 cm, with two seedlings per hill. *Lathyrus* seeds (cv. *Bio-L-212*) were relay-seeded into the field after the rice crop reached physiological maturity, utilizing the residual soil moisture for optimal growth. On the other hand, lentil seed (cv. *Moitree*) was sown at a depth of 3–4 cm in rows 30 cm apart from each other just after the harvesting of rainy-season rice. To achieve the optimum plant density in both pulse crops, under rice–pulse-based cropping systems, thinning was performed just once, about 28–30 days following seeding (60–70 plants/m²). In each *lathyrus* row, a 4 to 5 cm plant-to-plant spacing was maintained. The recommended dose of fertilizer (RDF) for rice was 60:30:30:: N:P₂O₅:K₂O kg/ha and for *lathyrus* and lentil it was 20:40:20::N:P₂O₅:K₂O kg ha^{−1} [18]. The source of the chemical fertilizers was urea (for N), single super phosphate (for P), and muriate of potash (for K). In rice, a full dose of P and K and ¼ of N were applied as basal. Half of N was applied 3 weeks after transplanting, and the balanced ¼ N was top-dressed at the panicle initiation stage. For *lathyrus* and lentil, the required dosage of fertilizer was administered at the time of seed planting [18]. All crops in the cropping system were grown in rainfed environments. In rice, Triazophos @ 1.5 mL/L of water was applied to control yellow stem borer. In accordance with the best management techniques, all other essential agronomic and cultural procedures were carried out [1].

2.3. Biometrical Measurements and Estimation of Yield

The growth attributes like plant height (cm), dry matter accumulation or biomass production (g/m² in rice and *lathyrus* and lentil), and leaf area index were observed in both experimental seasons at 30 DAS (days after sowing), 50 DAS, 70 DAS, and 90 DAS in rice; at 20 DAS and 40 DAS in *lathyrus* and lentil. The crop growth rate (g/m²/day) was estimated at 30–50, 50–70, and 70–90 DAS in rice. The above-mentioned growth attributes and number of branches/plants of *lathyrus* and lentil were measured at 20 and 40 DAS. In

the case of rice, the number of tillers/plant was recorded at 30 DAS, 50 DAS, 70 DAS, and 90 DAS.

Grain or seed yield (kg/ha), straw or stover yield (kg/ha), and harvest index (%), were estimated after harvest. To estimate the yield of rice, the entire produce from the net plot area (demarcated portion leaving the border area) was harvested and grain yields were determined [19]. For *lathyrus* and lentil, the mature pods were picked up from the net plot area, then pods were sun-dried and threshed. Seeds were dried properly to reduce the moisture content to 14.0%. The weight of seeds was recorded as g/plot and then converted to kg/ha.

2.4. Analysis of Plant and Soil Samples

2.4.1. Analysis of Soil Samples

Initial and post-harvest soil samples (0–15, 15–30, 30–50, 50–80, and 80–120 cm depth) from the experimental land types were collected and processed before analysis. Particle-size distribution of the soils was obtained by following the Hydrometer method [20]. Textural classes of the soils were determined from the percent contents of sand, silt, and clay with the help of the triangular textural diagram [21]. Organic carbon content was quantified as a percentage using the method from [22], as outlined by [23], wherein 2 g of soil were utilized, employing diphenylamine as an indicator. Available nitrogen (N) levels in the soil was assessed using the hot alkaline potassium permanganate method, as recommended by [24], facilitated by the Kel plus instrument. The available phosphorus (P) content was extracted using 0.5 M NaHCO₃, following the protocol proposed by [25], and quantified using a UV-VIS spectrophotometer. To determine available potassium (K), soil samples were treated with neutral ammonium acetate solution, as per the [26] method, and measured using a flame photometer.

Soil moisture was recorded at different soil depths (0–15, 15–30, 30–50, 50–80, and 80–120 cm) at 15 day intervals. Soil samples were collected with the help of a screw auger. Then the soil was taken into an aluminium moisture box. The weight of each box was taken with an electric balance. Then the soil samples were dried at 105 °C for 72 h. Volumetric soil moisture was recorded at different soil depths at periodic intervals as stated by [27]. The electrical conductivity of soil suspensions, prepared at a soil-to-water ratio of 1:5, was measured at room temperature (28 °C) using digital conductivity meter (model: Systronics, 363) [28]. The solute potentials (SP, Ψ_s) of the soil solution collected from the experimental field from different depths were calculated using the following formula by [29]:

$$\Psi_s = -22,580 \times \frac{EC_{1:5}}{W}$$

where Ψ_s is the solute potential, EC_{1:5} is the electrical conductivity (dS m⁻¹) and W is the gravimetric soil moisture content.

2.4.2. Measurements for Nutrient Accumulation, Partitioning, and Remobilization

Samples of plants (leaves stems, and grains/seeds) were cut/harvested and ground before N, P, and K concentration (percent) measurement after dry matter accumulation was measured. Plant samples were digested with concentrated H₂SO₄ and an acceleration digestion mixture until bright green coloration was achieved for N analysis. The digest was titrated with 0.025 (N) H₂SO₄ using the Micro-technique Kjeldahl's after being distilled with 40 percent NaOH [30]. The estimation of P and K from plant samples was determined as described by [23]. It was computed by multiplying the nutrient content (percentage) with the dry matter accumulation in the relevant plant component and dividing by 100 and represented as kg/ha.

The nutrient harvest index (NHI) and nutrient mobilization efficiency index (NMEI) of N/P/K were computed using the following expressions as suggested by [31].

$$\text{NHI} = \frac{\text{N uptake in grain (kg/ha)}}{\text{Total Nutrient uptake (kg/ha)}}$$

$$\text{NMEI} = \frac{\text{Nutrient concentration in Grain (mg/kg)}}{\text{Nutrient concentration in straw (mg/kg)}}$$

2.5. Cropping System Analysis

Rice Equivalent Yield (REY) was determined by dividing the total price of the produce by the price of rice per kg. To clarify, the REY of different crop sequences was computed by multiplying the seed yields of winter pulse crops in the cropping systems with their respective selling prices, and thus, the multiplied value derived was divided by the selling price of rice [32].

$$\text{REY (kg/ha)} = \frac{\text{Total price of produce to be compared}}{\text{Price of rice/kg}}$$

System productivity of the cropping sequence was obtained by the addition of rice the equivalent yield of each component crop.

Production efficiency was calculated by dividing the system productivity by the total duration of the system and was expressed in kg/ha/day [33].

$$\text{Production efficiency (kg/ha/day)} = \frac{\text{Total productivity of a system (kg/ha)}}{\text{Duration of the system (days)}}$$

2.6. Economic Analysis

The total costs of cultivation (expenditure on land preparation, seed materials, sowing/transplanting, thinning, plant protection, irrigation, harvesting, etc., and variable costs including the cost of manures and fertilizers, weeding, etc.) were calculated. Gross return was estimated by adding the return from the main product and by the product of each crop in sequence. Profit was calculated by deducting the total cost of cultivation from the total product value. The net production value was, thus, calculated by dividing the net profit by the total cost of cultivation.

$$\text{Gross return} = \text{Economic Yield} \times \text{selling price}$$

$$\text{Net return} = \text{Gross return} - \text{Total cost of cultivation}$$

$$\text{B : C ratio} = \frac{\text{Gross return}}{\text{Total cost of cultivation}}$$

The minimum support price (MSP) of the rice and lentil of the respective experimental years was considered as the selling price of the produce (grain or seed). For *lathyrus*, the selling price was considered as per the prevailing local market price of each experimental year. The summarized selling price of different crops considered in this experiment, is presented in Supplementary Table S1.

2.7. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) in split-strip plot design [17] using GenStat (Windows version 20.0) software. The significance of difference for sources of variance was tested by error mean square by Fisher Snedecor's 'F' test at a probability level of 0.05. For comparison of 'F' values and computation of critical difference (CD) at 5% level of significance, Fisher and Yates' tables were consulted. The ANOVA of all analyzed parameters is given year-wise in Supplementary Tables S6–S11. The Microsoft Excel 365 software (version 2020, Microsoft Inc., Redmond, WA, USA) and Origin Pro 2020 were used to draw graphs and figures. Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCoA) were performed using CANOCO Version 4.5 [34].

3. Results

3.1. Effect of Land Situation and Date of Sowing on the Performance of Rice

3.1.1. Vegetative Growth Responses of Rice to Land Situation and Sowing Date Factors

Important growth parameters of rice like plant height, above-ground biomass, and LAI gradually increased until maturity, irrespective of the land situation and sowing date over a couple of years. In both the experimental years, the plant height of rice at early and later growth stages (30, 70, and 90 DAT) did not differ significantly with different land situations, whereas, at 50 DAT only the plant height of rice varied with different land situations. The maximum plant height of rice throughout the growth period was observed from the plots under medium-lowland conditions. Earlier dates of sowing (1st and 2nd DOS i.e., 15 June to 21 June) produced taller rice plants at 50, 70, and 90 DAT than later sowing dates. (Supplementary Figure S3).

In both years, crops sown on earlier sowing dates (15 June to 28 June) recorded significantly higher dry matter accumulation. It was also observed that, at 50 DAT delay in sowing of rice can reduce the biomass accumulation by 18.37 and 11.13% compared to crop sown on 1st date (15 June) in year 1 and year 2 respectively. However, throughout the growth period, the land situation did not significantly affect the biomass accumulation in rice during both experimental years (Supplementary Figure S4).

In both years, throughout the growth period the maximum values of the leaf area index were observed from the plots under medium-lowland condition. Rice sown on earlier dates (15 June to 28 June) recorded significantly higher LAI than that of the late-sown crops. (Supplementary Figure S5).

3.1.2. Effect of Land Situation and Date of Sowing, on Yield Components and Yield of Rice

During the first year of the experiment, the land situation factor significantly influenced the panicle number/m², and crops grown under medium-lowland conditions performed significantly better than those grown under medium-upland conditions. Significantly higher fill grains/panicle of rice were recorded from the crops grown under medium-upland conditions in both the years of experimentation though test weight (1000 grain weight) of rice was not significantly influenced by the land situation factor. The date of sowing showed a significant variation in most of the yield components of rice except panicle length (varietal characteristics) in both years. Crops sown on the 1st and 2nd dates (15 June to 21 June) recorded significantly higher yield components like no. of panicles/m², fill grains/panicle, and test weight (g) during year 1 and year 2.

The variation in seed yield of rice as influenced by the land situation factor was significant ($p \geq 0.05$) during the second year, and at significantly higher grain yield (5005.0 kg/ha) was obtained from the medium-lowland situation (Table 2). Sowing date significantly ($p \leq 0.05$) influenced seed yield in both years. During year 1 and year 2, the maximum grain yield was obtained from the plants sown on 15 June (1st DOS), which was 20.4% and 20.17% more than the grain yield derived from late sown (19 July i.e., 6th DOS) plants in year 1 and year 2 respectively. Significantly the highest grain yield (5700 kg/ha and 5543 kg/ha) was recorded under treatment combinations medium lowland $\times$ 1st DOS (15 June) in the second year of experimentation only.

During both years significantly ($p \leq 0.05$) higher straw yield was obtained from the plots of medium-lowland condition (6787 kg/ha and 6653 kg/ha) than the straw yield derived from the plots of medium upland. The date of sowing factor significantly influenced the straw yield of rice. In both seasons of experimentation, significantly higher amounts of straw yield were obtained from the crops from early sown (15 June i.e., 1st DOS) plants (7054 and 6415 kg/ha for year 1 and year 2 respectively).

The harvest index indicates the efficiency of a crop plant in converting photosynthates into economical yield. Early sowing of rice (15 June) significantly improved the harvest Index (43.8% and 45.7% in year 1 and year 2 respectively).

Table 2. Effect of land situation and date of sowing on yield attributes and yield of rice.

Factors	No. of Panicles/m ²		Fill Grains/Panicle		Test Weight (g)		Grain Yield (kg/ha)		Straw Yield (kg/ha)		Harvest Index (%)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Land Situation (LS)												
Medium upland	306	326	159	168	20.5	21.1	4754	4782	6485	6530	42.2	42.2
Medium lowland	330	334	187	195	20.6	20.8	5023	5005	6787	6653	42.5	43.0
SEm (±)	4.08	5.82	1.24	0.64	0.10	0.41	99.8	36.4	37.7	47.5	0.54	0.48
LSD _{p≤0.05}	18.3	NS	5.59	2.88	NS	NS	NS	163.8	169	117	NS	NS
Date of Sowing (DOS)												
1st DOS	364	397	196	203	21.4	22.1	5506	5385	7054	6415	43.8	45.7
2nd DOS	329	336	194	199	21.2	21.9	5163	5330	6775	6361	43.2	45.7
3rd DOS	311	311	175	180	20.3	21.0	4925	4964	6625	7056	42.7	41.3
4th DOS	306	333	163	178	20.3	20.5	4844	4855	6531	7026	42.6	40.9
5th DOS	294	299	160	167	19.8	20.1	4513	4521	6450	6453	41.1	41.2
6th DOS	306	304	151	162	20.1	20.0	4381	4304	6381	6237	40.7	40.8
SEm (±)	11.4	13.5	6.57	2.34	0.24	0.35	109	86.1	215	128	0.80	0.32
LSD _{p≤0.05}	34.3	40.7	19.79	7.07	0.72	1.06	329	260	650	387	2.42	0.95
Cropping System (CS)												
Rice-Lathyrus	316	331	174	183	20.79	20.7	4912	4881	6624	6602	42.5	42.5
Rice-Lentil	321	329	172	180	20.24	21.1	4865	4905	6648	6581	42.1	42.7
SEm (±)	12.3	13.4	4.77	4.96	0.56	0.49	23.5	59.8	39.6	58.5	0.08	0.04
LSD _{p≤0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
LS × DOS	NS	NS	NS	NS	NS	NS	**	**	NS	NS	NS	NS
LS × CS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DOS × CS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LS × DOS × CS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July; DOS Days after sowing; ** Significance at $p \leq 0.01$, NS: Non-Significant].

The interactions of different yield attributing parameters and yield between land situation × cropping system; date of sowing × cropping system and land situation × date of sowing × cropping system were non-significant ($p \leq 0.05$) during both experimental seasons.

3.1.3. Effect of the Land Situation and Date of Sowing, on Macronutrient Uptake of Rice

The grain nitrogen uptake (%) was significantly affected by land situation (year 2) and date of sowing. The Medium-lowland condition produced more nitrogen (0.491%) in the second year of experiment and in both years significantly higher nitrogen content in rice grains was observed at an early date of sowing (1st and 2nd date of sowing i.e., 15 and 21 June). In both experimental years, in contrary to the grain N uptake, an opposite but significant trend was observed in straw N uptake as influenced by the sowing date factor. Higher N content in rice straw was observed when rice was sown on later dates (5 July–19 July). The crop grown under medium-upland condition recorded significantly higher straw N uptake (%) than the crop grown under medium-lowland conditions in year 1 only. In coordination with the grain N uptake, in both years, significantly higher total N uptake (grain + straw) was observed from the crops sown early (1st date of sowing i.e., 15 June). On the other hand, crops sown at medium-upland conditions recorded significantly higher total N uptake (grain + straw) (1.463%) in year 1 only.

Land situation and date of sowing significantly affected the grain phosphorous uptake (%). Rice sown in medium-lowland uptakes more nitrogen in both the years of experiment, while higher phosphorus content in rice grains was observed at an early date of sowing (2nd date of sowing i.e., 21 June). The crop grown under medium-upland conditions recorded significantly higher straw P uptake (%) than the crop grown under medium-lowland condition in both years. However, the date of sowing failed to exert any significant response on straw phosphorus uptake. In coordination with the grain P uptake, significantly higher total P uptake (grain + straw) (0.47% for year 1 and 0.50% for year 2) was observed from the crops sown early (2nd date of sowing i.e., 21 June) in both years. On the other hand, crop sown at medium-lowland conditions recorded significantly higher total P uptake (grain + straw) (0.43% for both year 1 and year 2).

In the case of potassium uptake both land situation and date of sowing are recorded to produce significant effect on rice grain potassium uptake. In year 1 and year 2, crops grown under medium-lowland condition recorded significantly higher K uptake (%) than crop grown under medium-upland condition. The date of sowing also influenced K uptake in rice grains. In year 1 and year 2 significantly higher potassium content in rice grains was observed at the early date of sowing (2nd date of sowing i.e., 21 June) Table 3 summarizes the nutrient uptake by grain and straw of rice in both the experimental years.

Table 3. Effect of land situation and date of sowing of rice on macronutrient uptake of rice.

Factors	Nitrogen Uptake				Phosphorous Uptake				Potassium Uptake			
	Grain (%)		Straw (%)		Grain (%)		Straw (%)		Grain (%)		Straw (%)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Land Situation (LS)												
Medium upland	0.915	0.934	0.549	0.493	0.23	0.23	0.12	0.14	0.23	0.23	2.25	1.84
Medium lowland	0.923	0.941	0.428	0.417	0.34	0.34	0.09	0.10	0.34	0.34	2.40	1.82
SEm (±)	0.003	0.003	0.018	0.017	0.003	0.004	0.005	0.004	0.003	0.004	0.062	0.046
LSD _{p≤0.05}	NS	0.007	0.080	NS	0.015	0.017	0.022	0.020	0.015	0.017	NS	NS
Date of Sowing (DOS)												
1st DOS	1.158	1.182	0.447	0.406	0.29	0.29	0.11	0.13	0.29	0.29	2.30	1.95
2nd DOS	0.920	0.939	0.400	0.364	0.36	0.37	0.11	0.12	0.36	0.37	2.29	1.88
3rd DOS	0.910	0.929	0.445	0.415	0.24	0.25	0.10	0.11	0.24	0.25	2.11	1.79
4th DOS	0.836	0.853	0.529	0.491	0.28	0.28	0.09	0.10	0.28	0.28	2.28	1.79
5th DOS	0.850	0.867	0.591	0.553	0.26	0.24	0.11	0.12	0.26	0.24	2.55	1.70
6th DOS	0.837	0.853	0.519	0.501	0.27	0.25	0.11	0.12	0.27	0.25	2.41	1.87
SEm (±)	0.016	0.017	0.018	0.017	0.005	0.006	0.006	0.008	0.005	0.006	0.142	0.101
LSD _{p≤0.05}	0.049	0.050	0.055	0.052	0.016	0.019	NS	NS	0.016	0.019	NS	NS
Cropping System (CS)												
Rice-Lathyrus	0.924	0.943	0.482	0.448	0.28	0.28	0.09	0.11	0.28	0.28	2.41	1.85
Rice-Lentil	0.913	0.932	0.495	0.495	0.28	0.28	0.12	0.13	0.28	0.27	2.24	1.80
SEm (±)	0.007	0.009	0.007	0.012	0.001	0.002	0.023	0.025	0.02	0.02	0.013	0.017
LSD _{p≤0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions												
LS × DOS	NS	NS	**	**	**	**	**	**	**	**	**	**
LS × CS	NS	NS	**	**	NS	NS	*	*	NS	NS	NS	NS
DOS × CS	NS	NS	NS	*	NS	NS	*	*	NS	NS	NS	NS
LS × DOS × CS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS

[Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July; DOS Days after sowing; ** Significance at $p \leq 0.01$, * Significance at $p \leq 0.05$, NS: Non-Significant].

3.2. Effect of Land Situation and, Date of Sowing on the Performance of Lathyrus

3.2.1. Effect of Land Situation and Date of Sowing, on Yield Components and Yield of Lathyrus

Yield attributing traits of *lathyrus* such as pod/plant, seed/pod, and test weight grown under the rice-lathyrus system were derived and the data are summarized in Table 4. Significantly higher numbers of pod/plant (30.10 and 45.48 respectively for year 1 and year 2) were recorded from the crops sown in medium-lowland situation for every year. Early sowing of *lathyrus* (2 November) significantly improved the number of pod/plant (51.19), which was statistically at par with the crops sown on 7 November (49.19) in the second year of study, while the first year of experimentation date of sowing factor revealed non-significant response on pod/plant of *lathyrus*. The seed/pod and test weight of *lathyrus* were not significantly varied as they were influenced by land situation factors. However, in both seasons of experimentation, the maximum value of seed/pod (4.55) was recorded from the crops sown on 2nd DOS (7 November), closely followed by the crops sown on 2nd November (4.28).

The variation in seed yield of *lathyrus* as influenced by the land situation factor was significant ($p \geq 0.05$) during both years (Table 4) and a significantly higher amount of seed yield was obtained from the medium-lowland situation in each year of experimentation, accounting 792 kg/ha and 1016 kg/ha for year 1 and year 2 respectively. During year 1 and year 2, the maximum grain yield was obtained from 2nd November (1st DOS) sown

plants; which was 56.42% and 43.44% more than the grain yield derived from late sown (29 November i.e., 6th DOS) plants. In both years of study, the significantly highest seed yield (1018 kg/ha and 1233 kg/ha for year 1 and year 2 respectively) was recorded under treatment combinations medium lowland $\times$ 1st DOS (2 November).

Table 4. Effect of land situation and date of sowing of rice on yield attributes and yield of *lathyrus*.

Factor	Pod/Plant		Seed/Pod		Test Weight (g)		Seed Yield (kg/ha)		Stover Yield (kg/ha)		Harvest Index (%)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Land situation (LS)												
Medium upland	28.42	39.52	3.90	3.88	41.51	41.00	709	970	2232	2327	24.0	29.4
Medium lowland	30.10	45.48	3.88	3.74	41.10	40.31	792	1016	2500	2647	24.0	27.8
SEm ($\pm$)	0.26	0.78	0.08	0.12	0.62	0.56	4.5	9.8	67.3	26.2	0.49	0.23
LSD _{p$\leq$0.05}	1.15	3.53	NS	NS	NS	NS	20.3	44.3	NS	117.8	NS	1.05
Date of Sowing (DOS)												
1st DOS	30.69	51.19	4.28	3.83	42.38	39.77	937	1192	2654	2991	26.1	28.5
2nd DOS	29.56	49.19	4.55	4.08	42.09	40.40	819	1085	2584	2509	24.2	30.4
3rd DOS	29.38	42.50	3.48	3.75	40.51	41.05	773	993	2484	2488	23.8	28.6
4th DOS	29.19	40.50	3.93	3.95	40.71	41.27	705	948	2370	2456	23.0	28.0
5th DOS	28.81	36.63	3.59	3.35	40.63	40.61	669	910	2120	2359	24.0	28.0
6th DOS	27.94	35.00	3.53	3.90	41.54	40.81	599	831	1982	2117	23.1	28.2
SEm ($\pm$)	0.54	1.68	0.22	0.13	0.72	0.49	25.2	27.5	77.3	79.6	0.56	0.38
LSD _{p$\leq$0.05}	NS	5.07	0.69	0.40	NS	NS	75.9	83.0	233.2	240.1	1.69	1.16
Interaction												
LS $\times$ DOS	NS	**	NS	NS	NS	NS	**	**	**	**	NS	NS

[Abbreviation: 1st DOS: 2 November; 2nd DOS: 7 November; 3rd DOS: 13 November; 4th DOS: 18 November; 5th DOS: 24 November; 6th DOS: 29 November; Year 1 and Year 2 represents rainy seasons of 2016 and 2017, respectively; ** Significance at $p \leq 0.01$, NS, Non-significant].

In year 1, stover yield did not significantly differ by land situation factor, but in year 2 significantly ($p \leq 0.05$) higher stover yield was obtained from the plots of medium-lowland condition (2647 kg/ha), which was 13.75% more than the stover yield derived from the plots of medium upland. In both seasons, a significantly higher amount of stover yield was obtained from the crops from (2 November i.e., 1st DOS) sown plants (2654 and 2994 kg/ha for year 1 and year 2 respectively).

The harvest index indicates the efficiency of a crop plant in converting photosynthates into economical yield. In the initial year, the harvest index of *lathyrus* did not significantly differ from the land situation factor, but in year 2 significantly ($p \leq 0.05$) higher harvest index was obtained from the plots of medium-upland condition (29.4) than the crops sown in medium-lowland condition (27.8). Early sowing of *lathyrus* (2 November) significantly improved the harvest Index (26.1%) in the first year of study, while in the second year of experimentation significantly ($p \leq 0.05$) higher harvest index was obtained from the plants sown on 7 November (30.4).

3.2.2. Effect of Land Situation and Date of Sowing, on Macronutrient Uptake of *Lathyrus*

Nitrogen content in *lathyrus* seed did not differ significantly by the variation in land situation. However, the date of sowing also influenced N uptake in seed. In both the experimental years significantly higher nitrogen content (3.89% and 4.02% for year 1 and year 2 respectively) in *lathyrus* seed was observed at an early date of sowing (2 November). The crop grown under medium-upland conditions recorded significantly higher stover N uptake (%) than crop grown under medium-lowland conditions in both years of study. In both experimental years, contrary to the grain N uptake, a significant and opposite trend was observed in stover N uptake as influenced by the sowing date factor. A significantly higher N content in *lathyrus* stover was observed when grass was sown on later sowing dates (24 November). In both years, significantly higher straw N uptake (%) (1.26 and 1.31% for year 1 and year 2 respectively) was recorded from the plants under medium-upland situation sown on 24 November (5th DOS). Phosphorus content in *lathyrus* seed diverged

non-significantly with the variation in land situation factor and date of sowing in both years of study (Table 5).

Table 5. Effect of land situation and date of sowing of rice on macronutrient uptake of *lathyrus*.

Factors	Nitrogen Uptake				Phosphorous Uptake				Potassium Uptake			
	Grain (%)		Stover (%)		Grain (%)		Stover (%)		Grain (%)		Stover (%)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Land Situation (LS)												
Medium upland	3.67	3.78	1.13	1.18	0.232	0.238	0.153	0.162	1.09	1.16	3.38	3.30
Medium lowland	3.75	3.90	1.03	1.07	0.250	0.256	0.144	0.152	1.19	1.24	3.60	3.28
SEm (±)	0.04	0.06	0.01	0.01	0.004	0.004	0.003	0.003	0.02	0.01	0.09	0.08
LSD _{p≤0.05}	NS	NS	0.05	0.05	NS	NS	NS	NS	0.08	0.07	NS	NS
Date of Sowing (DOS)												
1st DOS	3.89	4.02	1.07	1.11	0.258	0.264	0.169	0.179	1.11	1.16	3.45	3.50
2nd DOS	3.73	3.86	1.16	1.20	0.246	0.253	0.148	0.156	1.17	1.26	3.44	3.38
3rd DOS	3.71	3.84	1.03	1.07	0.239	0.245	0.147	0.156	1.04	1.12	3.17	3.22
4th DOS	3.64	3.76	1.01	1.05	0.222	0.227	0.143	0.151	1.18	1.23	3.41	3.21
5th DOS	3.63	3.75	1.18	1.23	0.241	0.247	0.141	0.150	1.21	1.23	3.83	3.08
6th DOS	3.67	3.82	1.04	1.08	0.239	0.245	0.142	0.151	1.14	1.20	3.62	3.37
SEm (±)	0.04	0.05	0.03	0.04	0.007	0.008	0.008	0.008	0.02	0.02	0.21	0.18
LSD _{p≤0.05}	0.13	0.15	0.10	0.11	NS	NS	NS	NS	0.07	0.07	NS	NS
Interactions												
LS × DOS	NS	NS	**	**	**	**	NS	NS	NS	NS	NS	NS

[Abbreviation: 1st DOS: 2 November; 2nd DOS: 7 November; 3rd DOS: 13 November; 4th DOS: 18 November; 5th DOS: 24 November; 6th DOS: 29 November; Year 1 and Year 2 represents rainy seasons of 2016 and 2017, respectively; ** Significance at $p \leq 0.01$, NS, Non-significant].

A significantly higher K uptake in seed (1.19% and 1.24% for year 1 and year 2 respectively) was obtained when *lathyrus* was grown in the medium-lowland situation. A significantly higher potassium content (1.21% and 1.23% for year 1 and year 2 respectively) in *lathyrus* seed was observed at late sown cops (24 November).

3.3. Effect of Land Situation and Date of Sowing on the Performance of Lentil

3.3.1. Effect of Land Situation, and Date of Sowing, on Yield Components and Yield of Lentil

Significantly higher numbers of pod/plant (76.17 and 84.53 respectively for year 1 and year 2) were recorded from the lentil crops sown in medium-lowland situation. Early sowing of lentil (23 November) significantly improved the number of pods/plant (88.02 and 96.25 for year 1 and year 2 respectively), which was statistically at par with the crops sown on 27 November (82.89 and 93.55 for year 1 and year 2 respectively) (Table 6). The seeds/pod and test weight of lentil were not significantly varied as influenced by land situation factors except in year 1. In the first year of experimentation, significantly higher numbers of seed pod⁻¹ (1.88) were recorded from the crops sown in the medium-lowland situation. The maximum value of seed/pod (1.90 and 2.21 for year 1 and year 2 respectively) was recorded from the crops sown on the 2nd DOS (27 November), closely followed by the crops sown on the 23rd of November and 2 December.

The variation in seed yield of lentil as influenced by the land situation factor was significant ($p \geq 0.05$) during the second year of study and the significantly higher amount of seed yield was obtained from medium-lowland situations accounting for 783.0 kg ha⁻¹. During year 1 and year 2, the maximum grain yield was obtained from 23 November (1st DOS) sown plants, which was 28.9% and 35.2% more than the grain yield derived from late sown (17 December i.e., 6th DOS) plants. Significantly the highest seed yield (912 kg/ha) was recorded under treatment combinations medium lowland × 1st DOS (2 November) in the second year of experimentation only.

Table 6. Effect of land situation and date of sowing of rice on yield attributes and yield of lentil.

Factor	Pods/Plant		Seed/Pod		Test Weight (g)		Seed Yield (kg/ha)		Stover Yield (kg/ha)		Harvest Index (%)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Land situation (LS)												
Medium upland	61.76	76.88	1.66	2.05	19.97	21.17	662.3	713.1	1759	1488	27.4	32.6
Medium lowland	76.17	84.53	1.88	2.10	19.94	21.71	668.0	783.0	1858	1761	26.4	30.8
SEm (±)	2.06	0.52	0.03	0.07	0.34	0.19	9.98	9.57	61.3	12.8	0.6	0.1
LSD _{p≤0.05}	9.25	2.34	0.12	NS	NS	NS	NS	43.08	NS	58	NS	0.6
Date of Sowing (DOS)												
1st DOS	88.02	96.25	1.80	2.18	21.39	21.47	784.7	906.9	2036	2010	27.9	31.1
2nd DOS	82.89	93.55	1.90	2.21	20.60	21.21	773.4	838.3	2009	1927	27.9	30.3
3rd DOS	63.35	72.99	1.72	2.10	19.50	20.83	693.1	759.0	1872	1644	27.1	31.7
4th DOS	65.25	81.05	1.88	1.98	19.29	22.10	612.5	748.8	1700	1538	26.4	32.9
5th DOS	59.84	70.98	1.68	2.09	19.67	21.80	569.1	647.5	1627	1402	26.1	31.7
6th DOS	54.42	69.39	1.63	1.90	19.28	21.22	558.1	588.1	1606	1225	25.9	32.7
SEm (±)	4.46	5.74	0.10	0.12	0.41	0.30	26.17	18.93	71.2	35.7	0.8	0.5
LSD _{p≤0.05}	13.44	17.31	NS	NS	1.23	NS	78.89	57.06	215	107	1.5	1.4
Interaction												
LS × DOS	NS	NS	NS	NS	NS	NS	NS	115	NS	**	NS	NS

[Abbreviation: 1st DOS: 23 November; 2nd DOS: 27 November; 3rd DOS: 2 December; 4th DOS: 7 December; 5th DOS: 12 December; 6th DOS: 17 December; Year 1 and Year 2 represents rainy seasons of 2016 and 2017, respectively; ** Significance at $p \leq 0.01$; NS; Non-significant].

In year 1, stover yield did not significantly differ by land situation factor, but in year 2 significantly ($p \leq 0.05$) higher stover yield was obtained from the plots of medium-lowland condition (1761 kg/ha), which was 15.50% more than the stover yield derived from the plots of medium upland. A significantly higher amount of stover yield was obtained from the crops from 23 November (1st DOS) sown plants in both years (2036 and 2010 kg ha⁻¹ for year 1 and year 2, respectively).

In year 1, the harvest index of lentil did not significantly differ by land situation factor, but in year 2, a significantly ($p \leq 0.05$) higher harvest index was obtained from the plots of medium-upland condition (32.8) than the crops sown in medium-lowland condition (30.8) (Table 6). Early sowing of lentil (23 November) significantly improved the harvest Index (27.9%) in the first year of study, while in the second year significantly ($p \leq 0.05$) higher harvest index was obtained from the plants sown on 7 December (32.9).

3.3.2. Effect of Land Situation, and Date of Sowing, on Macronutrient Uptake of Lentil

In both years, interactions between the land situation and sowing date revealed a non-significant impact on grain N uptake (%) (Table 7). The crop grown under medium-upland conditions recorded significantly higher stover N uptake (%) than the crop grown under the medium-lowland condition. Also, significantly higher straw N uptake (%) (1.99% and 2.11% for year 1 and year 2 respectively) was recorded from the plants under medium-upland situation sown on 12 December (5th DOS).

Phosphorus content in lentil seed differed non-significantly with the variation in land situation factor. The date of sowing factor significantly influenced P uptake in lentil seeds and stover in year 2 only and accordingly, significantly higher phosphorus content (0.44, 0.36) in lentil seed and stover respectively was observed at the early date of sowing (23 November).

Land situation and date of sowing significantly affected the potassium uptake by lentil seeds however, remained non-significant for stover potassium uptake. Significantly higher K uptake in seed (1.90% and 1.77% for year 1 and year 2 respectively) was obtained when lentil was grown in medium-lowland situation. Also, late sown crops (12 December as on 5th DOS) recorded significantly higher potassium content (1.93 and 1.80% for year 1 and year 2 respectively) in lentil seed.

Table 7. Effect of land situation and date of sowing of rice on macronutrient uptake of lentil.

Factors	Nitrogen Uptake				Phosphorous Uptake				Potassium Uptake			
	Grain (%)		Stover (%)		Grain (%)		Stover (%)		Grain (%)		Stover (%)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Land Situation (LS)												
Medium upland	3.71	3.93	1.79	1.94	0.36	0.39	0.30	0.33	1.73	1.66	2.33	2.68
Medium lowland	3.79	4.06	1.63	1.77	0.38	0.42	0.29	0.31	1.90	1.77	2.47	2.66
SEm ($\pm$)	0.04	0.06	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.02	0.06	0.06
LSD _{p≤0.05}	NS	NS	0.09	0.07	NS	NS	NS	NS	0.12	0.09	NS	NS
Date of Sowing (DOS)												
1st DOS	3.93	4.18	1.69	1.83	0.40	0.44	0.33	0.36	1.77	1.66	2.36	2.84
2nd DOS	3.77	4.02	1.83	1.99	0.38	0.42	0.29	0.32	1.85	1.76	2.36	2.73
3rd DOS	3.75	3.99	1.63	1.77	0.37	0.40	0.29	0.32	1.65	1.60	2.18	2.61
4th DOS	3.68	3.91	1.59	1.74	0.34	0.37	0.28	0.31	1.88	1.75	2.37	2.60
5th DOS	3.67	3.90	1.87	2.03	0.37	0.41	0.28	0.30	1.93	1.80	2.63	2.49
6th DOS	3.70	3.97	1.64	1.79	0.37	0.40	0.28	0.31	1.82	1.72	2.49	2.73
SEm ($\pm$)	0.04	0.05	0.05	0.06	0.01	0.01	0.01	0.02	0.04	0.03	0.15	0.15
LSD _{p≤0.05}	0.13	0.15	0.16	0.18	NS	0.04	NS	0.05	0.12	0.10	NS	NS
Interactions												
LS $\times$ DOS	NS	NS	**	**	**	**	**	**	**	**	**	**

[Abbreviation: 1st DOS: 23 November; 2nd DOS: 27 November; 3rd DOS: 2 December; 4th DOS: 7 December; 5th DOS: 12 December; 6th DOS: 17 December; Year 1 and Year 2 represents rainy seasons of 2016 and 2017, respectively ** Significance at $p \leq 0.01$; NS, Non-significant].

3.4. System Performance of Different Rice-Pulse Based Cropping Systems

3.4.1. Rice Equivalent Yield (REY) of Different Pulse Crop under the Rice-Pulse Cropping System

Rice equivalent yield (kg ha^{-1}) of different winter pulse crops in the sequence was estimated after the completion of the cropping cycle of two years, and it varied significantly with the variation in land situation and date of sowing. The relevant data are summarized in Table 8. Both the pulse crops (*lathyrus* and lentil) grown under medium-low-land conditions recorded significantly higher Rice Equivalent Yield (REY) than the pulse crops grown in the medium-lowland condition.

Table 8. Effect of land situation and date of sowing on rice equivalent yield (REY) of the winter pulse crops in the sequence (pooled data of two years).

Treatments	Rice Equivalent Yield (kg/ha)	
	<i>Lathyrus</i>	Lentil
Land situation (LS)		
Medium—upland	1379.6	1615.0
Medium—lowland	1486.8	1708.1
SEm ($\pm$)	8.90	16.20
LSD _{p≤0.05}	30.7	56.0
Date of Sowing (DOS)		
1st DOS	1750.5	1990.4
2nd DOS	1565.1	1892.8
3rd DOS	1451.7	1705.9
4th DOS	1358.4	1604.4
5th DOS	1298.0	1430.8
6th DOS	1175.3	1345.0
SEm ($\pm$)	30.7	37.2
LSD _{p≤0.05}	88.6	107.4

[Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July].

The date of sowing significantly ($p < 0.05$) influenced the REY of different pulse crops grown under rice-pulse based cropping systems (Table 8). *Lathyrus* and lentil, sown on ear-

lier dates (after harvesting of 1st and 2nd DOS sown rice i.e., 2 November and 7 November for *lathyrus* and 23 November and 27 November for lentil), recorded significantly higher values of REY (Table 8). It was observed that in comparison to the delayed sown pulse crops, early sown ones recorded 48.9% (for *lathyrus*) and 47.0% (for lentil) higher REY.

3.4.2. System Productivity and Production Efficiency of the Rice-Pulse Cropping Systems

The maximum system productivity and production efficiency were obtained from the crops grown under the medium-lowland situation. On the other hand, crops sown on earlier days i.e., 1st and 2nd date of sowing, recorded significantly higher system productivity and production efficiency. Interestingly the crops sown on the 1st sowing date recorded 23.4% and 20.18% higher system productivity and production efficiency, respectively as compared to the crops sown on the 6th sowing date.

Amongst different cropping systems, the rice-lentil system recorded higher system productivity (6552 kg/ha) than the rice-*lathyrus* system (6324 kg/ha). On the other hand, significantly higher production efficiency was recorded from the rice-*lathyrus* system (25.05 kg/ha/day) than the rice-lentil system (24.88 kg/ha/day) (Table 9).

Table 9. Effect of land situation, date of sowing and cropping system on system productivity and production efficiency of the cropping systems (pooled data of two years).

Factors	System Productivity (kg/ha)	Production Efficiency (kg/ha/day)
Land Situation (LS)		
Medium upland	6242	24.48
Medium lowland	6634	25.44
SEm ($\pm$)	52.5	0.20
LSD _p $\leq$ 0.05	236.2	0.92
Date of Sowing (DOS)		
1st DOS	7316	27.75
2nd DOS	6975	26.63
3rd DOS	6523	25.25
4th DOS	6331	24.76
5th DOS	5881	23.22
6th DOS	5603	22.15
SEm ($\pm$)	64.0	0.25
LSD _p $\leq$ 0.05	193.0	0.75
Cropping System (CS)		
Rice- <i>Lathyrus</i>	6324	25.05
Rice-Lentil	6552	24.88
SEm ($\pm$)	9.8	0.04
LSD _p $\leq$ 0.05	44.0	0.13

[Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July].

3.4.3. Economics of the Cropping Systems

In both the cropping systems, crops sown on earlier sowing date recorded higher gross return (GR), net return (NR), and B:C ratio (Supplementary Tables S2 and S3). Irrespective of the land situation, delay in sowing markedly decreased the economic return and thus the least NR and B:C ratio was obtained from the crops sown on the 6th sowing date (29 November for *lathyrus* and 17 December for lentil). On the other hand, crops grown under the medium-lowland conditions recorded higher GR and NR. Amongst different cropping systems, the highest economic return and B:C ratio (2.10) was obtained from the rice-*lathyrus* system when crops were sown on the 1st DOS under medium-lowland condition and this system was closely followed by the rice-lentil system (2.05) grown with same treatment combination.

3.4.4. Soil Properties and Nutrient Status after Completion of Two Years Cropping Sequence

The chemical properties i.e., organic carbon (%) and nutritional status (kg/ha) of initial soil; the soil after the harvest of 4th crop in sequence and the extent of increment or depletion of organic carbon and nutrients (N, P, and K) from the soil as compared to their initial values (in parenthesis) under the different land situation, and date of sowing factors are presented in Table 10.

Table 10. Organic carbon and nutrient status in final soil along with the extent of their total increase (+) or decrease (−) in the soil after the completion of two years (0–15 cm).

Factor	Rice-Lathyrus System						Rice-Lentil System					
	Organic Carbon (%)	Macronutrients (kg/ha)			pH	EC _{1:5} (dS/m)	Organic Carbon (%)	Macronutrients (kg/ha)			pH	EC _{1:5} (dS/m)
		N	P ₂ O ₅	K ₂ O				N	P ₂ O ₅	K ₂ O		
Medium upland												
1st DOS	0.57 (+0.07)	203 (+78)	22.3 (+8.0)	396 (−49)	6.59 (+1.14)	1.09 (+0.87)	0.52 (+0.02)	196 (+71)	23.8 (+9.5)	418 (−27)	7.40 (+1.95)	1.16 (+0.94)
2nd DOS	0.52 (+0.02)	198 (+73)	20.2 (+5.9)	460 (+15)	7.19 (+1.74)	1.14 (+0.92)	0.51 (+0.01)	194 (+69)	21.1 (+6.8)	405 (−40)	7.34 (+1.89)	1.33 (+1.11)
3rd DOS	0.53 (+0.03)	183 (+58)	20.1 (+5.8)	405 (−40)	7.49 (+2.04)	1.29 (+1.07)	0.55 (+0.05)	182 (+57)	21.1 (+6.8)	423 (−22)	7.25 (+1.80)	1.38 (+1.16)
4th DOS	0.52 (+0.02)	136 (+11)	19.6 (+5.3)	416 (−29)	6.93 (+1.48)	1.41 (+1.19)	0.51 (+0.01)	150 (+25)	20.3 (+6.0)	417 (−28)	7.40 (+1.95)	1.30 (+1.08)
5th DOS	0.53 (+0.03)	167 (+42)	21.0 (+6.7)	466 (−21)	7.31 (+1.86)	1.37 (+1.25)	0.52 (+0.02)	150 (+25)	21.0 (+6.7)	473 (+28)	6.77 (+1.32)	1.46 (+1.24)
6th DOS	0.51 (+0.01)	152 (+27)	20.3 (+6.0)	451 (−6)	7.42 (+1.25)	1.47 (+1.25)	0.50 (0.0)	140 (+15)	22.2 (+7.9)	462 (+17)	7.68 (+2.23)	1.44 (+1.22)
Medium lowland												
1st DOS	0.56 (+0.05)	293 (+155)	25.6 (+1.7)	461 (−4)	6.66 (+1.00)	1.13 (+1.00)	0.48 (−0.03)	282 (+144)	22.3 (−1.6)	418 (−47)	7.03 (+1.38)	1.25 (+1.12)
2nd DOS	0.44 (−0.07)	231 (+93)	22.3 (−1.6)	474 (−9)	6.39 (+1.08)	1.21 (+1.08)	0.44 (−0.08)	236 (+98)	23.3 (−0.6)	492 (+27)	6.90 (+1.25)	1.26 (+1.13)
3rd DOS	0.47 (−0.05)	260 (+122)	19.8 (−4.1)	434 (−31)	7.39 (+1.09)	1.22 (+1.09)	0.43 (−0.08)	276 (+138)	19.8 (−4.2)	425 (−40)	7.29 (+1.64)	1.31 (+1.18)
4th DOS	0.48 (−0.03)	191 (+53)	22.1 (−1.8)	436 (−29)	6.32 (+1.21)	1.34 (+1.21)	0.48 (−0.03)	216 (+78)	19.2 (−4.7)	402 (−53)	6.48 (+0.83)	1.28 (+1.15)
5th DOS	0.55 (+0.04)	210 (+72)	23.6 (−0.3)	431 (−34)	6.69 (+1.24)	1.37 (+1.24)	0.48 (−0.03)	213 (+75)	19.0 (−4.9)	408 (−57)	6.84 (+1.19)	1.38 (+1.25)
6th DOS	0.58 (+0.07)	194 (+56)	19.9 (−4.0)	426 (−39)	6.43 (+1.25)	1.38 (+1.25)	0.52 (+0.01)	205 (+67)	19.1 (−4.8)	427 (−38)	6.72 (+1.07)	1.42 (+1.29)

+, −: increment/decrement of the soil parameter from the initial soil data. [Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July; DOS, Days of sowing].

Irrespective of the date of sowing and cropping system, the organic carbon content of the post-harvest soil did not vary much with respect to initial soil status. However, higher values of soil available N, P, and K were derived from the early sown plots. The maximum increment of soil available N (+155 kg/ha) was recorded from the rice-lathyrus system grown under medium-lowland conditions when crops were sown on respective 1st date (15 June for rice and 2 November for lathyrus) and it was followed by the rice-lentil system (+144 kg/ha) with same treatment combinations.

3.5. Dynamic of Gravimetric Water Content, Soil Salinity and Solute Potential at Various Depths

In both land situations, the gravimetric moisture content at different soil depths of 0–15, 15–30, 30–50, 50–80, and 80–120 cm was observed (Figures 2 and 3). During the middle of February, the moisture content was seen to drop slightly and follow a constant dynamic thereafter. In contrast, soil salinity across all the soil depths tends to increase until the middle of February followed by a fall soon after in both years. With the drying of soil, the solute potential steadily decreased (negative) for entire soil depths until the middle of February followed by increase in value soon after. During the mid to end of February due

to the occurrence of rainfall, gravimetric water content and salinity level tend to decrease. However, an increasing trend was observed in the case of solute potential of the soil at various depths.

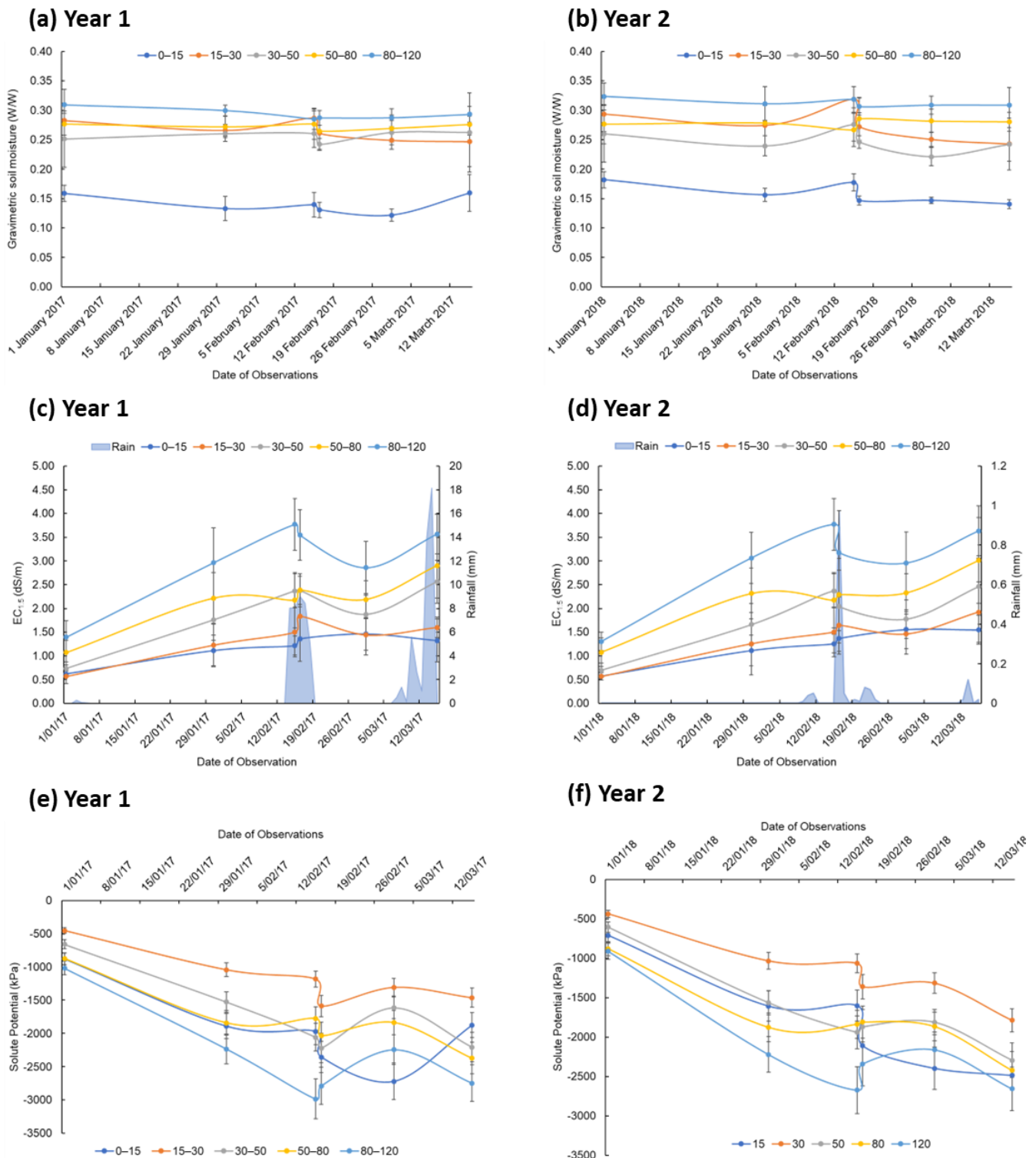


Figure 2. Gravimetric soil moisture (a,b), Soil Salinity level (c,d) and solute potential (e,f) at various depths of soil at medium-upland situation during the cropping seasons.

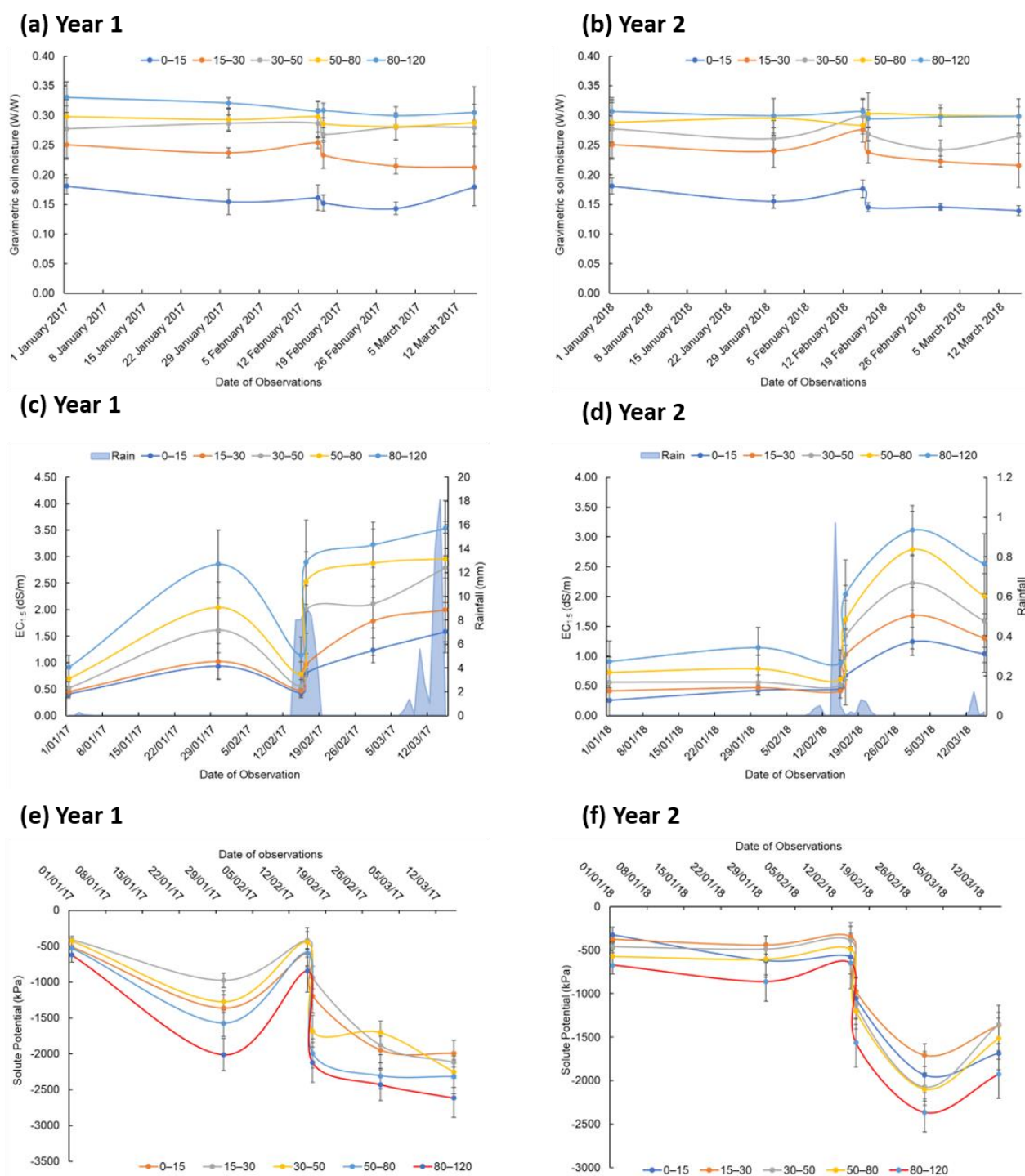


Figure 3. Gravimetric soil moisture (a,b), Soil Salinity level (c,d) and solute potential (e,f) at various depths of soil at medium-lowland situation during the cropping seasons.

3.6. Relationship between Seed Yield and Soil Factors (Gravimetric Water Content, Salinity, and Solute Potential)

The effect of gravimetric moisture content on the seed yield of *lathyrus* and lentil on both land situations in the experimental years seem to be non-significant. The relationship between salinity and seed yield of *lathyrus* was recorded to be negative under various land situations in the experimental period. However, a positive linear correlation was observed between solute potential and seed yield of *lathyrus* in both experimental years (Tables 11 and 12).

Table 11. Relationship between *lathyrus* seed yield and soil factors (Gravimetric soil moisture [GSM], soil salinity [SS], and solute potential [SP]) under rice-*lathyrus* cropping system during 2017–2018 and 2018–2019 growing seasons.

Independent Factors	Regression Equation	100R ² Value	Significant Level
Year 1			
GSM Medium Upland	$y = 589.8\text{GSM} + 625.8$	-	NS
Soil Salinity Medium Upland	$y = -237.7\text{SS} + 922.5$	91(−)	**
Solute Potential Medium Upland	$y = 0.112\text{SP} + 926.9$	36(+)	*
GSM Medium Lowland	$y = 3505.6\text{GSM} + 244.9$	-	NS
Soil Salinity Medium Lowland	$y = -235.4\text{SS} + 1004.0$	73(−)	*
Solute Potential Medium Lowland	$y = 0.175\text{SP} + 1013.7$	74(+)	**
Year 2			
GSM Medium Upland	$y = 7412.6\text{GSM} - 202.69$	-	NS
Soil Salinity Medium Upland	$y = -299.2\text{SS} + 1339.5$	70(−)	**
Solute Potential Medium Upland	$y = 0.183\text{SP} + 1302.2$	0.84(+)	**
GSM Medium Lowland	$y = 6877.1\text{GSM} - 62.9$	-	NS
Soil Salinity Medium Lowland	$y = -281.7\text{SS} + 1208.8$	70(−)	*
Solute Potential Medium Lowland	$y = 0.170\text{SP} + 1192.0$	74(+)	**

Note: “+” indicates a positive correlation while “−” indicates a negative relationship. Abbreviations: NS, nonsignificant, **, * Significance at 1%, and 5% levels of probabilities, respectively; Year 1 and Year 2 represents rainy seasons of 2016 and 2017, respectively.

Table 12. Relationship between lentil seed yield and soil factors (Gravimetric soil moisture [GSM], soil salinity [SS], and solute potential [SP]) under rice-lentil cropping system during 2017–2018 and 2018–2019 growing seasons.

Independent Factors	Regression Equation	100R ² Value	Significant Level
Year 1			
GSM Medium Upland	$y = 1141.5 \text{ GSM} + 463.7$	-	NS
Soil Salinity Medium Upland	$y = -176.6\text{SS} + 821.1$	80(−)	**
Solute Potential Medium Upland	$y = 0.10\text{SP} + 858.9$	47(+)	**
GSM Medium Lowland	$y = 2376 \text{ GSM} + 286.43$	-	NS
Soil Salinity Medium Lowland	$y = -219.8\text{SS} + 865.8$	84(−)	**
Solute Potential Medium Lowland	$y = 0.164\text{SP} + 876.6$	90(+)	**
Year 2			
GSM Medium Upland	$y = 7887 \text{ GSM} - 534.3$	-	NS
Soil Salinity Medium Upland	$y = -350.1\text{SS} + 1145.9$	71(−)	**
Solute Potential Medium Upland	$y = 0.21\text{SP} + 1096.2$	83(+)	**
GSM Medium Lowland	$y = 4584 \text{ GSM} - 63.72$	-	NS
Soil Salinity Medium Lowland	$y = -182.21\text{SS} + 907.7$	68(−)	**
Solute Potential Medium Lowland	$y = 0.11\text{SP} + 897.9$	72(+)	**

Note: “+” indicates a positive correlation while “−” indicates a negative relationship. Abbreviations: NS, nonsignificant, ** Significance at 1% levels of probabilities, respectively; Year 1 and Year 2 represents rainy seasons of 2016 and 2017, respectively.

3.7. Redundancy Analysis

Redundancy analysis (RDA) clearly explained the independent-dependent set correlations and cumulative percentage variance (dependent and independent-dependent set relation) of different growth and yield contributing parameters of rice affected by different sources of variations (date of sowing, land situations and year). Amongst the different sources of variations, the date of sowing of rice explained 48.5% of cumulative percentage variance (independent –dependent set relation) while land situation explained 43.1% variation on growth and yield components of rice (Supplementary Table S4). On the other hand, the year had an 8.4% contribution to total variation. Biplot analysis (Figure 4) clearly indicates that delay in sowing/transplanting of rice results in a reduction in dry

matter accumulation and also significantly reduced grain yield by fewer numbers of filled grain/panicle, reduced test weight (1000 seed weight) and harvest index. Thus, early sowing of rice should be recommended for its higher grain yield and timely inclusion of winter crops with better utilization of retained soil moisture.

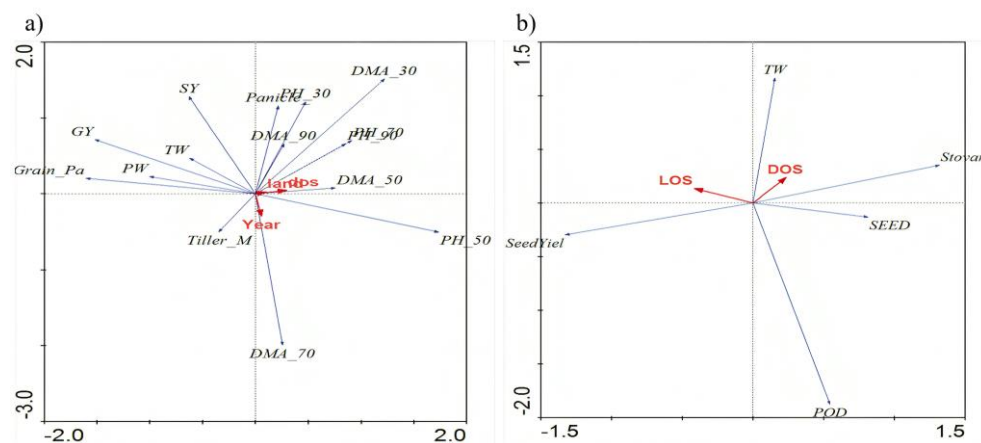


Figure 4. (a) Biplot analysis showing effect of date of sowing of rice on its growth parameters and yield (Abbreviations: DMA, Dry matter accumulation/m²; PH, Plant height, Panicle_, Panicle length; Tiller_m, Tiller/m; Straw_Yi, Straw yield/ha; Grain_Yi, Grain yield/ha, Test_Wei, Test weight (g); dos, Date of Sowing; Year, Year of Experiment); (b) Biplot analysis showing effect of date of sowing, land situation and year on yield and yield components of pulses (Abbreviations: SeedYield, Seed Yield of Pulse; SEED, Seed/pod, POD, Pod/plant, TW, test weight, Stover, Stover yield, TW, 1000 seed weight (g); dos, Date of Sowing; land, land situation).

RDA clearly also explained the independent-dependent set correlations and cumulative percentage variance of different growth and yield contributing parameters of different pulses (*lathyrus* and *lentil*) as affected by different sources of variations (the date of sowing, land situations and year). Amongst the different sources of variations date of sowing explained 75.2% of cumulative percentage variance (independent–dependent set relation) while land situation explained 24.8% variation on growth and yield components of pulses (Supplementary Table S5). On the other hand, the experimental year factor had no such contribution in regulating the yield components of pulse crops. Biplot analysis (Figure 4) clearly indicates that delay in sowing/transplanting results in a reduction of seed yield, seed/pod. Crops grown under the medium-lowland situation also performed better than those crops grown under the medium-upland situation. Thus, early sowing of pulse crops must be advocated for better utilization of residual soil moisture and escaping mid-season salinity stress.

4. Discussion

4.1. Vegetative Growth Responses of Rice

The height of the plant is an important growth character directly linked with the productive potential of the plant [35]. The plant height of rice progressively increased with increasing growth period from 30 to 90 DAT. Crop sown on later dates (12 July and 19 July) recorded significantly lower plant height than that sown on earlier dates (15 June to 21 June). On the other hand, on all dates of observations, crops grown under medium-lowland situations recorded significantly ($p < 0.05$) higher plant height than crop sown under medium-upland conditions. This result agrees with the findings of other investigators [36–38] who also observed a significant increase in plant height with early planting. The comparatively higher rate of photosynthesis and a lower rate of thermophoto effect caused higher conservation of photosynthates, which in turn was concomitant with favorable climatic conditions in early sown rice. The more the delay there was in sowing, the more reduction in plant height was observed. In case of late sowing, under

high temperature, the plant passes its growth stages faster and it would end its vegetative growth earlier and thus has a lower height. Delayed sown crops (15 July) might have experienced the effect of uncongenial low and high temperature coincided with the growth and reproductive phases, respectively, and ultimately resulted in untimely and forced maturity and low LAI [38].

Biomass accumulation is a good measure of competitive success because it reflects resource capture under the interference of neighbors. Correlations between rice grain yield and above-ground biomass (Figure 5) were highly significant ($R^2 = 0.81^{**}$). These results indicated that the grain yield of rice is largely dependent on above-ground biomass and biomass partitioning in grain/sink, and finally increase in an AGB level enhanced the grain yield of rice. The delay in sowing time can directly reduce the above-ground biomass of rice in different ways. Firstly, delays in the sowing date hastened the development between emergence and tillering, as well as decreased the cumulative incident radiation on the crop during the vegetative period. Secondly, the inferior attributes observed in delayed sowing may be attributed to the short period of vegetative growth and the adverse weather conditions, such as temperature, relative humidity, and solar radiation, which did not match the optimum degree for the vegetative and reproductive stages; as a consequence, low levels of photosynthetic products accumulated [39].

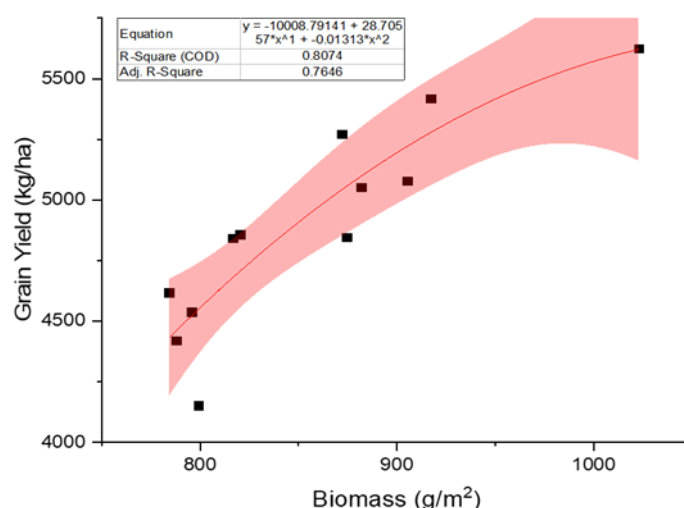


Figure 5. Relationship between grain yield (kg/ha) and above ground biomass (g/m²) of rice as influenced by land situation and date of sowing (based on mean data of two years).

4.2. Yield Attributes of Crops

Significantly higher amounts of grain and straw yield were obtained from the crops grown in the medium-lowland situation than that from the crop grown in the medium-upland situation. The crop sown on 1st sowing date produced 25.4% higher grain yield than the crop sown on the final sowing date (6th DOS: 15 July). A delay in the sowing rice beyond the optimum sowing window significantly reduced the straw yield of rice. The yield components and yield of rice were significantly higher when the crop was grown under medium-lowland condition. It was observed that the depth and duration of surface water ponding were significantly higher in medium-lowland conditions helping in rapid nutrient transformation, reduction in weed growth and end-season salinity stress. Optimal sowing time is a crucial factor influencing crop yield. Previous studies have demonstrated that delaying the sowing of rice beyond the optimal window can adversely impact crop yield [40]. This improvement in performance of early sown crops may be attributed to the greater remobilization of resources, likely linked to increased dry matter accumulation at anthesis, thereby enhancing the potential for dry matter remobilization [40,41]. Agrometeorological factors such as air temperature, solar radiation, and the seasonal distribution of rainfall also significantly influence the yield of rainy season rice [42,43].

Pulse crops grown in the medium-lowland situation recorded a higher number of pod/plant than the pulses grown under medium-upland conditions. *Lathyrus* and lentil sown on earlier dates (2 November and 7 November for *lathyrus* and 23 November and 27 November for lentil) recorded significantly higher amounts of pods/plants. It was noticed that delay in harvesting of rice significantly reduced pod/plant of the pulse crops by delaying the sowing of the succeeding crops. It was also observed that early sowing of pulse crops recorded 30.0% (from *lathyrus*) and 48.8% (for lentil) higher number of pod/plant than the delayed sown pulse crop produced. Pulses grown under the medium-lowland situation recorded a higher number of seeds/pods than those grown under medium-upland conditions. Extreme temperature vis-à-vis the occurrence of terminal moisture and salinity stress during the grain-filling period has been identified as a major source of variation in the seed yield of *lathyrus* and lentil [44]. These results may be corroborated with the findings of [45] who evaluated that the yield components (grain number per plant, pod number) of different lentil genotypes were significantly affected by planting dates. Ref. [46] also found that irrespective of the varieties, sowing of lentil between 1 November and 10 November was found to be advantageous and any delay in sowing may cause significant yield reduction in lentil. The different growth and yield attributes of rice and pulses (*lathyrus* and lentil) has recorded a positive and significant correlation (presented as heatmap) (Supplementary Figure S6).

4.3. Macronutrient Uptake by Rice

A significantly higher NPK uptake (%) was recorded in the crops grown under medium-lowland conditions than in crops grown under medium-upland conditions. A significantly higher NPK content in rice grains was observed at early dates of sowing (1st and 2nd date of sowing). Higher N content in rice straw was observed when rice was sown late (5 July–19 July). Correlations between grain yield and grain N uptake, grain yield and grain P uptake, and grain yield and grain K uptake (Figure 6) were revealed to be positive and of significant relationship ($R^2 = 0.66$, 0.25 and 0.27, respectively). On the other hand, correlations between grain yield and straw N uptake, and grain yield and straw P uptake were revealed to be significant and have a negative relationship ($R^2 = 0.55$ and 0.17, respectively). These results indicated that the grain yield of rice is largely reliant on efficient and rapid partitioning of plant nutrients from source (leaf and other plant organs) to sink (grain). Interestingly, correlation between grain yield and straw K uptake (Figure 6) was significant and a positive relationship was recorded ($R^2 = 0.14$), which might be due to the luxury consumption of K in straws of rice.

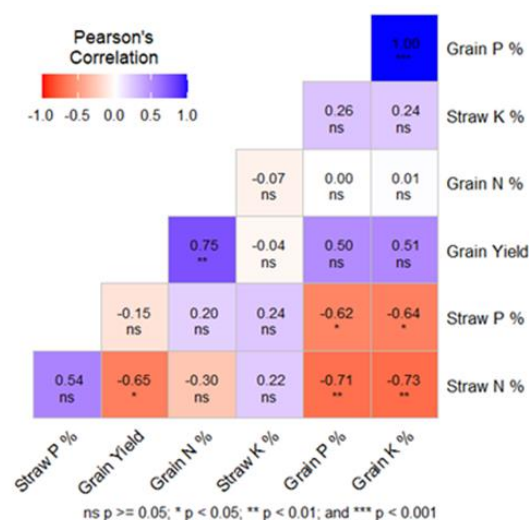


Figure 6. Heatmap showing the correlation between rice grain yield and macro nutrient uptake by grain and straw of rice.

Crops grown under medium-lowland conditions recorded significantly higher nutrient efficiency indices (both NHI and NEMI) than crops grown under medium-upland condition. In coordination with the grain NPK uptake, significantly higher nutrient efficiency indices (both NHI and NEMI) of rice were observed at early dates of sowing (15 and 21 June) (Figure 7).

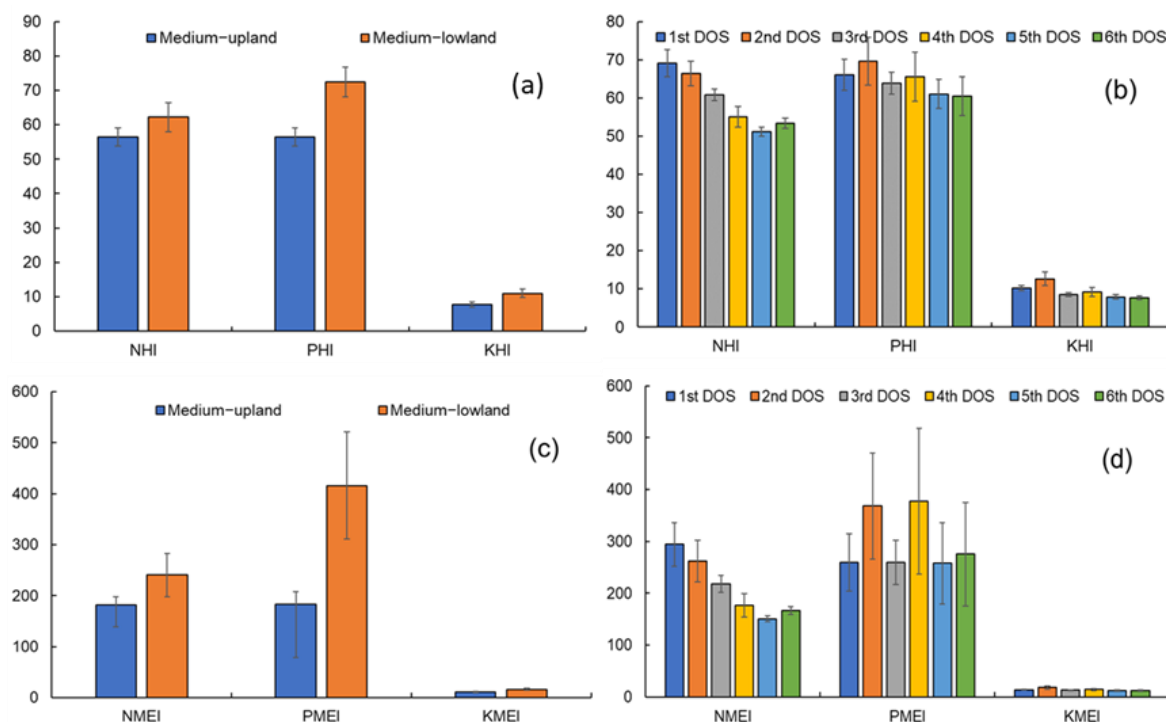


Figure 7. Nutrient harvest index (NHI) and Nutrient Mobilization Efficiency Index (NMEI) of rice as influenced by (a) land situation and (b) date of sowing; Nutrient mobilization efficiency index of rice as influenced by (c) land situation and (d) date of sowing (based on the mean data of year 1 and year 2) [Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July].

An assured supply of soil moisture during the vegetative growth period of the crop may boost the initial crop growth with profuse a root system. Thus, the crops grown under medium-lowland situations exhibited higher vegetative growth which leads to better uptake and partitioning of plant nutrients than the crops grown under medium-upland conditions. Better nutrient uptake, as observed in early sown crop, may probably be attributed to the development of an efficient root system with improved permeability coupled with better absorption and translocation of water and macronutrients, interception of solar radiation and assimilation of carbon dioxide when the crop sown on the optimum date [47].

4.4. Macronutrient Uptake by Pulses

Nutrient efficiency indices (NHI and NMEI) of different macronutrients (NPK) of winter pulses (*lathyrus* and lentil) were also significantly affected by land situation and sowing date factors. Crops grown under medium-lowland condition recorded considerably higher nutrient efficiency indices (both NHI and NEMI) than crops grown under medium-upland condition. In synchronization with the seed NPK uptakes, significantly higher nutrient efficiency indices (both NHI and NEMI) were observed from early sown (1st and 2nd date of sowing) pulse crops (Figures 8 and 9). A judicious supply of soil nutrient vis-a-vis moisture is greatly beneficial to the growth and development of the winter pulses. Thus, higher vegetative growth with profuse a root system is always positively correlated

with the better uptake of macronutrients and their efficient partitioning from the sink to the source [2]. In coordination with the preceding rice crop, winter pulses (*lathyrus* and lentil) grown under medium-lowland situation exhibited higher vegetative growth resulting in better nutrient uptake and translocation of photosynthates than the crops grown under medium-upland condition.

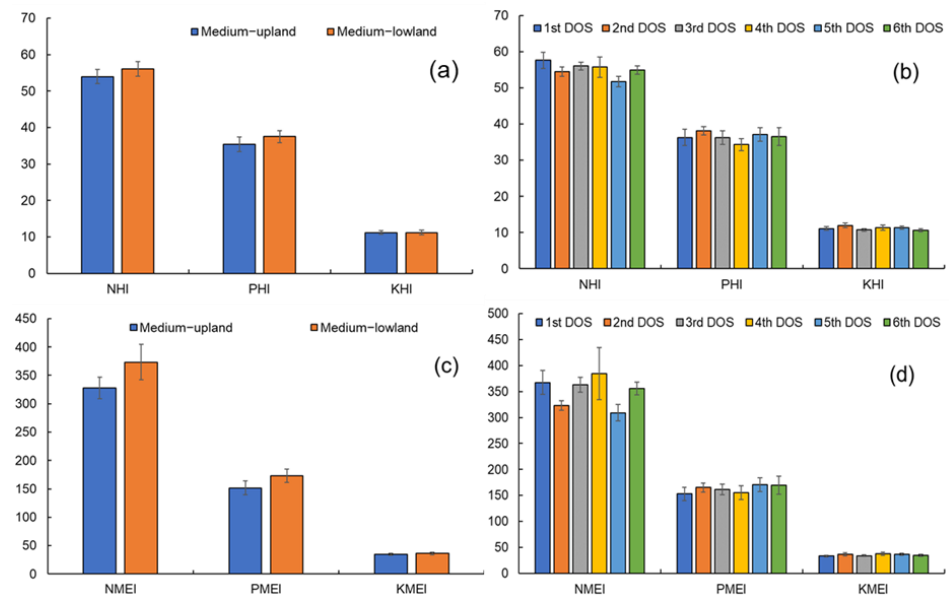


Figure 8. Nutrient harvest index (NHI) and Nutrient Mobilization Efficiency Index (NMEI) of *lathyrus* as influenced by (a) land situation and (b) date of sowing; Nutrient mobilization efficiency index of rice as influenced by (c) land situation and (d) date of sowing (based on the mean data of year 1 and year 2) [Abbreviation: 1st DOS: 2 November; 2nd DOS: 7 November; 3rd DOS: 13 November; 4th DOS: 18 November; 5th DOS: 24 November; 6th DOS: 29 November; DOS, Days after sowing].

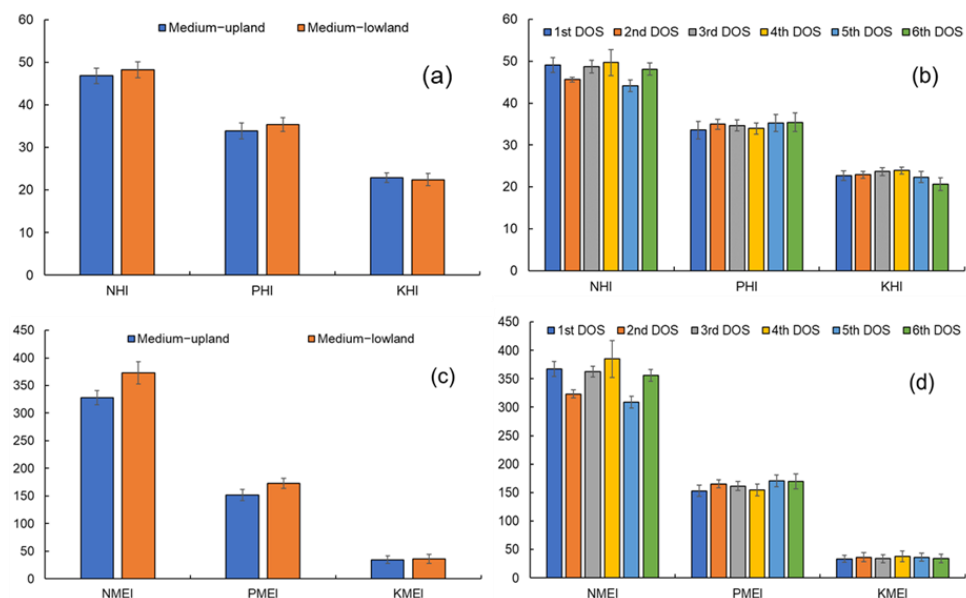


Figure 9. Nutrient harvest index (NHI) and Nutrient Mobilization Efficiency Index (NMEI) of *lentil* as influenced by (a) land situation and (b) date of sowing; Nutrient mobilization efficiency index of rice as influenced by (c) land situation and (d) date of sowing (based on the mean data of year 1 and year 2) [Abbreviation: 1st DOS: 23 November; 2nd DOS: 27 November; 3rd DOS: 2 December; 4th DOS: 7 December; 5th DOS: 12 December; 6th DOS: 17 December; DOS, Days after sowing].

4.5. Effect of Soil Factors (Gravimetric Soil Moisture, Soil Salinity and Solute Potential) on Yield of Pulses

In both years, crops sown later experienced increasing deficits of soil water and higher electrical conductivity of the soil extract (ECe), both of which restricted nutrient uptake [48]. Crops grown under medium-upland conditions exhibited higher solute potential (more negative value), likely due to lower soil moisture and higher salinity content. In both seasons, soil salinity, irrespective of land situation, showed a strong significant but negative correlation with the growth of pulse crops ($r^2 = 0.70\text{--}0.91$) (Tables 11 and 12). The most critical phase in the life cycle of pulses cultivated in saline environments is seed germination and the early development of seedlings. Saroj et al. [49] suggested that reduced germination under saline conditions could be due to increased osmotic pressure of the soil solution, which diminishes absorption rates and causes moisture stress in the seeds. Additionally, the influx of ions in large quantities could be toxic to seed embryos. Ref. [50] proposed that increased soil salinity impedes nitrogen mineralization and nitrification, further restricting nitrogen uptake and resulting in reduced yield. Solute potential (SP), a combined effect of salt stress and soil water deficit, is another critical stressor affecting pulse growth and development in the coastal zone of the Ganges Delta [51]. Lower SP (i.e., more negative values) impedes the uptake of water and nutrients by roots from the soil [52]. Lower SP values (> -700 kPa) from flowering to seed development in later sowing restrict water and nutrient uptake, resulting in fewer seeds per head, smaller seed size, and reduced seed yield. Yield attributes (pods per plant, branches per plant, and seeds per pod) and overall yield decline with lower SP in sunflower, as reported by [51,53]. Among the different land situations, pulses sown under medium-lowland conditions recorded a higher association with solute potential compared to crops grown under medium-upland conditions. Soil water uptake by plants is directly related to the total water potential created in the root zone of the plant which is governed by together the solute potential and the soil matric potential of the soil solutions [54]. In addition, the solute potential of the soil entirely depends on the salt percentage in the soil, while inversely proportional to the soil moisture content [54,55]. Thus, understanding the solute water potential is crucial for the seasonal salinity dynamics of the coastal saline zone.

5. Conclusions

From this extensive, two year environmental study of two rice-based cropping systems (rice-lathyrus and rice-lentil), the following can be concluded:

- The date of sowing significantly influenced the growth and yield attributes of rice in both years of experimentation. Significantly higher productions were obtained from medium lowland situations for both cropping systems.
- Irrespective of the land situation, rice sown on 15 June and 21 June recorded significantly higher grain yields.
- The date of sowing of rice and the land situation significantly influenced the seed and stover yield of different pulse crops. Irrespective of land situations, pulse crops sown on early dates recorded significantly higher seed yield.
- The te of sowing has influenced macro-nutrient uptake (NPK) in rice and pulse grains. In both the land situations, higher NPK content in rice grains was observed at an early date of sowing (15 June and 21 June). Amongst the pulse crops, *lathyrus* performed better than others due to its higher moisture and salinity stress tolerance capacity.
- A vivid understanding of the soil salinity and solute potential is crucial to the intensity of the rice-based cropping system in the coastal saline zone of the Indian Sundarbans.

Thus, earlier sowing improves the yield of an NUE of rice-pulse based cropping system in the wet and saline clay soils due to fewer crop stresses (soil water, soil salinity, soil solute potential, air temperature etc.) than with delayed sowing.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/soilsystems8030090/s1>, Table S1: Selling price of different

crops [56,57]; Table S2: Effect of land situation and date of sowing on economics of the crops under rice-lathyrus cropping system (based on mean data of two years); Table S3: Effect of land situation and date of sowing of economics of the crops under rice-lentil cropping system (based on mean data of two years); Table S4: RDA explaining the effect of date of sowing and land situation on growth and yield components of rice; Table S5: RDA explaining the effect of date of sowing and land situation on grain yield of pulse crops; Table S6: ANOVA table of yield attributes of the rice plant (Year 1); Table S7: ANOVA table of yield attributes of the Rice (Year 2); Table S8: ANOVA table of yield attributes of the Lentil (Year 1); Table S9: ANOVA table of yield attributes of the Lentil (Year 2); Table S10: ANOVA table of yield attributes of the *Lathyrus* (Year 1); Table S11: ANOVA table of yield attributes of the *Lathyrus* (Year 2); Figure S1: Location Map of the experimental site (Map was prepared with QGIS 3.10 Open-source Software, not for commercial use); Figure S2: Ponding depths during rice crops across different land situations were presented (Fig. a. year 1; Fig. b. year 2); Figure S3: Effect on plant height of rice as influenced by (a) land situation, (b) date of sowing; [Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July; DAT, Days after transplanting]; Figure S4: Effect on aerial dry biomass of rice as influenced by (a) land situation, (b) date of sowing [Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July; DAT, Days after transplanting]; Figure S5: Effect on LAI of rice as influenced by (a) land situation, (b) date of sowing [Abbreviation: 1st DOS: 15 June, 2nd DOS: 21 June, 3rd DOS: 28 June, 4th DOS: 5 July, 5th DOS: 12 July, 6th DOS: 19 July; DAT, Days after transplanting]; Figure S6: Correlation analysis between different growth and yield attributes of crops.

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