Supplementing Nitrogen in Combination with Rhizobium Inoculation and Soil Mulch in Peanut (Arachis hypogaea L.) Production System: Part II. Effect on Phenology, Growth, Yield Attributes, Pod Quality, Profitability and Nitrogen Use Efficiency

Mousumi Mondal 1, Milan Skalicky 2, Sourav Garai 1, Akbar Hossain 3,*, Sukamal Sarkar 1, Hirak Banerjee 1, Rajib Kundu 1, Marian Brestic 2,4,*, Celaleddin Barutcular 5, Murat Erman 6, Ayman EL Sabagh 6,7 and Alison M. Laing 8

1 Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Nadia 741252, West Bengal, India; mou.mousumi98@gmail.com (M.M); garai.sourav93@gmail.com (S.G); sukamalsarkarc@yahoo.com (S.S); hirak.bckv@gmail.com (H.B.); rajibagro2007@gmail.com (R.K.)
2 Department of Botany and Plant Physiology, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Kamycka 129, 16500 Prague, Czech Republic; skalicky@af.czu.cz
3 Bangladesh Wheat and Maize Research Institute (BWMRI), Dinajpur 5200, Bangladesh
4 Department of Plant Physiology, Slovak University of Agriculture, Tr. A. Hlinku 2, 94901 Nitra, Slovakia
5 Department of Field Crops, Faculty of Agriculture, University of Çukurova, Sarıçam/Adana 01250, Turkey; cbarutcular@gmail.com
6 Department of Field Crops, Faculty of Agriculture, Siirt University, Siirt 56100, Turkey; rektor@siirt.edu.tr (M.E.); aymanselbasagh@gmail.com (A.E.S.)
7 Department of Agronomy, Faculty of Agriculture, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
8 CSIRO Agriculture and Food, Brisbane, QLD 4067, Australia; alison.laing@csiro.au
* Correspondence: akbarhossainwrc@gmail.com (A.H.); marian.brestic@uniag.sk (M.B.)

Received: 24 August 2020; Accepted: 1 October 2020; Published: 5 October 2020

Abstract: Peanut (Arachis hypogaea L.) is adorned as the one of the important sources of vegetable oil, protein, vitamins and several minerals, which could mitigate the nutritional gap worldwide. However, peanut cultivation in winter suffers from low temperature stress and knowledge lacuna regarding the optimum dose nitrogen. Therefore, the present investigations were carried out during the winter seasons 2015–2016 and 2016–2017 at the district seed farm of Bidhan Chandra Krishi Viswavidyalaya, an agricultural university in West Bengal, India (23°26’ N, 88°22’ E, elevation 12 m above mean sea level) to facilitate the comprehensive study of plant growth, productivity and profitability of an irrigated peanut crop under varied levels of nitrogen: with and without a rhizobium inoculants and with and without polylethene mulch. Quality traits and nutrient dynamics were also itemized. Fertilizing with 100% of the recommended dose of nitrogen combined with rhizobium inoculant and polylethene mulch significantly enhanced peanut plant growth, yield and yield-attributing traits, while resulting in the maximum fertilizer (i.e., nitrogen, phosphorus and potassium) uptake by different plant parts. The greatest number of root nodules occurred in the treatment that received 75% of the recommended dose of nitrogen with rhizobium supplementation under polylethene mulch, while 50% of the recommended dose of nitrogen with no rhizobium resulted in maximum fertilizer nitrogen use efficiency. Applying the full recommended dose of nitrogen with the rhizobium inoculants and mulch resulted in maximum profitability in the peanut crop.

Keywords: biofertilizer; growth attributes; nitrogen dose; polylethene mulch; economic viability
1. Introduction

Peanut (*Arachis hypogaea* L.) is an important oilseed and food legume crop across the tropics and subtropics. Globally, it is the fourth most common source of edible oil and third most important source of vegetable protein [1]. India grows an estimated 7.93 MT peanuts annually from an area of 4.99 Mha, which has made it second (after China) as a global peanut producer [2]. India generates approximately 0.730 billion USD annually from peanut exports [3]. Producing peanut as an irrigated winter (November to March) crop is becoming popular as the yield is almost twice as much as that achieved for peanut grown in the wet (July to October) season; this also increases overall cropping system productivity [4]. Peanut as a winter crop is sown from the second fortnight of November until January. Prevailing low temperatures during the early growth phases have been considered a major obstacle for satisfactory plant development [5]. Additionally, high weed infestations and high soil surface evaporation leading to increased irrigation demand are critical factors that slow crop growth and development in winter. To alleviate these challenges, polythene mulches, a promising technology that has the potential to protect plants from low temperature stress, reduce soil surface evaporation and limit weed infestations, thus reducing water losses and subsequent irrigation demand [6,7]. Mulch also slows the immobilization of soil nutrients and reduces leaching losses beyond the root zone, thereby facilitating better nutrient availability for crops [8]. Jain et al. [5] confirmed that peanut grown under polythene mulching resulted in better growth, yield and quality traits as compared to no mulching. They reported 35.55% pod yield increase in peanut over the nonmulching situation. In another study, application of poly mulch registered greater dry matter (26.66%), pod yield (23.49%), kernel yield (27.22%), oil yield (27.74%) and protein yield (31.40%) in irrigated peanut [4].

Peanut is a nutrient intensive crop, and thus optimizing nutrient management, particularly the supply of nitrogen (N) in balance with crop demand, is a key factor of crop production [9]. Injudicious application of chemical fertilizers not only increases production costs, but also depletes the soil chemical and biological health and ultimately contributes to the deterioration of the cropping system [10]. In agricultural systems, N is the most important and the most limiting nutrient element [11]. Common symptoms of N deficiency include leaf yellowing and the slowing of cell division and enzymatic activities, leading to stunted plant growth [12]. Protein and oil synthesis are also directly affected by crop N uptake [13]. When growing legume crops such as peanut, an optimum starter (basal) dose of N is required to encourage early plant growth as the crop cannot fix sufficient atmospheric N from its root nodules in early growth phases [14]. Fertilizers with low nitrate concentrations favor initial seedling vigor [15] and better root nodulation, which may itself then contribute additional N to the plant [16]. In contrast, excess early application of inorganic N fertilizer to legume crops inhibits both root nodule formation and rhizobium (*Rh*) activities, thus restricting their potential symbiotic N fixation [17]. Therefore, supplementing N fertilizer with biofertilizer such as *Rh* has been widely proposed, with the aim of increasing the efficiency with which the peanut plant takes up the applied mineral N, as the biofertilizer assists mobilization of soil organic N into plant-available inorganic forms, and also facilitates fixation of atmospheric N within the soil [18]. The legume–*Rh* symbiosis is one of the most well-known plant microorganism interactions, and accounts for almost 41 kg N ha$^{-1}$ added into soils annually in peanut cultivation [19]. Argaw [20] reported significant increases in peanut dry matter, nodule number, grain yield and plant N uptake in eastern Ethiopia when N was applied at intermediary rates (20 kg ha$^{-1}$) and combined with *Rh* inoculation as compared to no N and *Rh* application. However, growth and yield potential were sharply decreased with higher dose, viz., 40 kg N ha$^{-1}$ in similar experiment. Osborne and Riedell [15] showed higher biomass and N accumulation with a maximum dose (24 kg ha$^{-1}$) of fertilizer N application in soybean. The *Bradyrhizobium japonicum* and *Bradyrhizobium elkanianae* are the most used root nodulating isolates for peanut cultivation; however, considerable attention should be given to the selection of optimal *Rh* strain as efficiency varies widely under different soil physical and chemical environmental constraints [21].
This objective of this research was to investigate the optimal dose of inorganic N combined with Rh supplementation under polythene mulch to maximize plant growth, productivity, profitability and soil nutrient dynamics in an irrigated peanut crop.

2. Materials and Methods

2.1. Site Characteristics

The field experiment was conducted at the district seed farm of the Kalyani under Bidhan Chandra Krishi Viswavidyalaya agricultural university in Nadia, West Bengal, India (23°26′ N, 88°22′ E, elevation 12 m above mean sea level), during the winter (November to March) seasons of 2015–2016 and 2016–2017. The agrometeorological observations and soil characteristics of both growing seasons are described in detail in Part I of this study [22].

2.2. Experimental Details

The experiment was carried out in split-plot design, replicated thrice. The main plots consisted of two treatments: peanut was either cultivated under white transparent polythene sheet (30 µ) or cultivated with no mulch. The subplots consisted of seven nutrient management practices: three different doses of N, viz., 100% (25 kg ha⁻¹), 75% (18.75 kg ha⁻¹), and 50% (12.50 kg ha⁻¹) of the recommended nitrogen dose (RND), with or without rhizobium (Rh) and the seventh subplot consisted of Rh with no N. Each 15 m² (3 × 5 m) subplot was separated by 0.5 m bund (embankment). N was applied as a starter dose in accordance with the prescribed treatment using urea (46% N). Recommended dose of phosphorus (P) and potassium (K) at 60 and 40 kg ha⁻¹ was applied uniformly in each subplot as basal dose from single super phosphate (SSP) and muriate of potash (MOP). The peanut (var. TG 51) was sown manually at 150 kg ha⁻¹ during the second fortnight of November in 2015 and 2016 at a distance of 30 cm row-to-row followed by 10 cm seed-to-seed at a depth of 3–4 cm. There were 33 plants present in a 1 m² area. Prior to sowing, seeds were treated with mancozeb and carbendazim (SAAF) @ 3 g kg⁻¹. Irrigations were given from the diesel-operated water-lifting pump at one week after sowing for better crop establishment, and another two were given at critical crop water requirement stages (pegging and pod formation). To check the weed flora under economic threshold level, pendimethilin 30% EC at 0.75 kg active ingredient (a.i.) ha⁻¹ was applied pre-emergently at 2 days after sowing (DAS), followed by two manual weeding at 20 DAS and 40 DAS. The whole plants were manually harvested from each plot and kept in a safe place for one week for sun-drying, and after that pods were collected manually. A complete description of experimental treatments, with more details of the field operations and peanut management practices, is provided in Part I [22].

2.3. Measurements and Analytical Procedures

2.3.1. Growth and Yield Attributes

The second rows from the border of each side of a plot were destructively sampled to record biometric observations, such as plant height, dry matter accumulation, root length and leaf area index (LAI). To determine yield attributes, five plants from the middle two rows of each plot were randomly selected and marked. At maturity, these five plants were harvested, dried and their yield was recorded. The obtained yield was then converted to respective plot area by multiplying the area of five random plant samples (each 0.03 m²) with plot area (15 m²).

To obtain seedling emergence and days required to emergence, the planted plots were observed every day after sowing. Each day, all newly emerged seedlings were marked with plastic indicators showing their emergence dates. The total percentage of the planted seeds that emerged was calculated by dividing the number of emerged seedlings by the total number of planted seeds and multiplying the result by 100.
Plant height, root length and dry matter were recorded from the five marked randomly selected plants in each plot at 30, 45, 60 and 75 days after emergence (DAE) and at harvest. Plant height was taken from ground level to the tip of the middle trifoliate leaf. To record dry matter production and root length, five plants from the penultimate row in each plot were carefully uprooted, washed thoroughly and sun-dried. The root length of these plants was measured from the base of the plant to tip of the root. The number of root nodules was counted from each plant. To record dry matter, plant biomass samples were separated into stem, leaf and root categories that were oven dried (70 °C) to obtain a constant dry weight. The aboveground dry weight was obtained by adding the dry weights of leaves and stems, expressed in g m$^{-2}$. Crop growth rate (CGR) was calculated using Equation (1):

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \times \text{GA g/m}^2/\text{day}$$  \hspace{1cm} (1)

where $W_2$ and $W_1$ are the final and initial dry weights of plant material per unit area at times $t_2$ (final time) and $t_1$ (initial time), respectively, and GA is the ground area (m$^2$). GA indicates respective plant spacing.

Leaf area index was measured by dividing the total leaf area of plants with the respective plant spacing.

Plants were harvested at physiological maturity and stacked in a safe place for a week to air dry. Peanut pods were collected from the harvested plants and plant yield was recorded at 9%–10% moisture and then converted into t ha$^{-1}$ basis. Haulm yield was recorded from remaining plant parts.

Postharvest, the peanut pods from ten randomly selected plants in each plot were counted and weighed to calculate an average weight of peanut pods per plant. The peg (modified gynophore that develops from the base of the ovary and grows down to the soil) to peanut pod conversion percentage was calculated using Equation (2):

$$\text{Peg to pod conversion} = \frac{\text{Number of pod plant}^{-1}}{\text{Number of peg plant}^{-1}} \times 100 \hspace{1cm} (2)$$

One thousand grams of seed pods were randomly selected from each treatment and split to release the peanut kernels, which were separated from the dry pod and their weight recorded. The shelling percentage was calculated using Equation (3):

$$\text{Shelling (\%)} = \frac{\text{Total weight of kernel}}{\text{Total weight of pod}} \times 100 \hspace{1cm} (3)$$

2.3.2. Nutrient and Quality Assessment

Methods of assessing nutrients in the soil and in different plant parts are described in Part I [22]. The uptake (kg ha$^{-1}$) of the key macronutrients N, phosphorus (P) and potassium (K) in different parts of the peanut (i.e., kernel and haulm) was calculated by multiplying the kernel yield and haulm yield with their respective nutrient concentrations. Protein and oil content in the peanut kernels were determined by a near-infrared (NIR) analyzer [5].

2.3.3. Calculation of Nutrient Indices

The influence of applied N fertilizer on peanut pod yield was assessed through different nutrient indices: partial factor productivity, agronomic efficiency, crop recovery efficiency and physiological efficiency, according to Equations (4)–(7), as suggested by Ray et al. [23]:

$$\text{PFP}_N = \frac{Y_N}{F_N} \hspace{1cm} (4)$$

$$\text{AE}_N = \frac{Y_N - Y_0}{F_N} \hspace{1cm} (5)$$
\[ RE_N = \frac{U_N - U_0}{F_N} \]  \hspace{1cm} (6)

\[ PE_N = \frac{Y_N - Y_0}{U_N - U_0} \]  \hspace{1cm} (7)

where PFP is the partial factor productivity, \( Y_N \) is the pod yield in a treatment plot that received fertilizer, \( F_N \) is the amount of fertilizer N applied to the crop, AE is the agronomic efficiency, \( Y_0 \) is the pod yield in a treatment plot that received no N fertilizer, RE is the crop recovery efficiency, \( U_N \) is the total N uptake in aboveground biomass at maturity in a treatment plot that received N fertilizer, \( U_0 \) is the total N uptake in aboveground biomass at maturity in a treatment plot that received no N fertilizer and PE is the crop physiological efficiency.

2.3.4. Economics Analysis

The economic analysis of peanut production systems was calculated by examining the cost of cultivation, gross revenue and net returns. These components were calculated on the basis of the prevailing market price of the input, output and services. Gross revenue was calculated by multiplying the pod yield with the peanut minimum support price. The net return was calculated by subtracting the cost of cultivation from the gross revenue and the benefit to cost ratio (B:C ratio) was calculated by dividing the gross revenue into the cost of cultivation. The incremental cost–benefit ratio was calculated by dividing the additional cost of experimental treatments (i.e., the costs resulting from applying mulch and N fertilizer) with the additional benefit (i.e., revenue generated).

2.3.5. Statistical Analysis

The data obtained from the experiment, were analyzed year wise with analysis of variance (ANOVA) for split-plot design using the STAR (Statistical Tool for Agricultural Research, International Rice Research Institute, Los Baños, Philippines) (Table S1). Significantly different means were separated at 0.05% or 0.01% probability level by Duncan’s multiple range test.

3. Results and Discussions

3.1. Growth Attributes

The effects of soil mulch and amount of N applied with or without Rh supplementation on the growth attributes of peanut are shown in Tables 1 and 2 for the 2015–2016 and 2016–2017 seasons, respectively. Peanut seedling emergence was significantly (\( p \leq 0.01 \)) higher (95.29% and 94.14% in the first and second years, respectively) under the polythene mulch than in the conventional (nonmulched) treatments. Seedling emergence was also significantly (\( p \leq 0.05 \)) influenced by nutrient management practice; in the 2015–2016 season, greater seedling emergence was observed from the treatment where the full recommended dose of nitrogen was applied with Rh seed inoculation. This was statistically greater than the treatments where N was applied at 50% of the recommended dose with Rh, and where Rh was used in the absence of N (Table 1). In the second experimental season, statistically higher seedling emergence was only observed between treatments where N was applied and that which had Rh alone applied (Table 2). The interaction between soil mulch and nutrient application did not show any significant variation in seedling emergence in either experimental year. Peanut seeds grown under polythene mulch required less time to emerge than those grown without mulch. Among the nutrient management treatments, those where the full recommended dose of N was applied with Rh biofertilization had the smallest time from sowing to seedling emergence in both 2015–2016 and 2016–2017. Better seedling emergence in less time may be due to more ambient soil temperature, a more uniform supply of soil moisture and reduction in soil compaction around the seeds under mulch, which helps to promote faster germination and emergence [24,25]. Deshwal et al. [24] suggest that applying a basal application of N concurrently with Rh coating in peanut seeds increases the percentage of seedlings that emerge.
### Table 1. Effect of soil mulch and nutrient management on peanut growth attributes in 2015–2016.

| Nutrient Management | Seedling Emergence (%) | Days to Emergence | Leaf Area Index | Nodule Number Plant⁻¹ |
|---------------------|-------------------------|-------------------|-----------------|-----------------------|
|                     | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean |
| 100% RDN            | 97.00 a  | 91.00 a | 94.00 A | 6.00 | 10.00 | 8.00 | 2.97 c | 2.67 f | 2.82 b | 3.46 b | 3.07 f | 3.26 b | 33.10 a | 29.50 a | 31.30 C | 49.76 a | 43.50 a | 46.63 D | 89.00 a |
| 75% RDN             | 95.00 a  | 88.00 a | 91.50 ABC | 6.00 | 10.00 | 8.00 | 2.86 d | 2.55 b | 2.71 c | 3.32 b | 2.87 b | 3.09 c | 36.23 a | 31.80 a | 33.52 BC | 54.56 a | 46.66 a | 50.61 C | 89.00 a |
| 50% RDN             | 95.00 a  | 90.00 a | 92.50 AB | 6.00 | 12.00 | 9.00 | 2.60 e | 2.41 i | 2.51 b | 2.74 i | 2.32 l | 2.53 b | 36.50 a | 35.93 a | 36.22 AB | 56.86 a | 53.93 a | 55.39 AB | 89.00 a |
| 100% RDN + Rhiz      | 97.00 a  | 88.00 a | 92.50 AB | 5.00 | 10.00 | 7.50 | 3.14 a | 2.76 e | 2.95 A | 3.52 A | 3.16 A | 3.34 A | 35.70 a | 33.97 a | 34.83 BC | 54.56 a | 51.26 a | 52.91 BC | 89.00 a |
| 75% RDN + Rhiz      | 96.00 a  | 89.00 a | 92.50 AB | 5.00 | 11.00 | 8.00 | 3.06 b | 2.60 b | 2.83 b | 3.42 b | 3.11 f | 3.27 b | 37.23 a | 33.63 a | 35.43 BC | 57.30 a | 50.33 a | 53.81 B | 89.00 a |
| 50% RDN + Rhiz      | 94.00 a  | 86.00 a | 90.00 BC | 6.00 | 12.00 | 8.00 | 2.68 f | 2.48 i | 2.58 b | 3.07 f | 2.43 l | 2.75 b | 41.03 a | 37.47 a | 39.25 A | 58.23 a | 55.60 a | 56.92 A | 89.00 a |
| Rhizobium (Rh)      | 93.00 a  | 85.00 a | 89.00 C  | 6.00 | 13.00 | 9.50 | 2.47 i | 2.26 k | 2.36 f | 2.56 k | 2.16 m | 2.26 f | 17.33 a | 21.03 a | 19.18 D | 33.8 a  | 27.46 a | 30.23 E  | 89.00 a |
| Mean                | 95.29 A  | 88.17 B | 92.55 B  | 5.71 | 11.28 | 9.50 | 2.83 A | 2.53 B | 3.13 A | 2.73 B | 33.73 A | 31.90 A | 32.04 A | 46.96 B |

Sources of variation: SC, soil covering; M, mulch; NM, nonmulch; N, nutrient management; DAE, days after emergence; SEM, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha⁻¹. Within each column, numbers followed by different letters indicate significant differences at p ≤ 0.05 (otherwise statistically at par); ** significant at p ≤ 0.01; * significant at p ≤ 0.05.

### Table 2. Effect of soil mulch and nutrient management on peanut growth attributes in 2016–2017.

| Nutrient Management | Seedling Emergence (%) | Days to Emergence | Leaf Area Index | Nodule Number Plant⁻¹ |
|---------------------|-------------------------|-------------------|-----------------|-----------------------|
|                     | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean | M          | NM      | Mean |
| 100% RDN            | 94.00 a  | 88.00 a | 91.00 A | 5.00 | 12.00 | 8.50 | 2.94 b | 2.61 f | 2.77 b | 3.69 b | 3.21 A | 3.45 b | 24.44 de | 23.19 a | 23.81 D | 53.17 ft | 49.30 b | 51.23 E |
| 75% RDN             | 95.00 a  | 89.00 a | 92.00 A | 6.00 | 11.00 | 8.50 | 2.78 d | 2.48 i | 2.63 D | 3.45 b | 2.96 f | 3.20 C | 25.09 od | 24.33 de | 24.71 CD | 58.57 cde | 52.57 fgh | 55.77 CD |
| 50% RDN             | 95.00 a  | 88.00 a | 91.50 A | 6.00 | 12.00 | 9.00 | 2.56 b | 2.33 k | 2.45 f | 2.87 i | 2.43 h | 2.65 b | 26.73 b | 25.48 BC | 24.38 de | 25.56 BC | 60.07 abc | 55.33 cde | 57.70 BC |
| 100% RDN + Rhiz     | 96.00 a  | 90.00 a | 93.00 A | 5.00 | 11.00 | 8.00 | 3.01 e | 2.67 e | 2.84 A | 3.95 b | 3.35 d | 3.65 A | 23.79 de | 24.00 bc | 23.89 B  | 58.17 hde | 51.97 fgh | 54.07 D  |
| 75% RDN + Rhiz      | 96.00 a  | 88.00 a | 92.00 A | 6.00 | 12.00 | 9.00 | 2.89 c | 2.58 e | 2.74 c | 3.64 b | 3.27 d | 3.45 B | 33.42 A | 26.23 bc | 29.82 A  | 59.60 de | 57.33 cde | 58.46 B  |
| 50% RDN + Rhiz      | 94.00 a  | 89.00 a | 91.50 A | 5.00 | 12.00 | 8.50 | 2.62 f | 2.37 l | 2.50 g | 3.26 d | 2.59 k | 2.94 D | 27.38 b | 25.22 cd | 26.30 B  | 63.43 ab | 62.27 ab | 62.80 A  |
| Rhizobium (Rh)      | 89.00 a  | 86.00 a | 87.50 B | 7.00 | 11.00 | 9.00 | 2.39 j | 2.21 l | 2.30 G | 2.47 b | 2.20 m | 2.33 F | 20.25 f | 17.73 h | 18.99 E  | 37.0 j  | 21.17 i | 29.08 F  | 89.00 a |
| Mean                | 94.14 A  | 88.29 B | 92.32 B  | 5.71 | 11.60 | 9.50 | 2.74 A | 2.47 B | 3.33 A | 2.86 B | 25.87 A | 23.58 B | 55.40 A | 50.01 B  |

Sources of variation: SC, soil covering; M, mulch; NM, nonmulch; N, nutrient management; SEM, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha⁻¹. Within each column, numbers followed by different letters indicate significant differences at p ≤ 0.05 (otherwise statistically at par); ** significant at p ≤ 0.01; * significant at p ≤ 0.05.
The effects of soil mulch and application of N with or without Rh on plant height is illustrated in Figure 1. A significantly ($p \leq 0.01$) higher peanut plant height was observed under polythene mulch through the growing season, irrespective of year (Figure 1a,b), and a similar trend was observed in treatments where peanut received the full recommended dose of N with the Rh supplementation (Figure 1c,d). Higher plant height under polythene mulch than without mulch was also observed by Ramakrishna et al. [26] and Jain et al. [5]. In our experiment, the peanut plant attained an average 31.94 cm height at 45 DAE in the first experimental season in the treatment where 100% of the recommended dose of N was applied with Rh; this was closely followed by the treatment where the same dose of N was applied without Rh (30.17 cm), and the treatment where 75% of the recommended dose of N was applied with Rh (29.63 cm). At the time of harvest, average plant heights of 44.84 and 45.82 cm were recorded under polythene mulch in the two experimental seasons; these heights were 16.46% and 12.19% higher than the average plant heights observed in the nonmulched treatments. Treatments with 100% of the recommended dose of N with Rh achieved average heights of 46.33 and 47.24 cm in the first and second experimental seasons, respectively; these were not significantly different from average plant heights in treatments with lower N applications. Namvar et al. [27] observed an increase of 30.90% in average plant height in leguminous plants under the application of 100% of the recommended dose of N with Rh inoculation over a control treatment. Increased plant height with increasing applied N in soybean was also reported by Caliskan et al. [28]. Mishra et al. [29] demonstrated that the addition of Rh as a seed inoculant combined with chemical fertilizer resulted in greater plant height rather than in treatments where plant seeds were not inoculated. Similar results were observed in average peanut root lengths throughout the experiment; treatments grown under mulch achieved statistically longer roots in both seasons than root lengths achieved in nonmulch treatments (Figure 2a,b). Treatments fertilized with 100% of the recommended dose of N combined with Rh seed inoculation increased the root length; results from these treatments were statistically different from those in other treatments (Figure 2c,d).

Figure 1. Effect of soil mulch (a,b) and nutrient management (c,d) on peanut plant height at different growth stages (data from the 2015–2016 and 2016–2017 crop seasons, respectively). DAE—days after emergence; error bars represent the least significant difference values. Different letters on the bars indicate significant differences.
Figure 2. Effect of soil mulch (a,b) and nutrient management (c,d) on peanut root length at different growth stages (data from 2015–2016 and 2016–2017 crop seasons, respectively). DAE—days after emergence; error bars represent the least significant difference values. Different letters on the bars indicate significant differences.

Greatest leaf area indexes (LAI) were obtained in mulched treatments compared to nonmulched; these results were statistically different (Tables 1 and 2). Amongst nutrient management practices, the treatment where 100% of the recommended dose of N was applied with Rl resulted in higher average LAI (2.95 and 3.34 at 45 and 60 DAE, respectively) in the first experimental season; a similar trend was observed in the subsequent season. LAI was reduced when Rl was applied without N, irrespective of experimental season. The interaction between mulch when N was applied at 100% of the recommended dose in combination with Rl inoculation increased LAI above any other treatment combination in both experimental seasons. Maximizing LAI with the application of higher doses of N in legumes was also observed by Caliskan et al. [28], who attributed this to higher solar radiation interception and consequently better dry matter accumulation.

Aboveground dry matter accumulation differed significantly throughout peanut growth stages. Higher average biomass was recorded in treatments under polythene mulching for both experimental seasons (Figure 3a,b). At harvest, the average aboveground dry matter accumulation in the mulched treatments in the first experimental season was 751.40 g m⁻², 3.16% higher than that in the nonmulched treatments; a similar trend was observed in the second experimental season. Differences in average aboveground dry matter between mulched and nonmulched treatments increased as the cropping season progressed; at 30 DAE average biomass under mulched treatments was 23.9 g higher than under nonmulched treatments, whereas at harvest average biomass was 91.5 g higher in the mulched treatments (Figure 3b). Similar results were observed for maximum root dry weight (Figure 4a,b), irrespective of crop growth stages or experimental season. These results are similar to those observed
by Jain et al. [5], who showed a positive correlation between polythene mulch and the growth attributes plant height, dry matter accumulation and LAI throughout the growing season. This result may be a consequence of the favorable microclimate under polythene mulch, which facilitates better nutrient mobilization by the peanut crop and enables greater photosynthate accumulation. CO\(_2\) gas under polythene mulch did not easily escape or mingle with surrounding air and thus was available for plant absorption and photosynthesis [30]. Mathenge et al. [17] also reported an increase of 38% in aboveground dry matter when a basal application of N was combined with biofertilization.

**Figure 3.** Effect of soil mulch (a,b) and nutrient management (c,d) on peanut aboveground dry matter accumulation at different growth stages (data from 2015–2016 and 2016–2017 crop seasons, respectively). DAE—days after emergence; error bars represent the least significant difference values.
Owing to a higher supply of N in the treatment where 100% of the recommended dose of N was applied with Rh, peanut plants in this treatment accumulated significantly higher aboveground biomass and root dry matter than was observed in other treatments (Figure 3c,d and Figure 4c,d). This treatment combination resulted in an average of 827.75 gm−2 aboveground dry matter at 75 DAE in 2015–2016 and of 983.89 g m−2 in the second year. These biomass data were over 80% higher than those observed in the treatment where Rh was applied in the absence of N fertilizer. A sufficient amount of N is an integral component of protein development and is essential to the structure and function of chloroplast and photosynthesis, which significantly contribute to higher biomass accumulation [31]. Additionally, Agraw [20] opined that Bradyrhizobium inoculation combined with application of the recommended N resulted in 25% higher total biomass accumulation by peanut plants. Badawi et al. [32] reported that Rh inoculation resulted in 40.58% and 21.02% higher shoot and root dry weights, respectively, over the uninoculated plants. Other previous studies have also demonstrated that leguminous crops have positive and higher correlations with basal applications of the recommended dose of N applied concurrently with Rh inoculants in different geographic locations [33,34]. Supplementing with Rh increases the readily available nutrients to plants; in the absence of this symbiotic N2 plants must expend more energy taking up nitrate and reducing it to a more useable form (i.e., NH3), which lowers the potential dry matter accumulation [35]. The crop growth rate of peanut differed significantly under mulch and nutrient management practices, as shown in Figure 5. In 2015–2016, average plant growth rate was slightly slower under mulch at earlier growth...
stages, but from 30 DAE it increased at a steady rate and peaked between 45–60 DAE (at 17.03 and 13.70 g m\(^{-2}\) day\(^{-1}\) in mulched and nonmulched treatments, respectively). Subsequently the growth rate decreased (Figure 5a). However, in 2016–2017, the growth rate steadily increased until approximately 50 DAE, before declining at a decreasing rate (Figure 5b). In both experimental seasons, the growth rate was always significantly higher in the mulched treatments than in the traditional (nonmulched) treatments for the whole growing season period, except the window between 75–90 DAE where no significant difference in growth rate was observed. Ghosh et al. [36] also observed that mulch improves peanut growth rate compared to nonmulched treatments. As well, noticeable increases in dry matter accumulation and crop growth between polyethylene film mulch and nonmulched treatments were observed by Subrahmaniyan et al. [37]. Figure 5c illustrates that an initial slow growth rate was observed in the treatment with \(Rh\) applied alone except in the period between 45–60 DAE, where the growth rate was higher (13.10 g m\(^{-2}\) day\(^{-1}\)) than that in the treatment where N was applied at 50% of the recommended dose, with or without \(Rh\) (12.49 and 11.59 g m\(^{-2}\) day\(^{-1}\) in treatments with and without \(Rh\), respectively). The application of the full recommended dose of N with the \(Rh\) inoculation resulted in a better peanut growth rate than the rates observed in any other nutrient management practices, irrespective of the crop growing season.

![Figure 5](image-url)  
**Figure 5.** Effect of soil mulch (a,b) and nutrient management (c,d) on peanut crop growth rate at different growth stages (data from 2015–2016 and 2016–2017 crop seasons, respectively). Error bars represent the least significant difference values.
A greater number of average peanut nodules per plant (52.04 and 55.40 in the first and second experimental seasons, respectively) was counted from mulched treatments; this was significantly $(p \leq 0.01)$ higher than the average number of nodules observed in the nonmulched treatments at 60 DAE, irrespective of growing season (Tables 1 and 2). The application of N doses with or without Rh inoculation also significantly influenced the nodule count. The treatment where 50% of the recommended N dose was applied with Rh supplementation resulted in the highest number of nodules per plant, followed by the treatment where 75% of the recommended N dose was applied, with or without Rh. The least number of nodules from each plant was observed in the treatment where Rh was applied in the absence of N. At 60 DAE, the treatments with 100% of the recommended dose of N reduced the average number of nodules by 18.24% and 18.47% in 2015–2016 and 2016–2017, respectively, compared to the average number of nodules in the treatment with 50% of the recommended dose of N with Rh. Earlier research has shown that nodule development is improved under moderate levels of N applied basally [17,27,38]. Higher rates of N fertilizer inhibit nodule formation in leguminous plant roots [39,40]. Within 3–5 weeks from planting, leguminous plants commence biological N fixation (BNF); at earlier growth stages BNF is negligible [41]. Thus, a small amount of N applied basally boosts the early plant growth, which contributes to improved nodule development at later growth stages [28]. Additionally, Namvar et al. [27] demonstrated that the Rh seed inoculation increases the number of nodules per plant compared to noninoculated legume plants. Their findings are in accordance with this present study.

3.2. Yield Attribution Characteristics

The effect of the treatment combinations on peanut yield and yield-attributing traits, including the dry-weight number of pods per plant, the percentage of pegs converted to pods and the shelling percentage, for both the 2015–2016 and 2016–2017 experimental seasons, are summarized in Table 3. In the 2015–2016 season, the greatest pod dry weight (32.53 g plant$^{-1}$) was observed in the treatment fertilized with 100% of the recommended dose of N with Rh and under polythene mulch; this was significantly $(p \leq 0.05)$ higher than all other treatments except that where the full dose of N was applied without Rh and under mulch. In the second experimental season, the same treatment combination again yielded the greatest pod dry weight (35.40 g plant$^{-1}$); this was statistically $(p \leq 0.01)$ different from all other treatments. The peg to pod conversion rate indicates the number of pods that were achieved from the pegs; this varied significantly with the presence of soil mulch $(p \leq 0.01)$ and by the N application rate doses $(p \leq 0.01)$ (Table 3). In the first experimental season, the highest conversion rate (97.85%) was observed in the treatment where the full recommended dose of N was applied with Rh under polythene mulch. However, there was no significant difference between treatments in the second experimental season; in this year more than 90% of pegs were productive. A similar trend was observed in the shelling percentage, where the significantly $(p \leq 0.05)$ highest values were observed in the treatments where mulch was applied (70.01% and 70.19% in the first and second seasons, respectively) and where 100% of the recommended dose of N was applied with Rh inoculation (71.57% and 72.78% in the first and second seasons, respectively) relative to the control treatment.

These results are in agreement with those reported by Ghosh et al. [36], who observed that polythene mulch positively influenced both the yield and yield-attributing characteristics of peanut. Under mulch the soil was not disturbed during the entire growing season, which improves the soil physical condition by reducing topsoil crusting and maintaining soil bulk density [4]. In contrast, rainwater impact and runoff increase top soil crusting in the nonmulched treatments. Additional soil disturbance during weeding and earthing-up operations may have increased bulk density in the nonmulched soil. The favorable soil structure under polythene mulch also improved the soil total porosity, capillary porosity and aeration porosity, which in turn may have improved pegging and pod formation in the soil [42]. Similar results, including higher pod dry weights, improved peg to pod conversion and shelling percentages were also reported under seed inoculated with Rh than under noninoculated peanut seed [43,44].
### Table 3. Effect of soil covering and nutrient management on yield and yield attributes of peanut in 2015–2016 and 2016–2017.

| Nutrient Management | Pod Dry wt. (g Plant\(^{-1}\)) | Peg to Pod Conversion (%) | Shelling (%) |
|---------------------|---------------------------------|---------------------------|--------------|
|                     | 2015–2016 | 2016–2017 | 2015–2016 | 2016–2017 | 2015–2016 | 2016–2017 | 2015–2016 | 2016–2017 | 2015–2016 | 2016–2017 | 2015–2016 | 2016–2017 | 2015–2016 | 2016–2017 |
|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 100% RDN            | 30.26     | 22.08     | 30.23     | 25.23     | 78.96     | 70.18     | 69.03     | 69.64     | 26.17     | 20.23     | 69.47     | 68.47     | 68.56     | 68.64     |
| 75% RDN             | 24.44     | 22.11     | 23.59     | 67.33     | 67.17     | 67.94     | 66.07     | 65.31     | 15.67     | 15.50     | 66.93     | 65.47     | 65.31     | 63.51     |
| 50% RDN             | 17.14     | 14.21     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     | 15.67     |
| 100% RDN + Rhizobium| 32.36     | 26.58     | 33.90     | 78.85     | 69.16     | 70.35     | 69.07     | 69.07     | 16.00     | 19.00     | 78.07     | 78.07     | 78.07     | 78.07     |
| Mean                | 23.34     | 18.06     | 21.62     | 27.34     | 27.34     | 27.34     | 27.34     | 27.34     | 10.13     | 10.13     | 27.34     | 27.34     | 27.34     | 27.34     |

Sources of variation:
- **SC**, soil covering; **M**, mulching; **NM**, nonmulching; **N**, nutrient management; **SEm±**, standard errors of means; **LSD**, least significant differences of means; **RDN**, recommended dose of nitrogen, i.e., 25 kg ha\(^{-1}\). Within mulching or nutrient management, numbers followed by different letters indicate significant differences at \(p \leq 0.05\) (otherwise statistically at par); ** significant at \(p \leq 0.01\); * significant at \(p \leq 0.05\).
3.3. Nutrient Uptake

The nutrient uptake in different plant parts of peanut, i.e., the kernel and haulm, are shown in Tables 4 and 5. Higher N uptake in the kernel and haulm was recorded in mulched treatments. Similarly, total N uptake was 20.09% higher in mulched than in nonmulched treatments (Figure 6a). Subrahmaniy et al. [37] also reported a positive correlation between polythene mulch and nitrogen uptake by a peanut crop. Additionally, the N uptake varied significantly (p ≤ 0.01) with applied N doses along with Rhizobium inoculation; highest N uptake in both the kernel and haulm was observed in the treatment where N was applied at 100% of the recommended dose with Rhizobium bio-fertilization, irrespective of the experimental season. The greatest reduction in N uptake was observed in the treatment without applied N (i.e., where Rhizobium was applied alone). The interaction effect (soil cover × nutrient) significantly influenced the kernel N uptake, whereas N accumulation in the haulm did not differ significantly in 2016–2017. The highest N uptake (115.55 and 84.25 kg ha⁻¹ in the kernel and haulm, respectively) was observed from the interaction of polythene mulch with the treatment where 100% of the recommended dose of N was applied with Rhizobium inoculation in the first growing season (Table 4).

![Figure 6. Effect of soil mulch (a,b) and nutrient management (c,d) on peanut total nutrient uptake at different growth stages (data from 2015–2016 and 2016–2017 crop seasons, respectively). DAE—days after emergence; error bars represent the least significant difference values. Different letters on the bars indicate significant differences.](image-url)
Table 4. Effect of soil covering and nutrient management on Nitrogen (N), Phosphorus (P) and Potassium (K) uptake in different plant parts of peanut in 2015–2016.

| Nutrient Management | N Uptake | P Uptake | K Uptake |
|---------------------|----------|----------|----------|
|                     | Kernel   | Haulm    | Kernel   | Haulm    | Kernel   | Haulm    |
| M       | NM       | Mean     | M       | NM       | Mean     | M       | NM       | Mean     | M       | NM       | Mean     |
| 100% RDN  | 101.23 ± 83.23 D       | 92.48 ± 79.07 C       | 73.00 ± 66.94 D       | 21.16 ± 17.49 C       | 19.33 ± 7.00 ±       | 6.63 ± 5.64 D       | 19.22 ± 19.16 C       |
| 75% RDN  | 93.02 ± 85.16 C       | 73.97 ± 62.07 ±       | 68.02 ± 19.65 ±       | 15.89 ± 6.08 C       | 12.94 ± 4.60 C       | 6.94 ± 4.09 C       | 12.81 ± 19.16 C       |
| 50% RDN  | 85.66 ± 77.04 D       | 67.28 ± 66.91 D       | 61.98 ± 16.02 ±       | 12.94 ± 4.60 C       | 14.48 ± 4.09 C       | 6.94 ± 4.09 C       |
| 100% RDN + Rh  | 115.55 ± 88.43 D       | 101.99 ± 76.07 ±       | 75.80 ± 66.91 D       | 16.04 ± 12.25 ±       | 14.06 ± 12.25 ±       |
| 75% RDN + Rh  | 92.75 ± 80.18 ±       | 72.82 ± 65.46 ±       | 68.33 ± 17.11 ±       | 19.21 ± 6.83 ±       | 17.11 ± 6.83 ±       |
| 50% RDN + Rh  | 94.13 ± 82.95 C       | 75.79 ± 67.90 ±       | 75.80 ± 18.02 ±       | 14.06 ± 6.07 ±       | 16.04 ± 6.07 ±       |
| Rhizobium (Rh)  | 39.99 ± 36.10 ±       | 32.22 ± 34.77 ±       | 30.29 ± 7.25 ±       | 6.92 ± 2.64 ±       | 2.53 ± 2.53 ±       |
| Mean      | 90.59 ± 70.76 ±       | 71.64 ± 58.68 ±       | 43.71 ± 14.72 ±       | 6.58 ± 4.88 ±       | 5.84 ± 4.88 ±       |

Sources of variation
- SC: soil covering; M, mulching; NM, nonmulching; N, nutrient management; SEms: standard errors of means; LSD: least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha⁻¹. Within mulching or nutrient management, numbers followed by different letters indicate significant differences at p ≤ 0.05 (otherwise statistically at par); ** significant at p ≤ 0.01; * significant at p ≤ 0.05.

Table 5. Effect of soil covering and nutrient management on Nitrogen (N), Phosphorus (P) and Potassium (K) uptake in different plant parts of peanut in 2016–2017.

| Nutrient Management | N Uptake | P Uptake | K Uptake |
|---------------------|----------|----------|----------|
|                     | Kernel   | Haulm    | Kernel   | Haulm    | Kernel   | Haulm    |
|                     | M       | NM       | Mean     | M       | NM       | Mean     | M       | NM       | Mean     |
| 100% RDN  | 108.09 ± 83.76 ±       | 95.92 ± 75.26 ±       | 79.83 ± 22.44 ±       | 18.02 ± 20.23 ±       |
| 75% RDN  | 94.21 ± 77.17 ±       | 85.94 ± 74.86 ±       | 70.68 ± 18.04 ±       | 15.48 ± 16.75 ±       |
| 50% RDN  | 87.97 ± 67.95 ±       | 77.96 ± 66.49 ±       | 63.63 ± 14.81 ±       | 13.56 ± 13.56 ±       |
| 100% RDN + Rh  | 119.29 ± 91.10 ±       | 105.19 ± 88.81 ±       | 72.66 ± 25.10 ±       | 14.33 ± 14.33 ±       |
| 75% RDN + Rh  | 102.54 ± 80.08 ±       | 76.08 ± 19.90 ±       | 6.90 ± 7.37 ±       | 6.58 ± 6.58 ±       |
| 50% RDN + Rh  | 95.49 ± 74.74 ±       | 67.67 ± 27.07 ±       | 6.30 ± 7.43 ±       | 6.58 ± 6.58 ±       |
| Rhizobium (Rh)  | 38.89 ± 32.18 ±       | 29.64 ± 30.91 ±       | 0.52 ± 2.75 ±       | 5.14 ± 5.14 ±       |
| Mean      | 92.42 ± 71.26 ±       | 63.44 ± 71.26 ±       | 73.64 ± 25.10 ±       | 14.59 ± 14.59 ±       |

Sources of variation
- SC: soil covering; M, mulching; NM, nonmulching; N, nutrient management; SEms: standard errors of means; LSD: least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha⁻¹. Within mulching or nutrient management, numbers followed by different letters indicate significant differences at p ≤ 0.05 (otherwise statistically at par); ** significant at p ≤ 0.01; * significant at p ≤ 0.05.
In both seasons, phosphorus uptake in the peanut kernel was highest (24.93 kg ha\(^{-1}\) and 25.10 kg ha\(^{-1}\) in 2015–2016 and 2016–2017, respectively) in the treatment when 100% of the recommended dose of N was applied with \(R_h\) and under polythene mulch (Tables 4 and 5). P uptake by the haulm followed a similar trend; however, in the second season there was no significant variation in uptake between treatments.

Potassium uptake by the kernel and haulm was significantly \((p \leq 0.01)\) influenced by mulch as well as by nutrient management. The treatment where 100% of the recommended dose of N was applied with \(R_h\) and mulch resulted in the highest K uptake (21.50 and 21.81 kg ha\(^{-1}\) in the first and second seasons, respectively) by the kernel. The same treatment combination maximized K uptake by the haulm in the first season; however, differences in K uptake were not significant in 2016–2017. Figure 6 illustrates significant influence of soil mulch and nutrient management on the total uptake of P and K. Experimental plots under polythene mulch improved P and K uptake, and in the case of nutrient management higher uptake was observed in the treatment that received 100% of the recommended dose of N with \(R_h\) in both experimental seasons. By obstructing direct rainfall to the soil, polythene mulch reduces the loss by leaching of the key plant macronutrients. Moreover, low crop weed competition under mulch also contributes to greater plant nutrient availability. Sharma et al. [45] reported higher N, P and K uptake by peanut plants under 100% of the recommended N dose applied with \(R_h\) inoculation. Supplementation with \(R_h\) inoculation combines with peanut’s own ability to fix biological N, resulting in higher plant N accumulation than is observed in noninoculated peanut plants [46,47]. Furthermore, inoculation facilitates the mobilization from organic forms of nutrients to more readily plant-available inorganic forms, thus providing another avenue for better nutrient availability [48]. As a consequence of greater kernel and haulm yield, total nutrient uptake by the peanut plant was maximized in the treatment with 100% of the recommended dose of N with \(R_h\) and under polythene mulch, as shown in Part I of this study [22]. Additional detail on soil nutrient availability and nutrient concentrations in different plant parts are also summarized in Part I of this research.

3.4. Quality Traits

The oil content in the peanut kernel was not significantly influenced by soil mulch, whereas the amount of N applied, with or without biofertilization by \(R_h\), did significantly \((p \leq 0.01)\) influence this quality trait in both experimental seasons (Table 6). The oil content in the kernel was higher with higher applications of N; maximum average oil contents (47.80% and 48.83% in the 2015–2016 and 2016–2017 seasons, respectively) were recorded from the treatments where 100% of the recommended dose of N was applied with \(R_h\). The interaction between mulch and nutrient management significantly influenced the oil content in the first growing season, whereas in the second there was no significant difference between treatments. Similarly, the kernel protein content also differed significantly with the amount of N applied (Table 6). The highest protein contents (26.25% and 26.31% in the first and second seasons, respectively) were observed in the treatment where 100% of the recommended dose of N was applied with \(R_h\) inoculants. Soil polythene mulch had no significant effect on protein content in 2015–2016, while in the 2016–2017 season the treatment where mulch was combined with 100% of the recommended dose of N with \(R_h\) resulted in significantly higher protein content in the peanut kernel than in all other treatments.

In previous studies, higher peanut oil and protein contents in plants grown under polythene mulch were also reported by Jain et al. [5]. Sharma et al. [45] and Hasan and Sahid [43] both also observed the improved quality of peanut kernels in terms of protein and oil content when 100% of the recommended dose of N was applied with \(R_h\) seed inoculation when compared to treatments with comparable N application rates but with noninoculated seed.
Table 6. Effect of soil covering and nutrient management on quality traits of peanut in 2015–2016 and 2016–2017.

| Nutrient Management | 2015–2016 Oil % | 2016–2017 Oil % | 2015–2016 Protein % | 2016–2017 Protein % |
|---------------------|----------------|----------------|---------------------|---------------------|
|                     | M   | NM | Mean | M   | NM | Mean | M   | NM | Mean | M   | NM | Mean |
| 100% RDN            | 46.98<sup>b</sup> | 46.96<sup>b</sup> | 46.97<sup>B</sup> | 48.19<sup>a</sup> | 48.26<sup>a</sup> | 48.22<sup>B</sup> | 25.65<sup>ab</sup> | 25.67<sup>ab</sup> | 25.66<sup>AB</sup> | 25.48<sup>d</sup> | 25.53<sup>c</sup> | 25.51<sup>B</sup> |
| 75% RDN             | 45.13<sup>d</sup> | 45.12<sup>d</sup> | 45.12<sup>D</sup> | 45.99<sup>a</sup> | 45.98<sup>a</sup> | 45.98<sup>D</sup> | 24.87<sup>bcd</sup> | 24.56<sup>cd</sup> | 24.71<sup>CD</sup> | 24.62<sup>g</sup> | 24.53<sup>h</sup> | 24.58<sup>D</sup> |
| 50% RDN             | 42.27<sup>f</sup> | 41.95<sup>g</sup> | 42.11<sup>F</sup> | 43.08<sup>a</sup> | 43.02<sup>E</sup> | 23.56<sup>ef</sup> | 23.32<sup>f</sup> | 23.54<sup>E</sup> | 23.38<sup>i</sup> | 23.34<sup>k</sup> | 23.46<sup>F</sup> |
| 100% RDN + Rhizobium (Rh) | 47.85<sup>a</sup> | 47.75<sup>a</sup> | 47.80<sup>A</sup> | 48.91<sup>a</sup> | 48.83<sup>A</sup> | 26.26<sup>a</sup> | 26.24<sup>a</sup> | 26.25<sup>A</sup> | 26.35<sup>b</sup> | 26.28<sup>b</sup> | 26.31<sup>A</sup> |
| 75% RDN + Rhizobium (Rh) | 45.53<sup>c</sup> | 45.55<sup>c</sup> | 45.54<sup>C</sup> | 46.65<sup>a</sup> | 46.55<sup>C</sup> | 25.19<sup>bc</sup> | 25.16<sup>bc</sup> | 25.17<sup>BC</sup> | 24.93<sup>f</sup> | 25.02<sup>e</sup> | 24.98<sup>C</sup> |
| 50% RDN + Rhizobium (Rh) | 42.43<sup>e</sup> | 42.41<sup>e</sup> | 42.42<sup>E</sup> | 43.55<sup>a</sup> | 43.43<sup>E</sup> | 24.07<sup>d</sup> | 24.12<sup>def</sup> | 24.09<sup>DE</sup> | 23.62<sup>j</sup> | 23.76<sup>i</sup> | 23.69<sup>E</sup> |
| Mean                | 44.07<sup>A</sup> | 44.00<sup>A</sup> | 44.91<sup>A</sup> | 45.05<sup>A</sup> | 44.91<sup>A</sup> | 24.35<sup>A</sup> | 24.31<sup>A</sup> | 24.33<sup>A</sup> | 24.25<sup>B</sup> |

Sources of variation:

| Source | SE± | LSD | SE± | LSD | SE± | LSD | SE± | LSD |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|
| SC     | 0.016 | ns  | 0.002 | ns  | 0.12 | ns  | 0.004 | 0.01 ** |
| N      | 0.027 | 0.080 ** | 0.165 | 0.48 ** | 0.23 | 0.67 ** | 0.008 | 0.02 ** |
| SC × N | 0.040 | 0.114 ** | 0.216 | ns  | 0.32 | 0.93 ** | 0.011 | 0.03 ** |

SC, soil covering; M, mulching; NM, non-mulching; N, nutrient management; SE±, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha<sup>−1</sup>. Within mulching or nutrient management, numbers followed by different letters indicate significant differences at p ≤ 0.05 (otherwise statistically at par); ** significant at p ≤ 0.01; * significant at p ≤ 0.05.
3.5. N Use Efficiency

The different N use efficiency (NUE) indices: partial factor productivity (PFP\textsubscript{N}), agronomic efficiency (AE\textsubscript{N}), crop recovery efficiency (RE\textsubscript{N}) and physiological efficiency (PE\textsubscript{N}), were strongly influenced by the different application rates of N (Tables 7 and 8). With increased application of N fertilizer, there was a reduction in PFP\textsubscript{N}, AE\textsubscript{N}, RE\textsubscript{N} and PE\textsubscript{N} in both experimental seasons. Several other studies have also reported this result [49–51]. The correlation between the amount of N applied and NUE in both mulched and nonmulched treatments is illustrated in Figure 7 for 2015–2016 and Figure 8 for 2016–2017. NUE increased markedly with declining application N up to a certain level (50% RDN) and thereafter decreased sharply. Applying more N fertilizer than required by the peanut crop resulted in a considerably less nutrient-efficient crop. A negative correlation between fertilizer rate and NUE was also reported by Stamatiadis [52]; N is rapidly lost when fertilizer inputs surpass the crop’s capacity to assimilate the nutrient [53,54].

![Figure 7. Relationship between nitrogen application rates and \textit{Rh} inoculation (1 = 50% RDN (12.5 kg ha\textsuperscript{-1}); 2 = 50% RDN (12.5 kg ha\textsuperscript{-1}) + \textit{Rh}; 3 = 75% RDN (18.75 kg ha\textsuperscript{-1}); 4 = 75% RDN (18.75 kg ha\textsuperscript{-1}) + \textit{Rh}; 5 = 100% RDN (25 kg ha\textsuperscript{-1}); 6 = 100% RDN (25 kg ha\textsuperscript{-1}) + \textit{Rh}) and nitrogen use efficiency in peanut under mulched (a) and nonmulched (b) treatments in 2015–2016.](image)

![Figure 8. Relationship between nitrogen application rates and \textit{Rh} inoculation (1 = 50% RDN (12.5 kg ha\textsuperscript{-1}); 2 = 50% RDN (12.5 kg ha\textsuperscript{-1}) + \textit{Rh}; 3 = 75% RDN (18.75 kg ha\textsuperscript{-1}); 4 = 75% RDN (18.75 kg ha\textsuperscript{-1}) + \textit{Rh}; 5 = 100% RDN (25 kg ha\textsuperscript{-1}); 6 = 100% RDN (25 kg ha\textsuperscript{-1}) + \textit{Rh}) and nitrogen use efficiency in peanut under mulched (a) and nonmulched (b) treatments in 2016–2017.](image)
Table 7. Effect of soil covering and nutrient management on PFPN, AEN, REN and PEN of peanut in 2015–2016.

| Nutrient Management | Partial Factor Productivity of Applied Nitrogen (PFPN) | Agronomic Efficiency of Applied Nitrogen (AEN) | Crop Recovery Efficiency of Applied Nitrogen (REN) | Physiological Efficiency of Applied Nitrogen (PEN) |
|---------------------|--------------------------------------------------------|------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
|                     | M           | NM         | Mean | M           | NM         | Mean | M           | NM         | Mean | M           | NM         | Mean |                                  |
| 100% RDN            | 153.20      | 128.00     | 140.60 | 89.60       | 76.40      | 83.00 | 3.49        | 2.83       | 3.16 | 25.68       | 26.98      | 26.33|
| 75% RDN             | 192.00      | 162.67     | 177.33 | 107.20      | 93.87      | 100.53 | 3.43        | 2.96       | 3.19 | 31.25       | 31.75      | 31.50|
| 50% RDN             | 276.80      | 230.40     | 253.60 | 149.60      | 127.20     | 138.40 | 3.96        | 3.21       | 3.59 | 37.74       | 39.61      | 38.67|
| 100% RDN + Rh       | 158.40      | 131.60     | 145.00 | 94.80       | 80.00      | 87.40 | 4.11        | 3.18       | 3.64 | 23.05       | 25.19      | 24.12|
| 75% RDN + Rh        | 200.00      | 169.07     | 184.53 | 115.20      | 100.27     | 107.73 | 4.13        | 3.68       | 3.90 | 27.92       | 27.22      | 27.57|
| 50% RDN + Rh        | 289.60      | 232.00     | 260.80 | 162.40      | 128.80     | 145.60 | 4.95        | 3.95       | 4.45 | 32.80       | 32.57      | 32.69|
| Rhizobium (Rh)      |             |            |       |             |            |       |             |            |      |             |            |      |                                  |
| Mean                | 211.67      | 175.62     | 119.80 | 101.09      | 4.01       | 3.30  | 29.74       | 30.55      |      |                                  |

M, mulching; NM, nonmulching; SEm ±, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha⁻¹.

Table 8. Effect of soil covering and nutrient management on PFPN, AEN, REN and PEN of peanut in 2016–2017.

| Nutrient Management | Partial Factor Productivity of Applied Nitrogen (PFPN) | Agronomic Efficiency of Applied Nitrogen (AEN) | Crop Recovery Efficiency of Applied Nitrogen (REN) | Physiological Efficiency of Applied Nitrogen (PEN) |
|---------------------|--------------------------------------------------------|------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
|                     | M           | NM         | Mean | M           | NM         | Mean | M           | NM         | Mean | M           | NM         | Mean |                                  |
| 100% RDN            | 146.00      | 120.00     | 133.00 | 78.80       | 64.40      | 71.60 | 2.81        | 2.13       | 2.47 | 28.00       | 30.27      | 29.14|
| 75% RDN             | 186.13      | 151.47     | 168.80 | 96.53       | 77.33      | 86.93 | 3.08        | 2.19       | 2.64 | 31.31       | 35.27      | 33.29|
| 50% RDN             | 265.60      | 214.40     | 240.00 | 131.20      | 103.20     | 117.20 | 3.40        | 2.25       | 2.82 | 38.60       | 45.89      | 42.24|
| 100% RDN + Rh       | 154.80      | 124.40     | 139.60 | 87.60       | 68.80      | 78.20 | 3.57        | 2.44       | 3.01 | 24.51       | 28.22      | 26.37|
| 75% RDN + Rh        | 197.33      | 156.80     | 177.07 | 107.73      | 82.67      | 95.20 | 3.87        | 2.66       | 3.26 | 27.87       | 31.08      | 29.47|
| 50% RDN + Rh        | 284.80      | 221.60     | 253.20 | 150.40      | 110.40     | 130.40 | 4.76        | 2.77       | 3.76 | 31.61       | 39.89      | 35.75|
| Rhizobium (Rh)      |             |            |       |             |            |       |             |            |      |             |            |      |                                  |
| Mean                | 205.78      | 164.78     | 108.71 | 84.47       | 3.58       | 2.41  | 30.32       | 35.10      |      |                                  |

M, mulching; NM, nonmulching; SEm ±, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha⁻¹.
3.6. Economic Benefits Achieved with Different Treatments

The economic benefits achieved under different treatments were examined in terms of the cost of cultivation, gross revenue, net return, benefit to cost ratio and incremental cost–benefit ratio. Irrespective of N levels, treatments with mulch achieved higher gross returns, net benefits and benefit to cost ratios (Tables 9 and 10) in both growing seasons. Higher crop productivity under polythene mulches likely to result in these higher returns. In another peanut experiment, [4] reported better profitability from polythene mulch treatments (544.11 USD ha$^{-1}$) than from nonmulched treatments (411.51 USD ha$^{-1}$). In this experiment, we observed that the treatment where 100% of the recommended dose of N was applied with Rh had the highest cost of cultivation (737.29 $ ha$^{-1}$ and 752.04 USD ha$^{-1}$ in 2015–2016 and 2016–2017, respectively); this cost declined with lower N application rates. This treatment also achieved the greatest higher net benefit (1113.13 USD ha$^{-1}$ and 1153.94 USD ha$^{-1}$ in the first and second seasons, respectively) and benefit to cost ratios (2.51 and 2.53 in the first and second seasons, respectively) than all other N application rates. The lowest net benefit (79.97 USD ha$^{-1}$) was observed in the treatment where Rh inoculation was applied without N fertilizer. This may be due to poor plant growth and low crop productivity. The interaction between mulch and the application of 100% of the recommended dose of N with Rh resulted in higher gross benefits, net benefits and benefit to cost ratios. The minimum incremental cost–benefit ratio (ICBR) was recorded from the application of 100% of the recommended dose of N without Rh, closely followed by the treatment with the same application of N with Rh supplementation, indicating that these are the treatments with the maximum net return per unit cost of production. However, peanut cultivated without mulch resulted in the lowest ICBR. These findings are similar to those observed by Love et al. [55] and Baishya et al. [56], who reported that net returns were relatively low at when no N was applied and increased with increasing application rate of N up to the full recommended dose.
Table 9. Effect of soil covering and nutrient management on economics of summer peanut in 2015–2016.

| Nutrient Management | Cost of Cultivation (USD ha\(^{-1}\)) | Gross Return (USD ha\(^{-1}\)) | Net Return (USD ha\(^{-1}\)) | B:C ratio | ICBR |
|---------------------|----------------------------------------|---------------------------------|-------------------------------|---------|------|
|                     | M | NM | Mean | M | NM | Mean | M | NM | Mean | M | NM | Mean | M | NM | Mean |
| 100% RDN            | 767.3 | 692.27 | 729.79 | 1952.37 | 1636.32 | 1794.35 | 1185.07 | 944.05 | 1064.56 | 2.54 | 2.36 | 2.46 | 0.117 | 0.078 | 0.097 |
| 75% RDN             | 761.8 | 686.78 | 724.29 | 1840.23 | 1559.86 | 1697.49 | 1078.42 | 873.08 | 973.20 | 2.42 | 2.27 | 2.34 | 0.123 | 0.078 | 0.101 |
| 50% RDN             | 754.01 | 678.98 | 716.49 | 1763.76 | 1473.20 | 1615.93 | 1009.75 | 794.22 | 899.44 | 2.34 | 2.17 | 2.26 | 0.125 | 0.077 | 0.101 |
| 100% RDN + Rh        | 774.8 | 699.77 | 737.29 | 2018.64 | 1682.20 | 1850.42 | 1243.84 | 982.43 | 1113.13 | 2.54 | 2.40 | 2.51 | 0.117 | 0.082 | 0.109 |
| 75% RDN + Rh        | 769.3 | 694.28 | 731.8 | 1911.59 | 1621.03 | 1763.76 | 1142.28 | 926.75 | 1031.96 | 2.48 | 2.33 | 2.41 | 0.122 | 0.081 | 0.102 |
| 50% RDN + Rh        | 761.5 | 686.48 | 723.99 | 1845.32 | 1478.30 | 1661.81 | 1083.81 | 791.82 | 937.82 | 2.42 | 2.15 | 2.30 | 0.123 | 0.086 | 0.104 |
| Rhizobium (Rh)      | 691.6 | 616.57 | 654.08 | 815.61 | 662.69 | 734.05 | 124.01 | 46.12 | 79.97 | 1.18 | 1.07 | 1.12 | 0.491 | 0.000 | 0.245 |
| Mean                | 754.33 | 679.3 | 744.26 | 1733.18 | 1442.62 | 1788.27 | 1243.84 | 982.43 | 1113.13 | 2.55 | 2.40 | 2.51 | 0.117 | 0.082 | 0.109 |

M, mulching; NM, nonmulching; B:C ratio, benefit to cost ratio; (ICBR, incremental cost–benefit ratio; SEM±, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha\(^{-1}\); 1 USD = 68.66 Indian National Rupees.

Table 10. Effect of soil covering and nutrient management on economics of summer peanut in 2016–2017.

| Nutrient Management | Cost of Cultivation (USD ha\(^{-1}\)) | Gross Return (USD ha\(^{-1}\)) | Net Return (USD ha\(^{-1}\)) | B:C ratio | ICBR |
|---------------------|----------------------------------------|---------------------------------|-------------------------------|---------|------|
|                     | M | NM | Mean | M | NM | Mean | M | NM | Mean | M | NM | Mean | M | NM | Mean |
| 100% RDN            | 789.56 | 714.53 | 752.04 | 2012.08 | 1684.87 | 1848.48 | 1222.52 | 970.34 | 1096.43 | 2.55 | 2.36 | 2.45 | 0.118 | 0.081 | 0.103 |
| 75% RDN             | 772.16 | 697.13 | 734.65 | 1894.96 | 1605.04 | 1750.00 | 1122.80 | 907.91 | 1015.36 | 2.45 | 2.30 | 2.38 | 0.115 | 0.070 | 0.103 |
| 50% RDN             | 754.53 | 679.50 | 717.02 | 1818.28 | 1515.76 | 1667.02 | 1063.75 | 836.26 | 950.00 | 2.41 | 2.23 | 2.32 | 0.107 | 0.056 | 0.100 |
| 100% RDN + Rh        | 789.56 | 714.53 | 752.04 | 2080.88 | 1731.09 | 1905.99 | 1291.32 | 1016.56 | 1153.94 | 2.64 | 2.42 | 2.53 | 0.112 | 0.078 | 0.102 |
| 75% RDN + Rh        | 772.16 | 697.13 | 734.65 | 1971.11 | 1669.12 | 1820.12 | 1198.95 | 971.99 | 1085.47 | 2.55 | 2.39 | 2.47 | 0.108 | 0.065 | 0.102 |
| 50% RDN + Rh        | 754.53 | 679.50 | 717.02 | 1902.31 | 1523.63 | 1712.97 | 1147.78 | 844.13 | 995.96 | 2.52 | 2.24 | 2.38 | 0.100 | 0.055 | 0.098 |
| Rhizobium (Rh)      | 707.91 | 632.88 | 670.39 | 838.24 | 681.72 | 759.98 | 130.33 | 48.84 | 89.58 | 1.18 | 1.08 | 1.13 | 0.497 |
| Mean                | 762.92 | 678.89 | 744.32 | 1788.27 | 1442.62 | 1788.27 | 1243.84 | 982.43 | 1113.13 | 2.55 | 2.40 | 2.51 | 0.117 | 0.082 | 0.109 |

M, mulching; NM, nonmulching; B:C ratio, benefit to cost ratio; (ICBR, incremental cost–benefit ratio; SEM±, standard errors of means; LSD, least significant differences of means; RDN, recommended dose of nitrogen, i.e., 25 kg ha\(^{-1}\); 1 USD = 68.66 INR.
4. Conclusions

After two peanut cropping seasons, this research demonstrated that polythene mulch significantly improves peanut growth, productivity, profitability, and nutrient dynamics over conventional nonmulched management practices. This is a consequence of the improved production environment sustained at every growth stage, which facilitated overall improved development of the peanut crop. Likewise, N applied at 100% of the recommended dose with \( R_h \) seed inoculation significantly improved crop yield, yield-attributing characteristics, seed quality and the uptake of major nutrients. While the application of higher rates of N adversely affected root nodulation and N fertilizer use efficiency, it maximized economic returns in terms of net revenue, benefit to cost ratio and the incremental cost–benefit ratio. We conclude that applying the full recommended dose of N (i.e., 25 kg ha\(^{-1}\)) as a basal application combined with \( R_h \) inoculants will be highly beneficial for irrigated peanut crops when grown in the winter season under polythene mulch.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/10/1513/s1, Table S1: Analysis of variance.

Author Contributions: Conceptualization, M.M., S.G. and H.B.; methodology, M.M. and H.B.; software, S.S.; validation, M.M., S.G., M.S., H.B. and A.H.; formal analysis, M.M., S.G., A.H., M.S. and S.S.; investigation, M.M. and R.K.; resources, M.M. data curation, M.M., S.G. and S.S.; writing—original draft preparation, M.M., S.G. and S.S.; writing—review and editing, A.H., M.S., M.B., C.B., M.E., A.E.S. and A.M.L.; visualization, A.H., M.B., H.B. and C.B.; supervision, S.K.G.; project administration, R.K.; funding acquisition, M.S., A.H., M.B., C.B., M.E. and A.E.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by ICAR–AICRP on Groundnut, Kalyani Centre, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India, and the APC was funded by the projects VEGA 1/0589/19 and VEGA 1/0683/20.

Acknowledgments: The authors sincerely acknowledge the contributions of the Department of Agronomy of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India, for providing necessary laboratory facility during the investigation. The authors are highly grateful to field staffs of District Seed Farm, BCKV, Kalyanai for necessary technical helps during the field experiment period.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Ojiewo, C.; Janila, P.; Bhatnagar-Mathur, P.; Pandey, M.K.; Desmae, H.; Okori, P.; Mwololo, J.; Ajeigbe, H.; Njguna-Mungai, E.; Muricho, G.; et al. Advances in crop improvement and delivery research for nutritional quality and health benefits of groundnut (Arachis hypogaea L.). Front. Plant Sci. 2020, 11, 1–15. [CrossRef] [PubMed]

2. GOI. Agriculture. Statistical Year Book India. Government of India. Ministry of Statistics and Programme Implementation, New Delhi. 2018. Available online: http://www.mospi.gov.in/statistical-year-book-india/2018/177 (accessed on 17 February 2020).

3. Rathnakumar, A.L.; Singh, R.; Parmar, D.L.; Misram, J.B. Groundnut: A crop profile and compendium of notified varieties of India; Directorate of Groundnut Research: Gurajat, India, 2013.

4. Jain, N.K.; Jat, R.A.; Yadav, R.S.; Bhaduri, D.; Meena, H.N. Polythene mulching and fertigation in peanut (Arachis hypogaea): Effect on crop productivity, quality, water productivity and economic profitability. Indian J. Agric. Sci. 2018, 88, 1168–1178.

5. Jain, N.K.; Meena, H.N.; Bhaduri, D. Improvement in productivity, water-use efficiency, and soil nutrient dynamics of summer peanut (Arachis hypogaea L.) through use of polythene mulch, hydrogel, and nutrient management. Commun. Soil Sci. Plant Anal. 2017, 48, 549–564. [CrossRef]

6. Awe, G.; Reichert, J.M.; Timm, L.C.; Wendroth, O.O. Temporal processes of soil water status in a sugarcane field under residue management. Plant Soil 2014, 387, 395–411. [CrossRef]

7. Martín-Closas, L.; Costa, J.; Pelacho, A.M. Agronomic Effects of Biodegradable Films on Crop and Field Environment. In Green Chemistry and Sustainable Technology; Springer Science and Business Media LLC: Berlin/Heidelberg, Germany, 2017; pp. 67–104.
8. Wang, Y.P.; Li, X.G.; Fu, T.; Wang, L.; Turner, N.C.; Siddique, K.H.; Li, F.-M. Multi-site assessment of the effects of plastic-film mulch on the soil organic carbon balance in semiarid areas of China. Agric. For. Meteorol. 2016, 228, 42–51. [CrossRef]

9. Mohapatra, A.K.B.; Dixit, L. Integrated nutrient management in rainy season groundnut (Arachis hypogaea). Indian J. Agron. 2010, 55, 123–127.

10. Jat, N.L.; Jain, N.K.; Choudhary, G.R. Integrated nutrient management in fenugreek (Trigonella foenum-graecum). Indian J. Agron. 2006, 51, 331–333.

11. Xie, K.-Y.; Li, X.; He, F.; Zhang, Y.; Wan, L.; David, B.H.; Wang, D.; Qin, Y.; Gamal, M.A.F. Effect of nitrogen fertilization on yield, N content, and nitrogen fixation of alfalfa and smooth bromegrass grown alone or in mixture in greenhouse pots. J. Integr. Agric. 2015, 14, 1864–1876. [CrossRef]

12. Salvagiotti, F.; Cassman, K.; Specht, J.; Walters, D.; Weiss, A.; Dobermann, A. Nitrogen uptake, fixation and response to rhizobium N in soybeans: A review. Field Crop. Res. 2008, 108, 1–13. [CrossRef]

13. Gorissen, S.H.M.; Crombag, J.J.R.; Senden, J.M.G.; Waterval, W.A.H.; Bierau, J.; Verdijk, L.B.; Van Loon, L.J.C. Protein content and amino acid composition of commercially available plant-based protein isolates. Amino Acids 2018, 50, 1685–1695. [CrossRef]

14. Ohyama, T.; Minagawa, R.; Ishikawa, S.; Yamamoto, M.; Hung, N.V.P.; Ohtake, N.; Sueyoshi, K.; Sato, T.; Nagumo, Y.; Takahashi, Y. Soybean seed production and nitrogen nutrition. In A Comprehensive Survey of International Soybean Research-Genetics, Physiology, Agronomy and Nitrogen Relationships; IntechOpen: London, UK, 2013; pp. 115–157.

15. Osborne, S.L.; Riedell, W.E. Impact of low rates of nitrogen applied at planting on soybean nitrogen fixation. J. Plant Nutr. 2011, 34, 436–448. [CrossRef]

16. Moreau, D.; Voisin, A.S.; Salon, C.; Munier–Jolain, N. The model symbiotic association between Medicago truncatula cv. Jemalong and Rhizobium meliloti strain 2011 leads to N–stressed plants when symbiotic N2 fixation in the main N source for plant growth. J. Exp. Bot. 2008, 59, 3509–3522. [CrossRef] [PubMed]

17. Mathenge, C.; Thuita, M.; Masso, C.; Gweyi-Onyango, J.; Vanlauwe, B. Variability of soybean response to rhizobia inoculant, vermicompost, and a legume-specific fertilizer blend in Siaya County of Kenya. Soil Tillage Res. 2019, 194, 104290. [CrossRef] [PubMed]

18. Arora, N.K. Plant microbe symbiosis: Fundamentals and advances. In Plant Microbe Symbiosis: Fundamentals and Advances; Springer: Berlin/Heidelberg, Germany, 2013.

19. Argaw, A. Development of environmental friendly bioinoculate for peanut (Arachis hypogaea L.) production in Eastern Ethiopia. Environ. Syst. Res. 2017, 6, 1–12. [CrossRef]

20. Argaw, A. Integrating inorganic NP application and Bradyrhizobium inoculation to minimize production cost of peanut (Arachis hypogaea L.) in Eastern Ethiopia. Agric. Food Secur. 2018, 7, 20. [CrossRef]

21. Nievas, F.; Bogino, P.; Nocelli, N.; Giordano, W. Genotypic analysis of isolated peanut-nodulating rhizobial strains reveals differences among populations obtained from soils with different cropping histories. Appl. Soil Ecol. 2012, 53, 74–82. [CrossRef]

22. Mondal, M.; Skalicky, M.; Garai, S.; Gunri, S.K.; Hossain, A.; Sarkar, S.; Banerjee, H.; Kundu, R.; Brestic, M.; Barutcular, C.; et al. Supplemeneting nitrogen in combination with Rhizobium inoculation and soil mulch in peanut (Arachis hypogaea L.) production system: Part I. Effect on productivity, nutrient dynamics, soil moisture and microbial activity. Agronomy 2020, in press.

23. Ray, K.; Banerjee, H.; Bhattacharyya, K.; Dutta, S.; Phonglosa, A.; Pari, A.; Sarkar, S. Site-specific nutrient management for maize hybrids in an inceptisol of West Bengal, India. Exp. Agric. 2017, 54, 874–887. [CrossRef]

24. Deshwal, V.K.; Dubey, R.C.; Maheshwari, D.K. Isolation of plant growth promoting strains of Bradyrhizobium (Arachis sp.) With biocontrol potential against Macrophomina phaseolina causing charcoal rot of peanut. Curr. Sci. 2003, 84, 443–448.

25. Mondal, M.; Gunri, S.K.; Sengupta, A.; Kundu, R. Productivity enhancement of rabi groundnut (Arachis hypogaea L.) under polythene mulching and rhizobium inoculation under new alluvial zone of West Bengal. Int. J. Curr. Microbiol. Appl. Sci. 2018, 7, 2308–2313. [CrossRef]

26. Ramakrishna, A.; Tam, H.M.; Wani, S.P.; Long, T.D. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crop. Res. 2006, 95, 115–125. [CrossRef]
27. Namvar, A.; Seyed, S.R.; Khandan, T.; Jafari, M.M. Seed inoculation and inorganic nitrogen fertilization effects on some physiological and agronomical traits of chickpea (Cicer arietinum L.) in irrigated condition. J. Cent. Eur. Agric. 2013, 14, 28–40. [CrossRef]

28. Caliskan, S.; Özkaya, I.; Caliskan, M.; Arslan, M. The effects of nitrogen and iron fertilization on growth, yield and fertilizer use efficiency of soybean in a Mediterranean-type soil. Field Crop. Res. 2008, 108, 126–132. [CrossRef]

29. Mishra, M.; Kumar, U.; Mishra, P.K.; Prakash, V. Efficiency of plant growth promoting Rhizobacteria for the enhancement of Cicer arietinum L. growth and germination under salinity. Adv. Biol. Res. 2010, 4, 92–96. [CrossRef]

30. Anikwe, M.; Mbah, C.; Ezeaku, P.; Onyia, V. Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (Colocasia esculenta) on an ultisol in southeastern Nigeria. Soil Tillage Res. 2007, 93, 264–272. [CrossRef]

31. Stefanelli, D.; Goodwin, I.; Jones, R. Minimal nitrogen and water use in horticulture: Effects on quality and content of selected nutrients. Food Res. Int. 2010, 43, 1833–1843. [CrossRef]

32. Badawi, F.; Biomy, A.; Desoky, A. Peanut plant growth and yield as influenced by co-inoculation with Bradyrhizobium and some rhizo-microorganisms under sandy loam soil conditions. Ann. Agric. Sci. 2011, 56, 17–25. [CrossRef]

33. Janagard, M.S.; Ebadi-Segherloo, A. Inoculated soybean response to starter nitrogen in conventional cropping system in Moghan. J. Agron. 2016, 15, 26–32. [CrossRef]

34. Masso, C.; Mukhongo, R.W.; Thuita, M.; Abaidoo, R.; Ulzen, J.; Kariuki, G.; Kalumuna, M. Biological inoculants for sustainable intensification of agriculture in Sub-Saharan Africa smallholder farming systems. In Climate Change and Multi-Dimensional Sustainability in African Agriculture; Springer Science and Business Media LLC: Berlin/Heidelberg, Germany, 2016; pp. 639–658.

35. Fogut, T. Rhizobium inoculation improves yield and nitrogen accumulation in soybean (Glycine max) cultivars better than fertilizer. N. Z. J. Crop. Hort. 2006, 34, 115–120. [CrossRef]

36. Ghosh, P.; Dayal, D.; Bandyopadhyay, K.; Mohanty, M. Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. Field Crop. Res. 2006, 99, 76–86. [CrossRef]

37. Subrahmaniyan, K.; Kalaiselvan, P.; Balasubramanian, T.N. Microclimate variations in relation to different types of polyethylene-film mulch on growth and yield of groundnut (Arachis hypogaea). Indian J. Agron. 2008, 53, 184–188.

38. Abbasi, A.; Jafari, D.; Sharifi, S.R. Nitrogen rates effects and seed inoculation with Rhizobium leguminosarum and plant growth promoting Rhizobacteria (PGPR) on yield and total dry matter of chickpea (Cicer arietinum L.). J. Eng. Appl. 2013, 3–23, 3275–3280.

39. Bekere, W.; Kebede, T.; Dawud, J. Growth and nodulation response of soybean (Glycine max L.) to lime, Bradyrhizobium japonicum and nitrogen fertilizer in acid soil at Melko, South Western Ethiopia. Int. J. Soil Sci. 2013, 8, 25–31. [CrossRef]

40. Keino, L.; Batjukya, F.; Ng’Etich, W.; Otinga, A.N.; Okalebo, J.R.; Njoroge, R.; Mukalama, J. Nutrients limiting soybean (Glycine max L.) growth in acrisols and ferralsols of Western Kenya. PLoS ONE 2015, 10, e0145202. [CrossRef]

41. Werner, D.; Newton, W.E. Nitrogen Fixation in Agriculture, Forestry, Ecology, and Environment; Springer: New York, NY, USA, 2005.

42. Subrahmaniyan, K.; Kalaiselvan, P.; Balasubramanian, T.N.; Zhou, W. Soil properties and yield of groundnut associated with herbicides, plant geometry, and plastic mulch. Commun. Soil Sci. Plant Anal. 2008, 39, 1206–1234. [CrossRef]

43. Hasan, M.; Bin Sahid, I. Evaluation of rhizobium inoculation in combination with phosphorus and nitrogen fertilization on groundnut growth and yield. J. Agron. 2016, 15, 142–146. [CrossRef]

44. Asante, M.; Ahiahor, B.D.K.; Atakora, W.K. Growth, Nodulation, and Yield Responses of groundnut (Arachis hypogaea L.) as influenced by combined application of rhizobium inoculant and phosphorus in the Guinea Savanna zone of Ghana. Int. J. Agron. 2020, 2020, 1–7. [CrossRef]

45. Sharma, S.; Jat, N.L.; Puniya, M.M.; Shivran, A.C.; Choudhary, S. Fertility levels and biofertilizers on nutrient concentrations, uptake and quality of groundnut. Ann. Agric. Res. New Series 2014, 35, 71–74.

46. Devi, K.N.; Singh, T.B.; Athokpam, H.S.; Singh, N.B.; Samurailatpam, D. Influence of inorganic, biological and organic manures on nodulation and yield of soybean (Glycine max Merril L.) and soil properties. Aust. J. Crop Sci. 2013, 7, 1407–1415.
47. Ronner, E.; Franke, A.; Vanlauwe, B.; Dianda, M.; Edeh, E.; Ukem, B.; Bala, A.; Van Heerwaarden, J.; Giller, K.E. Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers’ fields in northern Nigeria. Field Crop. Res. 2016, 186, 133–145. [CrossRef]

48. Schütz, L.; Gattinger, A.; Meier, M.; Müller, A.; Boller, T.; Mäder, P.; Mathimaran, N. Improving crop yield and nutrient use efficiency via biofertilization-A global meta-analysis. Front. Plant Sci. 2018, 8, 2204. [CrossRef] [PubMed]

49. Chen, H.; Liu, J.; Zhang, A.; Chen, J.; Cheng, G.; Sun, B.; Pi, X.; Dyck, M.; Si, B.; Zhao, Y.; et al. Effects of straw and plastic film mulching on greenhouse gas emissions in Loess Plateau, China: A field study of 2 consecutive wheat-maize rotation cycles. Sci. Total. Environ. 2017, 579, 814–824. [CrossRef] [PubMed]

50. Kiani, M.; Gheysari, M.; Mostafazadeh-Fard, B.; Majidi, M.M.; Karchani, K.; Hoogenboom, G. Effect of the interaction of water and nitrogen on sunflower under drip irrigation in an arid region. Agric. Water Manag. 2016, 171, 162–172. [CrossRef]

51. Srivastava, R.; Panda, R.; Chakraborty, A.; Halder, D. Enhancing grain yield, biomass and nitrogen use efficiency of maize by varying sowing dates and nitrogen rate under rainfed and irrigated conditions. Field Crop. Res. 2018, 221, 339–349. [CrossRef]

52. Stamatiadis, S.; Tsadilas, C.; Samaras, V.; Schepers, J.; Eskridge, K. Nitrogen uptake and N-use efficiency of Mediterranean cotton under varied deficit irrigation and N fertilization. Eur. J. Agron. 2016, 73, 144–151. [CrossRef]

53. Jin, L.; Cui, H.; Li, B.; Zhang, J.; Dong, S.-T.; Liu, P. Effects of integrated agronomic management practices on yield and nitrogen efficiency of summer maize in North China. Field Crop. Res. 2012, 134, 30–35. [CrossRef]

54. Zhu, L.; Liu, J.; Luo, S.-S.; Bu, L.-D.; Chen, X.-P.; Li, S. Soil mulching can mitigate soil water deficiency impacts on rainfed maize production in semiarid environments. J. Integr. Agric. 2015, 14, 58–66. [CrossRef]

55. Love, S.L.; Stark, J.C.; Salaiz, T. Response of four potato cultivars to rate and timing of nitrogen fertilizer. Am. J. Potato Res. 2005, 82, 21–30. [CrossRef]

56. Baishya, L.K.; Kumar, M.; Ghosh, M.; Ghosh, D.C. Effect of integrated nutrient management on growth, productivity and economics of rainfed potato in Meghalaya hills. Int. J. Agric. Environ. Biotechnol. 2013, 6, 69–77.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).