sustainability

Article

Foliar Application of Magnesium at Critical Stages Improved the Productivity of Rice Crop Grown under Different Cultivation Systems

Hakoomat Ali [1], Naeem Sarwar [1,*], Shah Muhammad [1], Omer Farooq [1], Atique-ur Rehman [1], Allah Wasaya [2], Tauqeer Ahmad Yasir [2], Khurram Mubeen [3] and Muhammad Naeem Akhtar [4]

1 Department of Agronomy, Bahauddin Zakariya University, Multan 60000, Pakistan; hha94@bzu.edu.pk (H.A.); shahmuhammad039@gmail.com (S.M.); umeruaf@gmail.com (O.F.); atiqjugg@gmail.com (A.-u.R.)
2 Bahadur Sub-Campus, College of Agriculture, Bahauddin Zakariya University, Layyah 31200, Pakistan; wasayauaf@gmail.com (A.W.); tauqeer.yasir@bzu.edu.pk (T.A.Y.)
3 Department of Agronomy, Muhammad Nawaz Sharif University of Agriculture, Multan 60000, Pakistan; khurram.mubeen@mnsuam.edu.pk
4 Pesticide Quality Control Laboratory, Multan 60000, Pakistan; muhammaduam01@gmail.com
* Correspondence: naeemsarwar@bzu.edu.pk

Abstract: Climatic variations have created many challenges for farmers, but the most important one is the change in the dynamics of nutrient uptake by plants. Nutrients that were sufficient in soil are now found deficient, an issue that needs more focus in order to sustain crop productivity. Magnesium is very important plant nutrient that has a direct role in chlorophyll synthesis and interacts with other nutrients to manage physiological mechanisms. We designed field experiments focusing on the foliar application of magnesium at different growth and reproductive stages of a rice crop. Results reveal that the combination of rice cultivation system and magnesium application, i.e., flooded rice with Mg application at seedling + tillering + panicle initiation (F_6T_2), significantly improved crop growth and exhibited noticeable results in crop yield and grain quality. Moreover, the rice crop also recorded the highest benefit cost ratio (BCR) when kept flooded and fertilized with Mg at three stages; viz seedling, tillering, and panicle initiation; during both the years. Combined application of magnesium at growth and reproductive stages improved crop performance both in aerobic as well as in flooded rice, but the crop grown under flooded condition showed accelerated performance in both cropping seasons, which reflects its viability and economic feasibility.

Keywords: fine rice (*Oriza sativa* L.); aerobic rice; flooded rice; growth indices; magnesium (Mg) and yield potential

check for updates

Citation: Ali, H.; Sarwar, N.; Muhammad, S.; Farooq, O.; Rehman, A.-u.; Wasaya, A.; Yasir, T.A.; Mubeen, K.; Akhtar, M.N. Foliar Application of Magnesium at Critical Stages Improved the Productivity of Rice Crop Grown under Different Cultivation Systems. *Sustainability* **2021**, *13*, 4962. https://doi.org/10.3390/su13094962

Academic Editor: Jan Hopmans

Received: 26 February 2021
Accepted: 21 April 2021
Published: 28 April 2021

1. Introduction

Rice is grown as the second major grain crop in Pakistan and is considered a potential export commodity. Declining water resources and uneven climatic variations have created many challenges for the rice growers. Water-saving rice cultivation systems can save a tremendous amount of irrigation water, but it compromises yield due to the unavailability of some nutrients under aerobic soil culture [1–5]. Application of some beneficial nutrients and growth regulators are being studied to see their impact on rice production and abiotic stress management [6–9]. In the years 2018–2019, the worlds' rice production was 499.16 million tons [10], but because the population is growing faster, scientists will have to find a way to produce more rice in the coming years. The United Nations estimated that a six to eight billion person increase in the world population would occur between 2000 and 2025, and thus 40% more rice would be needed to meet dietary requirements up to 2025 [11].

In Pakistan, rice is being grown following conventional methods of flooding and by manual transplantation, which are laborious as well as costly methods [2,3]. As a result, farmers are now looking for water-saving techniques, such as aerobic rice, to reduce their labor and irrigation water expenses. In aerobic rice, cultivars are grown under dry land conditions, just like other cereals such as wheat, with or without supplemental irrigation. Without having aerobic cultivars, this change may alter soil nutrient dynamics, making it an unsuitable alternative due to reduced crop yield [3,4,12]. Mg availability to plants depends on various factors, including the distribution and chemical properties of the source rock material and its grade of weathering, site specific climatic and anthropogenic factors, agronomic management, and organic and mineral fertilization practices [13,14]. In rice crop, Mg fertilization improves the uptake of nitrogen and enhances rice yield [15]; it shows a specific role in dry matter production and its translocation in rice crop [16].

Latent and acute Mg deficiency is a common phenomenon in crop production [17]. Development of chlorosis requires preceding degradation of chlorophyll since Mg acts as a central atom in the chlorophyll molecule. As Mg is strongly bound to this molecule, chlorosis appears to be a late response to Mg deficiency. Magnesium is an integral part of chlorophyll [18,19] and has a specific role in dry matter formation and its partitioning [20]. Magnesium has a weak soil bond and is more mobile in the soil than calcium, potassium, and ammonium nitrates, and thus it is more available for a plant [21–23]. Studies revealed that appropriate application of magnesium improved grain quality, grain yield, and yield attributing factors in lentil and rice crops [24–26]. Additional studies reported improved rice crop performance under magnesium supplementation [27–29]. Both methods, soil and foliar application, were found reliable for meeting the Mg requirement of plants [19] and gave appreciable results in a variety of different crops [30]. Magnesium responds positively under sole application as well as when integrated with other nutrients [31]. Studies also confirmed that during magnesium deficiency, plants stored carbohydrates in leaves, which reduced root growth attributes and numerous other vegetative characteristics and eventually caused yield reduction [22,32].

Changes in a rice cultivation system and changes in the nutrient dynamics in soil lead crops to face nutritional stress, which in turn impairs rice crop growth and yield [3,4,33]. Inclusion of Mg as part of rice nutrient management may create a better balance in the soil or the plant, resulting in better management of plant stresses. We hypothesized that Mg application could help in maintaining the chlorophyll content in the plants, improve assimilates translocation toward grain, and would even strengthen plants grown under aerobic conditions. Consequently, we designed the current experiment with Mg application at various growth or reproductive stages in a rice crop grown under different cultivation systems.

2. Materials and Methods

A fine rice cultivar, Super Basmati, which is one of most grown cultivars, was used for both flooded and aerobic rice cultivation systems. Certified and good quality seeds were purchased from the famous seed company ICI Pakistan. For this purpose, the field experiment was designed as a randomized complete block design (RCBD) with split plot arrangements, having three replications. Plot size was 4 m $\times$ 4 m with total area of 576 m^{-2}. There were twelve treatment combinations, which are explained in Table 1. At first, Pre-sowing soil analysis was conducted, which showed that soil was sandy clay loam and had an average nutrient profile (Table 1). For land preparation, one deep plough followed by two shallow ploughs and then planking were employed for good soil tilth. Besides, ridges were made to separate different plots for various treatments and a water channel was also designed in such a way that all plots could be irrigated easily with a single irrigation source. Bunds were tightened and covered with plastic, so water could not be mixed among different plots. Hence, climate data was also taken for the period spanning two years, which showed that the crop received more rainfall in the second year as compared to the first year (Figure 1).

Table 1. Physical and chemical analysis of the soil.

Determination	2016	2017
(a) Physical		
Sand (%)	50.28	50.19
Silt (%)	23.70	23.61
Clay (%)	26.02	26.20
Texture Class	Sandy Clay Loam	
(b) Chemical		
pH	7.5	7.80
Total Soluble Salts (%)	0.23	0.24
Organic Matter (%)	0.79	0.82
Total Nitrogen (%)	0.054	0.045
Available Phosphorus (ppm)	7.30	7.40
Potassium (ppm)	171	185
DTPA Mg (ppm)	11	14

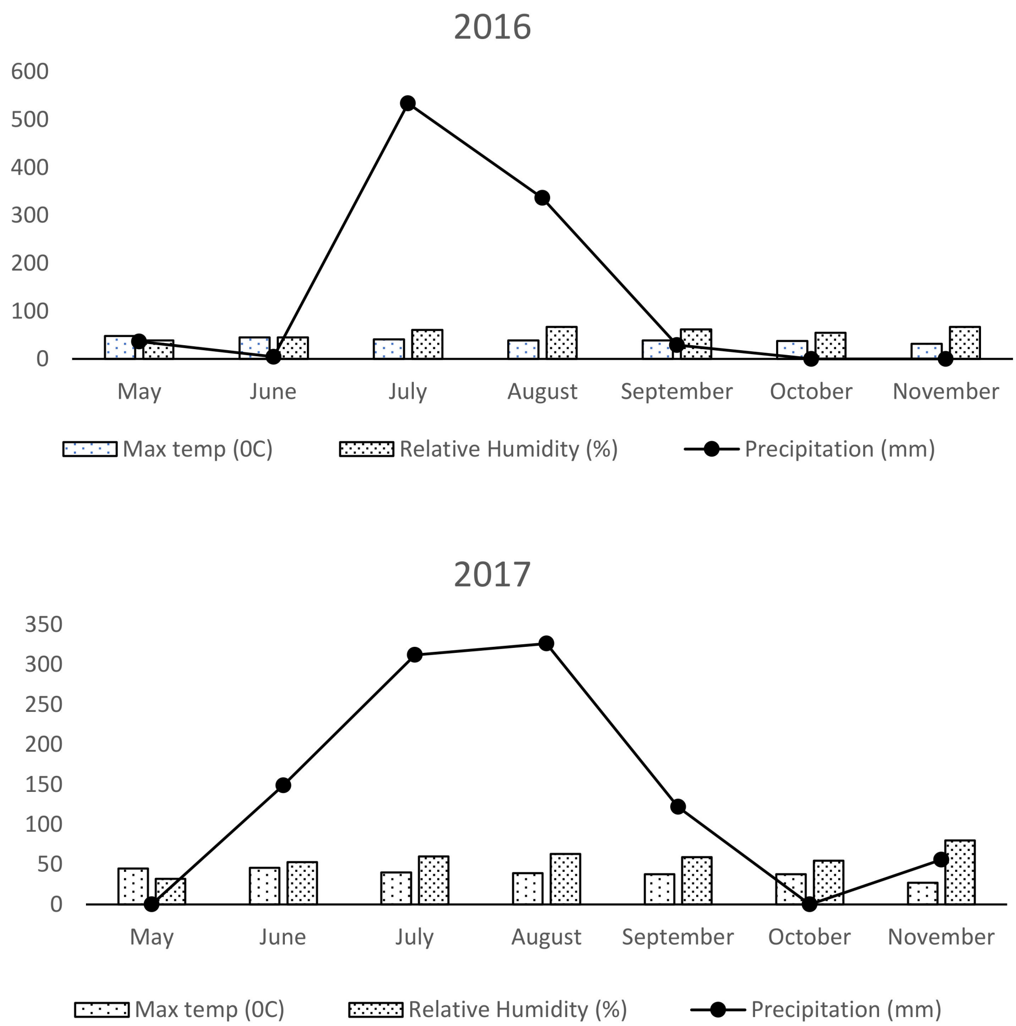

Figure 1. Climatic variations during the growing periods for the years 2016 and 2017.

2.1. Crop Husbandry

The rice seeds were treated with fungicide and direct seeded at 75 kg ha^{-1}. Rice nursery was raised by using seeds at the rate of 1 kg/marla on the same date of sowing for aerobic rice. Then, uprooting of the nursery and its transplanting in the main field was performed manually by maintaining plant to plant and row to row distance of 22 cm.

Recommended amount of fertilizers like nitrogen at the rate of 140 kg ha^{-1} was applied as urea, phosphorus 80 kg ha^{-1} as Diammonium Phosphate (DAP), potassium 60 kg ha^{-1} as Sulphate of Potash (SOP) and lastly zinc at the rate of 12 kg ha^{-1} as $ZnSO_4$. Besides, nitrogen was provided in three equal splits at the time of seed bed preparation, tillering, and panicle initiation. However, whole of P, K, and Zn was also dispersed at the time of seed bed preparation.

In flooded rice, irrigation water was maintained at 3–4 cm in depth during transplantation and a constant water depth of 5–6 cm was maintained after one week of the transplantation. However, irrigation was stopped one week before the harvesting, when the signs of physiological maturity were appeared. For weed control, Butachlor was put in at the rate of 800 mL ha^{-1} in transplanted rice after one week of the transplantation.

To protect the rice field from borer and leaf folder, 25 kg ha^{-1} carbofuran was broadcasted after seven weeks of the transplantation and direct seeded duration. Thiophenate methyl was utilized to control fungal diseases like blast, when it reached the economic threshold level (ETL). For the application of foliar spray at different stages, a stock solution of 2% $MgSO_4$ was prepared and employed at different growth and reproductive stages as explained in Table 2. Two g of magnesium sulphate was dissolved per liter (dm^{-3}) of the solution and a surfactant like 0.1% Tween 20 was added in the solution to ensure proper mixing of the nutrient in the solution. Likewise, the foliar spray was sprinkled in the morning (08:00 to 10:00 a.m.), on the sunny days during the years 2016 and 2017. All the growth parameters like leaf area index, leaf area duration, crop growth rate, and net assimilation rate were measured, by following the procedure described by the previous researcher [34]. For chlorophyll contents, fresh green leaves were collected from each treatment and weighed for 0.5 g, grinded using mortar and manufactured volume of 5 mL using acetone. Finally, the reading of this solution is recorded on the spectrophotometer at 645 and 663 wavelengths, hence total contents were measured following the formula below [35].

$$Total\ chlorophyll = (20.2 \times D645 + 8.02 \times D663) \times \frac{5}{1000 \times 0.05}\ mg/gfw$$

Table 2. Treatment plan for the experiment layout.

Foliar Application of Mg (2% $MgSO_4$)	Rice Cultivation Systems	
	Aerobic Rice (T_1)	**Flooded Rice (T_2)**
Seedling (F_1)	F_1T_1	F_1T_2
Tillering (F_2)	F_2T_1	F_2T_2
Panicle initiation (F_3)	F_3T_1	F_3T_2
Seedling + Panicle initiation F_4)	F_4T_1	F_4T_2
Tillering + Panicle initiation (F_5)	F_5T_1	F_5T_2
Seedling + Tillering + Panicle initiation (F_6)	F_6T_1	F_6T_2

Various yield attributes were calculated by using standard procedure. Ten primary tillers were tagged from each treatment, measured kernel/panicle and its average was drawn out. Additionally, grain yield per plant was also calculated by using portable electric weighing balance. Moreover, the area of one square meter of the land was harvested and total tillers were counted manually. This sample was earmarked as per treatment and placed in the sunshine for drying. In the next step, those samples were threshed manually to remove all grains and the weight of 1000 grains was reckoned from each treatment.

For quality parameters, panicles were randomly selected, like of sterile, abortive, opaque, and normal kernel. A common electric lamp was used for this counting by positioning panicles in front of the light source, and then we converted it into percentage.

2.2. Statistical Analysis

The collected data was tested for normality, by Shapiro–Wilk normality test, which indicated that some of the parameters had non-normal distribution. Therefore, non-normally distributed parameters were transformed by Arcsine transformation technique to meet the normality assumption of the Analysis of Variance (ANOVA). One-way ANOVA was used to test the significance in the dataset. Likewise, LSD at 5% probability was operated as post hoc test to separate the means where ANOVA indicated significant differences were noted. Every analysis was performed on SPSS software version 21.

3. Results

3.1. Growth Pattern of Rice Crop

Foliar application of magnesium significantly affected the various growth parameters of the rice crop grown in different rice cultivation systems. It was evident that the treatment combination revealed that foliar application of magnesium sulphate improved the crop performance both in aerobic as well as in flooded rice, but the crop grown under flooded condition showed accelerated growth in both the cropping seasons. Hence, it was demonstrated that the treatment combination of Flooded rice: Mg application at Seedling + Tillering + Panicle initiation (F6T2) significantly boosted the leaf area index (17.5%, 26.07%), ameliorated the leaf area duration (51.38%, 40.56%), enhanced the crop growth rate (66%, 64%), and refined the net assimilation rate (78%, 77%) over the treatment combination of F1T1. This treatment combination was also found alike as in the Flooded system: Mg application at Tillering + Panicle initiation (F5T2) in LAI, LAD in the first year, while F4T2 under LAD in the second year of the experimentation. While in aerobic rice, Treatment: Mg application at Seedling + Tillering + Panicle initiation (T1F6) also exhibited the supreme results and improved LAI (16%, 17%), upgraded LAD (51%, 30%), refined CGR (63%, 61%), and enhanced NAR (76%, 75%) over treatment F1T1. It was also noted from the results that the crop grown with minimum Mg application significantly reduced the growth as compared to the ample application (Table 3).

Table 3. Variations in growth parameters under foliar application of magnesium in different rice cultivation systems.

Treat	2016				2017			
	LAI	LAD (Days)	CGR (g/m^2/Day)	NAR (g/m^2/Day)	LAI	LAD (Days)	CGR (g/m^2/Day)	NAR (g/m^2/Day)
F_1T_1	4.96 ± 0.74 f	70.3 ± 2.4 i	8 ± 1.2 h	2.12 ± 1.2 g	4.98 ± 05 f	85 ± 3.1 i	9 ± 2.1 h	2.19 ± 0.5 g
F_2T_1	5.48 ± 0.54 e	80.3 ± 2.9 hi	10 ± 0.8 g	3.26 ± 1.8 f	5.59 ± 0.41 e	98.3 ± 2.8 g	11 ± 3.1 g	3.27 ± 0.9 f
F_3T_1	5.48 ± 0.74 e	80.67 ± 3.1 h	13 ± 0.8 f	3.27 ± 0.9 f	5.59 ± 0.2 e	73.3 ± 3.2 j	13 ± 1.2 f	3.26 ± 0.12 f
F_4T_1	5.82 ± 0.47 d	95.33 ± 4 f	16 ± 0.7 e	5.70 ± 1.8 e	5.92 ± 0.4 d	84 ± 2.5 i	17 ± 1.5 e	5.70 ± 0.9 e
F_5T_1	5.81 ± 0.58 d	120 ± 5.2 e	19 ± 0.9 d	5.70 ± 2.1 e	5.91 ± 0.51 d	128 ± 2.8 e	19 ± 0.9 d	5.71 ± 1.2 e
F_6T_1	5.91 ± 0.74 c	142.3 ± 9.2 b	22 ± 1.2 b	8.76 ± 2.5 b	6.01 ± 0.4 c	123 ± 2.4 f	23 ± 1.2 b	8.78 ± 1.3 b
F_1T_2	5.22 ± 0.84 e	85 ± 3.1 g	13 ± 1.9 f	3.26 ± 3.1 f	5.58 ± 0.21 e	98 ± 3.2 g	13 ± 2.1 f	3.27 ± 0.25 f
F_2T_2	5.90 ± 0.45 c	95 ± 4.2 f	16 ± 2.1 e	5.70 ± 2.4 e	6 ± 0.41 c	88 ± 4.2 h	17 ± 0.9 e	5.72 ± 1.2 e
F_3T_2	5.90 ± 0.74 c	125 ± 8.2 d	19 ± 3.2 d	6.61 ± 4.1 d	6 ± 0.51 c	145 ± 4 b	19 ± 1.2 d	6.60 ± 1.3 d
F_4T_2	5.94 ± 0.46 b	129.6 ± 9.6 c	20 ± 4.2 c	7.72 ± 3.2 c	6.3 ± 0.12 b	148.3 ± 5.2 a	20 ± 2.1 c	7.77 ± 1.7 c
F_5T_2	5.98 ± 0.25 a	140 ± 12.2 ab	22 ± 4 b	8.76 ± 3.5 b	6.81 ± 0.41 a	132.7 ± 5.8 d	23 ± 2.5 b	8.76 ± 1.3 b
F_6T_2	5.98 ± 0.31 a	144 ± 14.2 a	24 ± 4.5 a	9.77 ± 3.1 a	6.82 ± 0.24 a	143.33 ± 6.1 c	25 ± 2.4 a	9.79 ± 2.1 a

Means with different letters, differ significantly. LAI: Leaf area index, LAD: Leaf area duration, CGR: Crop growth rate, NAR: Net assimilation rate, T_1: Aerobic, T_2: Flooded, F_1: Mg application at seedling stage, F_2: Mg application at Tillering, F_3: Mg application at Panicle initiation, F_4: Mg application at Seedling + Panicle initiation, F_5: Mg application at Tillering + Panicle initiation, F_6: Mg application at Seedling + Tillering + Panicle initiation.

3.2. Response of Yield Attributes

Treatment comparison for yield attributes also revealed the significant response to foliarly applied magnesium sulphate at different growth stages, in both cultivation systems, i.e., aerobic and flooded rice and in both growing seasons. In the case of plant height, treatment combination of the flooded rice: Mg application at Seedling + Tillering + Panicle initiation (F6T2) enhanced plant height (29.30, 26.61%) over the treatment F1T1, and followed by the treatment combination of the flooded rice: Mg application at

Tillering + Panicle initiation (F5T2). In aerobic condition, treatment F6T1 also increased the plant height (21.23, 20.86%) over treatment F1T1. This treatment combination (T6T2) also enhanced about 28% total tillers, improved 1000-grain weight (83, 79%), groomed kernel/panicle (48.87, 48.14%), and lastly upgraded the paddy yield (52.71, 49%) in comparison to F1T1. Similarly, the highest magnesium level in aerobic rice (F6T1) also recorded 21% taller plants, 17% more total tillers, 34% higher kernel/panicle, 70% heavier grain weight and about 38–45% more paddy yield than examined in the treatment F1T1 in both the years, respectively. The highest paddy yield showed that Mg application at growth and reproductive stages produced higher grains that were growing under flooded condition. Treatment combination of F5T2 also demonstrated very interesting results in which we applied Mg at two stages (growth + reproductive), i.e., Tillering + Panicle initiation. Similarly, in aerobic rice system, these treatment combinations improved the yield in all the areas as compared to the other treatments explained. However, this system persisted as inferior compared with the flooded rice production system. Besides, treatment combination with minimum Mg application, i.e., Mg application at seedling stage, manifested the lowest performance both in aerobic and flooded rice systems. Therefore, the pattern of all the highlighted trends of the various treatments under both the cultivation systems was found quite similar in the two consecutive years, i.e., 2016 and 2017 (Table 4).

Table 4. Variations in yield parameters under the foliar application of magnesium in different rice cultivation systems.

Treat	2016					2017				
	PH (cm)	TT	K/P	1000-GW (g)	PY (g/Plant)	PH (cm)	TT	K/P	1000-GW (g)	PY (g/Plant)
F_1T_1	89 ± 1.8 j	166 ± 4.2 h	68.7 ± 1.3 h	6 ± 0.3 k	12.2 ± 0.02 g	91 ± 2.1 j	166 ± 1.7 i	70.6 ± 1.7 h	8 ± 0.8 l	13.1 ± 0.8 f
F_2T_1	101 ± 1.2 i	179 ± 4.8 g	81 ± 1.5 g	11 ± 0.7 i	15.2 ± 0.8 e	103 ± 1 i	179 ± 2.8 g	83 ± 0.54 g	13 ± 1.2 j	16.2 ± 0.7 e
F_3T_1	104 ± 2.1 h	185 ± 3.8 f	87 ± 0.9 f	14 ± 1.1 h	16.3 ± 0.4 e	106 ± 1.2 h	185 ± 1.8 f	89.0 ± 0.9 f	16 ± 1.2 i	15.6 ± 0.8 e
F_4T_1	107 ± 2.4 g	190 ± 3.8 e	93 ± 0.78 e	17 ± 0.9 f	17.6 ± 0.8 de	109 ± 1.9 g	190 ± 2.2 e	95.0 ± 1.2 e	19 ± 0.9 g	18.6 ± 1.2 d
F_5T_1	109 ± 2.3 f	196 ± 3.7 d	98 ± 1.1 d	19 ± 1.4 e	18.6 ± 0.7 d	111 ± 0.9 f	196 ± 2.3 d	100 ± 1.9 d	21 ± 1.2 f	19.6 ± 1.4 d
F_6T_1	113 ± 1.9 bc	202 ± 4.1 bc	104 ± 1.4 c	23 ± 1.7 c	19.7 ± 0.4 c	115 ± 1.1 d	202 ± 2.8 cd	107 ± 2.3 c	25 ± 1.8 d	24 ± 0.9 c
F_1T_2	100 ± 1.8 i	178.7 ± 4.2 gh	81 ± 1.1 g	10 ± 1.2 j	17.3 ± 0.6 f	102 ± 1.8 i	178 ± 2.4 h	83 ± 0.2 g	12 ± 1.9 k	17.3 ± 1.4 e
F_2T_2	106 ± 2.1 g	191 ± 2.9 e	93 ± 1.2 e	16 ± 0.9 g	21.4 ± 0.2 c	108 ± 2 g	191 ± 1.9 e	95 ± 0.7 e	18 ± 2.1 h	18.7 ± 2.1 c
F_3T_2	111 ± 1.9 c	197 ± 4.3 d	99 ± 0.9 d	21 ± 1.3 d	19.2 ± 0.7 d	113 ± 2.1 e	197 ± 1.2 d	101 ± 1.1 d	23 ± 4 e	20.1 ± 2.3 d
F_4T_2	111 ± 2.5 c	203 ± 4.4 c	105.2 ± 1.3 c	25 ± 1.4 bc	24.7 ± 0.6 b	117 ± 2.4 c	203 ± 2.3 c	107 ± 2.1 c	27 ± 2.8 c	24.9 ± 1.9 c
F_5T_2	119 ± 2.4 b	212 ± 3.1 b	114 ± 0.78 b	29 ± 2.1 b	25.7 ± 0.8 ab	121 ± 1.7 b	212 ± 2.8 b	116 ± 2.3 b	31 ± 1.9 b	25.8 ± 1.5 b
F_6T_2	126 ± 2.8 a	231 ± 3.4 a	133 ± 0.94 a	36 ± 1.4 a	25.8 ± 0.9 a	124 ± 1.9 a	231 ± 1.9 a	135 ± 0.9 a	39 ± 1.7 a	25.9 ± 1.8 a

Means with different letters, differ significantly. PH: Plant Height, TT: Total Tillers, K/P: Kernel/panicle, GW: Grain Weight, PY: Paddy Yield, T_1: Aerobic, T_2: Flooded, F_1: Mg application at seedling stage, F_2: Mg application at Tillering, F_3: Mg application at Panicle initiation, F_4: Mg application at Seedling + Panicle initiation, F_5: Mg application at Tillering + Panicle initiation, F_6: Mg application at Seedling + Tillering + Panicle initiation.

3.3. Kernel Quality

Results revealed that the application of the strategy of foliar application of Mg significantly improved and enhanced the quality traits of the fine rice. Thus, the treatment combination of Flooded rice: Mg application at Seedling + Tillering + Panicle initiation (F6T2), produced on average of about 41.5% higher normal kernels as compared with F1T1. Similarly, under aerobic system treatment, F6T1 recorded 39.57% more normal kernels than F1T1. Normal kernels are the grains which were fully filled and healthiest which can represent quality grains, these grains were found inferior in treatment combination of F1T1 (aerobic rice: Mg application at seedling stage). This treatment combination was also found second-class as compared to flooded rice too. Similarly, if we see the unwanted kernels, it was obvious from the results that the treatment combination of F6T2 recorded 45.64% lower abortive kernels, 40% less opaque kernels and 16.72% reduction in sterile kernels. Hence, in aerobic rice treatment comparison, it was also evident that the treatment F6T1 also reduced about 20.70% abortive kernels, decreased 8% opaque kernel, and declined 8.55% sterile kernels in comparison with the treatment F1T1.These unwanted kernels were found highest in treatments with minimum application of Mg, i.e., a single application on the seedling stage. All these kernels have a share in overall yield of the crop, as these are partially filled or unfilled grains, but in the sense of quality, these grains impair overall rice quality. Trend was also similar in both the cropping years (Table 5).

Table 5. Variations in the quality parameters under the foliar application of magnesium in different rice cultivation systems.

Treat	2016				2017			
	Normal Kernel (%)	Abortive Kernel (%)	Opaque Kernel (%)	Sterile Kernel (%)	Normal Kernel (%)	Abortive Kernel (%)	Opaque Kernel (%)	Sterile Kernel (%)
F_1T_1	40.3 ± 5.1 h	16.3 ± 0.8 a	15.9 ± 0.4 a	13.4 ± 0.2 b	44. 9 ± 1.5 g	17.9 ± 0.2 a	15.9 ± 0.21 ab	13.5 ± 0.21 b
F_2T_1	67.9 ± 8.1 e	14.5 ± 0.7 b	15.9 ± 0.2 ab	11.2 ± 0.5 h	69.6 ± 1.8 e	15.4 ± 0.24 c	15.9 ± 0.41 a	11.4 ± 0.34 h
F_3T_1	65.2 ± 7.3 g	14.6 ± 1.2 b	16.0 ± 0.3 a	12.2 ± 0.21 f	66.9 ± 1.6 f	15.4 ± 0.34 c	16 ± 0.33 a	12.3 ± 0.24 f
F_4T_1	66.9 ± 5.4 f	11.3 ± 1.3 d	15.8 ± 0.41 ab	12.8 ± 0.3 c	69.9 ± 1.7 de	15.3 ± 0.21 c	15.8 ± 0.31 b	12.9 ± 0.10 c
F_5T_1	68.2 ± 6.2 e	14.1 ± 0.7 b	15.8 ± 0.24 bc	12.4 ± 0.5 d	70.9 ± 2.3 cde	15.1 ± 0.27 c	15.8 ± 0.38 bc	11.4 ± 0.12 h
F_6T_1	69.2 ± 4.2 d	14.3 ± 0.21 b	14.6 ± 0.54 bc	12.1 ± 0.4 g	70 ± 8.1 cde	12.1 ± 0.34 f	14.6 ± 0.21 d	12.5 ± 0.31 d
F_1T_2	64.3 ± 5.8 g	14.5 ± 0.34 b	15.12 ± 0.31 b	12.3 ± 0.4 e	67 ± 2.3 f	16.1 ± 0.47 b	15.1 ± 0.41 bc	12.4 ± 0.34 e
F_2T_2	69.6 ± 6.1 d	14.5 ± 0.41 b	14.9 ± 0.24 c	14 ± 0.5 a	71.3 ± 2.6 bc	15.3 ± 0.61 c	14.9 ± 0.34 c	14.1 ± 0.21 a
F_3T_2	69.6 ± 7.1 c	13.5 ± 0.12 c	14.2 ± 0.8 cd	12.4 ± 0.4 d	71.7 ± 1.9 ab	14.4 ± 0.51 d	14.2 ± 0.36 cd	12.5 ± 0.25 d
F_4T_2	69.5 ± 4.2 d	14.5 ± 1.2 b	13.2 ± 0.4 d	11 ± 0.21 i	71.9 ± 1.7 ab	11.8 ± 0.31 g	13.2 ± 0.31 e	11.1 ± 0.31 j
F_5T_2	70.2 ± 5.2 b	10.9 ± 0.9 d	10.2 ± 0.7 de	11.1 ± 0.3 i	71.1 ± 2.5 bcd	11.2 ± 0.27 h	10.1 ± 0.21 ef	12.2 ± 0.24 g
F_6T_2	73.2 ± 4.3 a	7.4 ± 0.21 e	9.5 ± 0.3 e	11.2 ± 0.1 h	75.9 ± 2.7 a	8.1 ± 0.29 i	9.5 ± 0.24 f	11.2 ± 0.12 i

Means with different letters, differ significantly. T_1: Aerobic, T_2: Flooded, F_1: Mg application at seedling stage, F_2: Mg application at Tillering, F_3: Mg application at Panicle initiation, F_4: Mg application at Seedling + Panicle initiation, F_5: Mg application at Tillering + Panicle initiation, F_6: Mg application at Seedling + Tillering + Panicle initiation.

Similarly, other quality traits also showed the significance of the foliar application of magnesium, as the treatment combination of Flooded rice: Mg application at Seedling + Tillering + Panicle initiation (F6T2) produced highest kernel protein contents and kernel amylose contents. While the single application of Mg at the seedling stage in aerobic cultivation system produced the lowest protein contents. Likewise, the leaf analysis for Mg contents, i.e., LMgC (ppm), also disclosed that its highest dose enhanced its contents as compared to the other treatments. Thus, it is also evident that the maximum leaf magnesium conc. (460.77 ppm) was produced with foliar applied $MgSO_4$ at Seedling + Tillering + Panicle initiation growth stages under flooded irrigation system, as compared to all the other combinations. However, minimum leaf magnesium conc. (213.19 ppm) was detected in foliar application of $MgSO_4$ at the Seedling stage under aerobic conditions. It might be the cause that plant improved growth with an efficient amount of chlorophyll contents, which further enhanced the yield and the quality trains of the rice crop (Table 6). The crop grown under flooded condition and received Mg at the most of its growth stages also recorded highest BCR in both the years, while in the second year crop received Mg application at tillering and panicle initiation (F5T2) also noted similar BCR with treatment combination of flooded rice: Mg application at Seedling + Tillering + Panicle initiation (F6T2), Table 7.

Table 6. Effect of the foliar application of Mg on total chlorophyll contents, kernel amylose contents, kernel protein contents, and leaf Mg contents in rice grown under different rice cultivation systems.

Treat	2016				2017			
	TCC (mg g^{-1} FW)	KAC (%)	KPC (%)	LMgC (ppm)	TCC (mg g^{-1} FW)	KPC (%)	KAC (%)	LMgC (ppm)
F_1T_1	1.19 ± 0.01 f	5.51 ± 0.05 i	3.19 ± 0.07 f	213.1 ± 0.01 f	1.23 ± 0.07 f	3.1 ± 0.05 g	7.51 ± 0.04 i	223.1 ± 0.04 g
F_2T_1	2.27 ± 0.05 e	8.45 ± 0.07 h	5.27 ± 0.03 e	255.2 ± 0.08 e	2.29 ± 0.07 e	5.2 ± 0.02 f	8.45 ± 0.01 h	265.2 ± 0.07 f
F_3T_1	2.27 ± 0.04 e	10.87 ± 0.03 g	5.27 ± 0.04 e	355.2 ± 0.07 e	2.29 ± 0.01 e	5.2 ± 0.09 f	10.87 ± 0.05 g	345.2 ± 0.01 f
F_4T_1	2.61 ± 0.08 cd	12.12 ± 0.05 f	6.61 ± 0.06 d	366.6 ± 0.04 d	2.62 ± 0.02 de	6.6 ± 0.07 e	12.12 ± 0.06 f	376.6 ± 0.03 e
F_5T_1	2.60 ± 0.04 d	15.23 ± 0.06 e	6.6 ± 0.05 cd	406.60 ± 0.06 cd	2.61 ± 0.07 d	6.6 ± 0.06 cd	15.23 ± 0.04 e	416.6 ± 0.07 cd
F_6T_1	2.70 ± 0.02 c	17.34 ± 0.08 d	6.7 ± 0.07 c	416.70 ± 0.07 c	2.71 ± 0.05 cd	6.7 ± 0.07 d	17.34 ± 0.02 d	436.7 ± 0.09 d
F_1T_2	2.26 ± 0.09 ef	10.87 ± 0.07 g	5.2 ± 0.07 ef	215.2 ± 0.02 ef	2.28 ± 0.06 ef	5.26 ± 0.06 fg	10.87 ± 0.06 g	235.2 ± 1.0 fg
F_2T_2	2.27 ± 0.07 e	17.34 ± 0.03 d	6.6 ± 0.06 d	266.61 ± 0.06 d	2.28 ± 0.04 e	6.6 ± 0.02 cd	17.34 ± 0.08 d	286.6 ± 0.8 cd
F_3T_2	2.70 ± 0.05 c	20.41 ± 0.07 c	7.7 ± 0.04 c	377.7 ± 0.07 c	2.70 ± 0.02 c	7.7 ± 0.03 bc	20.41 ± 0.07 c	387.7 ± 1.2 bc
F_4T_2	2.72 ± 0.04 b	20.43 ± 0.09 c	7.7 ± 0.02 bc	387.7 ± 0.02 bc	3.00 ± 0.01 bc	7.69 ± 0.07 c	20.43 ± 0.06 c	397.6 ± 0.05 c
F_5T_2	2.76 ± 0.3 ab	22.54 ± 0.02 b	9.7 ± 0.04 b	419.7 ± 0.01 b	3.51 ± 0.03 ab	9.76 ± 0.02 b	22.54 ± 0.02 b	429.7 ± 0.06 b
F_6T_2	2.77 ± 0.08 a	24.74 ± 0.04 a	10.7 ± 0.07 a	460.7 ± 0.07 a	3.52 ± 0.04 a	11.7 ± 0.09 a	28.74 ± 0.07 a	471.7 ± 0.04 a

Means with different letters, differ significantly. TCC: total chlorophyll contents, KAC: kernel amylose contents, KPC: kernel protein contents, LMgC: leaf magnesium contents, T_1: Aerobic, T_2: Flooded, F_1: Mg application at seedling stage, F_2: Mg application at Tillering, F_3: Mg application at Panicle initiation, F_4: Mg application at Seedling + Panicle initiation, F_5: Mg application at Tillering + Panicle initiation, F_6: Mg application at Seedling + Tillering + Panicle initiation.

Table 7. Cost benefit ratio of the rice crop during the foliar application of magnesium on different cultivation methods.

Years	Treatments	Cultivation Method	Grain Yield kg ha^{-1}	Gross Value (Rs/ha)	Total Cost (Rs/ha)	Net Return (Rs/ha)	BCR
2016	Seedling stage	Aerobic	1400	169,650	111,000	58,650	1.53
	Tillering	Aerobic	1500	181,650	112,000	69,650	1.62
	Panicle initiation	Aerobic	1500	181,650	112,500	69,150	1.61
	Seedling + Panicle initiation	Aerobic	1600	193,650	113,000	80,650	1.71
	Tillering + Panicle initiation	Aerobic	1650	199,650	110,000	89,650	1.82
	Seedling + Tillering + Panicle initiation	Aerobic	1720	208,050	112,000	96,050	1.86
	Seedling stage	Flooded	1800	217,650	112,500	105,150	1.93
	Tillering	Flooded	1970	238,050	113,000	125,050	2.11
	Panicle initiation	Flooded	2100	253,650	113,500	140,150	2.23
	Seedling + Panicle initiation	Flooded	2250	271,650	114,000	157,650	2.38
	Tillering + Panicle initiation	Flooded	2400	289,650	115,000	174,650	2.52
	Seedling + Tillering + Panicle initiation	Flooded	2500	301,650	117,000	184,650	2.58
2017	At seedling stage	Aerobic	1450	180,250	112,000	68,250	1.61
	Tillering	Aerobic	1550	192,550	113,000	79,550	1.70
	Panicle initiation	Aerobic	1600	198,700	113,500	85,200	1.75
	Seedling + Panicle initiation	Aerobic	1700	211,000	114,000	97,000	1.85
	Tillering + Panicle initiation	Aerobic	1750	217,150	111,000	106,150	1.96
	Seedling + Tillering + Panicle initiation	Aerobic	1820	225,760	113,000	112,760	2.00
	At seedling stage	Flooded	1900	235,600	113,500	122,100	2.08
	Tillering	Flooded	2070	256,510	114,000	142,510	2.25
	Panicle initiation	Flooded	2200	272,500	114,500	158,000	2.38
	Seedling + Panicle initiation	Flooded	2350	290,950	115,000	175,950	2.53
	Tillering + Panicle initiation	Flooded	2500	309,400	116,000	193,400	2.67
	Seedling + Tillering + Panicle initiation	Flooded	2550	315,550	118,000	197,550	2.67

4. Discussion

It is perceptible from the analysis and results that the rice crop needs Mg at various stages and the uniform spread of Mg application over growing season at some critical stages can definitely boost the rice crop production. The results demonstrate that from 59 to 84% of the nutrients present in the ripe plants were absorbed between tillering and flowering. Additionally, more than 90% of the N and K, 80% of the P and Ca, and 65% of the Mg were absorbed prior to flowering, and then soaked up after heading [36]. Hence, it was also riveting to note that Mg when applied at the tillering stage only resulted in reduced growth indices over those where Mg was applied at two stages, i.e., seedling and tillering stage. It depicts that rice plants positively responded to Mg supply at seedling and tillering stages consequently. Hence, growth is improved even further in plots where rice plants were supplied with Mg at panicle initiation stage too. Significantly, the minimum growth (LAI, LAD, CGR, NAR, etc.) was reflected in rice plants grown in aerated condition treated with one-time Mg application at the seedling stage. It might be due to the reduced irrigation water and less absorbed nutrients in aerobic rice plants [1,2], and we need to be more careful about nutrient application while growing the crop in aerobic soil culture [7–9].

In addition, the yield associated parameters reflected significant variations among employed treatments. Besides, highest paddy yield was attained in the flooded plots, where rice plants received Mg fertilization at three stages, i.e., seedling, tillering, and panicle initiation, that could be attributed, to improve tillers, to enhance kernel to panicle ratio and the production of the heavier 1000 grains (Table 4). Hence, it might be due to the sufficient availability of Mg nutrients to all the rice plants, which may create balance among different essential nutrients and plants to improve physiological mechanisms including photosynthesis. Some previous studies also reported better crop performance under Mg application under foliar or soil application methods [17,27,29].

High mobility of Mg in the soil as well as in the plants have got attention for its needs to be considered in the nutrient management. Therefore, the understanding of Mg physiology in the plants and its role under stress condition is highly important for successful and sustainable crop production [37]. Thus, for wheat it has been shown that the nitrogen application has not only improved the Mg uptake, but also enhanced the translocation from the root to the shoot. Similarly, by increasing the NO3− supply increased the uptake of Mg, but decreased the translocation [38]. Particularly, under low Mg conditions, there was a higher risk of Mg deficiency symptom development. Besides, the actual Mg availability over a growing season heavily depends on (i) various environmental factors (rainfall and timing, etc.), (ii) site-specific conditions (soil type, availability of other nutrients, etc.), and (iii) the crop species making a precise prediction almost impossible [37]. Additionally, Mg application significantly improved the kernel yield which might be due the direct role of Mg in plants as well its role in the uptake of other nutrients as reported previously [39]. The yield differences among aerobic and flooded rice ranged from 8 to 69% depending on the number of seasons, dry and wet seasons and varieties. Similarly, the yield gap between aerobic and flooded rice can be owing to the variation in the sink formation and to some extent it depends upon the grain filling percentage and 1000 grain weight. Therefore, among the yield components the sink size could have resulted in more yield gap between aerobic and flooded rice [40].

Mg directly involves in chlorophyll synthesis, contributing to improve photosynthesis and assimilates production. Likely, the heavier grains under Mg application at three stages suggest that Mg uptake and assimilation could have improved the dry matter production, translocation and accumulation. Hence, the data reflects the importance of Mg application to rice plants at the three stages under reduced/flooded condition. It was pertinent to observe that besides growth and yield, the highest normal kernel % was obtained after injecting Mg fertilizer dose at seedling, tillering and panicle initiation. Whereas least abortive kernels, opaque kernels, and sterile kernels % age was also produced in the treatment F6T2 under Mg application at three different stages. Mg is an integral part of chlorophyll, and by providing supplemental Mg, can improve photosynthetic efficiency too. Improved Mg fertilization at critical stages can also aid in improving the quality of the production.

Improved TCC, KAC, KPC, and LMgC were found highest in the flooded rice plots supplied with Mg at 3 stages viz seedling, tillering, and panicle initiation. Therefore, the degree of the enrichment of the above parameters decreased gradually as the Mg supplementation reduced from 3 to 1. Hence, it was again discerned that the plots with poor condition owing to flooding, reflected better performance in terms of parameters mentioned above. Likewise, the higher leaf Mg content in plots receiving Mg at all the 3 stages mentioned above explains why the total chlorophyll contents are higher in these plots as compared to the other plots receiving less Mg. Moreover, the flooded plots with rice plants having better leaves TCC and LMgC, TPC, and KAC in comparison to the aerobically maintained plots. Higher benefit cost ratio (BCR) in rice plots kept flooded and fertilized with Mg at three stages viz seedling, tillering, and panicle initiation during both the years reflects the viability and economic feasibility of application of Mg at the above mentioned three stages during both the years of the study. However, during the 2nd year of this study, the plots where Mg was applied to the soil at two stage, i.e., tillering and panicle initiation under flooded condition, demonstrated similar benefit cost ratios (BCR), as was the case where three-time Mg was applied. It might be due to most favorable climatic conditions and the higher soil magnesium contents, which alleviated the crop performance.

5. Conclusions

Rice plants grown under flooded condition and with combined application of Mg at growth and reproductive stages (F6T2) enhanced (52.71% and 49.42%) grain yield over rice grown in aerobic condition and with single application of Mg at seedling stage (F1T1) in both growing seasons, respectively. Similarly, rice produced aerobically also enhanced (38%, 45%) paddy yield with combined Mg application (F6) as compared with single application (F1). Moreover, the strategy of combined Mg fertilization on growth as well as on reproductive stages (F6) also emerged as economically sound with the highest BCR (2.58, 2.53) under flooded condition followed by aerobic system (1.86, 2.0) in both cropping seasons.

Author Contributions: H.A.: conceptualize the experiment and supervise the research work; N.S.: plan layout and methodology; S.M.: collected data; O.F.: helped for statistical analysis; A.-u.R. and K.M.: writing and preparation of initial draft; A.W.: review and editing; T.A.Y.: investigation; M.N.A.: visualization. All authors have read and agreed to the published version of the manuscript.

Funding: Research work was funded by Office of innovation, research and commercialization (ORIC), Bahauddin Zakariya University Multan Pakistan.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Challinor, A.J.; Watson, J.; Lobell, D.B.; Howden, S.M.; Smith, D.R.; Chhetri, N. A meta-analysis of crop yield under climate change and adaptation. *Nat. Clim. Change* **2014**, *4*, 287–291. [CrossRef]
2. Sarwar, N.; Maqsood, M.; Wajid, S.A.; Anwar-ul-Haq, M. Impact of nursery seeding density, nitrogen, and seedling age on yield and yield attributes of fine rice. *Chil. J. Agric. Res.* **2011**, *71*, 343–348. [CrossRef]
3. Sarwar, N.; Ali, H.; Ahmad, A.; Ullah, E.; Ahmad, S.; Mubeen, K.; Hill, J.E. Water wise rice cultivation on calcareous soil with the addition of essential micronutrients. *J. Anim. Plant Sci.* **2013**, *23*, 244.
4. Sarwar, N.; Ali, A.; Maqsood, M.; Ullah, E.; Shahzad, M.; Mubeen, K.; Shahzad, A.N.; Shahid, M.A.; Ahmad, A. Phenological response of rice plants to different micronutrients application under water saving paddy fields on calcareous soil. *Turk. J. Field Crop.* **2013**, *18*, 52–57.
5. Sarwar, N.; Ali, H.; Maqsood, M.; Ahmad, A.; Ullah, E.; Khaliq, T.; Hill, J.E. Influence of nursery management and seedling age on growth and economic performance of fine rice. *J. Plant Nutr.* **2014**, *37*, 1287–1303. [CrossRef]
6. Sarwar, N.; Javaid, M.H.; Neelam, A.; Rehaman, A.; Farooq, O.; Wasaya, A.; Mubeen, K.; Ghani, A.; Mushtaq, M.Z. Application of spermidine to manage water stress for improved fine rice yield and quality. *Pure Appl. Biol.* **2020**, *9*, 1813–1819. [CrossRef]
7. Sarwar, N.; Rehman, A.; Farooq, O.; Wasaya, A.; Saliq, S.; Mubeen, K. Improved auxin level at panicle initiation stage enhance the heat stress tolerance in rice plants. In Proceedings of the 2019 Agronomy Australia Conference, Wagga Wagga, Australia, 25–29 August 2019.
8. Fu, G.; Zhang, C.; Yang, X.; Yang, Y.; Chen, T.; Zhao, X.; Fu, W.; Feng, B.; Zhang, X.; Tao, L.; et al. Action mechanism by which SA alleviates high temperatureginduced inhibition to spikelet differentiation. *Chin. J. Rice Sci.* **2015**, *29*, 637–647.
9. Zhang, C.X.; Feng, B.H.; Chen, T.T.; Zhang, X.F.; Tao, L.X.; Fu, G.F. Sugars, antioxidant enzymes and IAA mediate salicylic acid to prevent rice spikelet degeneration caused by heat stress. *Plant Growth Regul.* **2017**, *83*, 313–323. [CrossRef]
10. USDA. *USDA's April 2019 World Agricultural Supply and Demand Estimates Report*; USDA: Washington, DC, USA, 2019.
11. Fahad, S.; Muhammad, Z.I.; Abdul, K.; Ihsanullsh, D.; Saud, S.A. Consequences of high temperature under changing climate optima for rice pollen characteristics-concepts and perspectives. *Arch. Agron. Soil Sci.* **2018**. [CrossRef]
12. Gao, X.; Zou, C.; Fan, X.; Zhang, F.; Hoffland, E. From flooded to aerobic conditions in rice cultivation: Consequences for zinc uptake. *Plant Soil.* **2006**, *280*, 41–47. [CrossRef]
13. Mikkelsen, R. Soil and fertilizer magnesium. *Better Crops* **2010**, *94*, 26–28.
14. Scheffer, F.; Schachtschabel, P.; der Bodenkunde, L.; Verlag, S.A.; Senthilkumar, H.K.; Bindraban, P.S.; Thiyagarajan, T.M. *Water-Wise Rice Production*; International Rice Research Institute: Los Banos, CA, USA, 2002.
15. Choudhury, T.M.A.; Khanif, Y.M. Evaluation of Effects of Nitrogen and Magnesium Fertilization on Rice Yield and Fertilizer Nitrogen Efficiency Using 15n Tracer Technique. *J. Plant Nutr.* **2001**, *24*, 855–871. [CrossRef]
16. Ding, Y.; Luo, W.; Xu, G. Characterisation of magnesium nutrition and interaction of magnesium and potassium in rice. *Ann. Appl. Biol.* **2006**, *149*, 111–123. [CrossRef]
17. Römheld, V.; Kirkby, E.A. *Magnesium Functions in Crop Nutrition and Yield*; The International Fertiliser Society: York, UK, 2007; pp. 151–171.
18. Bybordi, A.; Jasarat, A.S. Effects of the foliar application of magnesium and zinc on the yield and quality of three grape cultivars grown in the calcareous soils of iran. *Not. Sci. Biol.* **2010**, *2*, 81–86. [CrossRef]
19. Kumar, V.; Ladha, J.K. Direct seeding of rice: Recent developments and future research needs. *Adv. Agron.* **2011**, *111*, 297–413.
20. Deng, W.; Luo, K.; Li, D.; Zheng, X.; Wei, X.; Smith, W.; Thammina, C.; Lu, L.; Li, Y.; Pei, Y. Over expression of an Arabidopsis magnesium transport gene, At MGT1, in Nicotiana benthamiana confers Al tolerance. *J. Exp. Bot.* **2006**, *57*, 4235–4243. [CrossRef]
21. Shaul, O. Magnesium transport and function in plants: The tip of the iceberg. *Biometals* **2002**, *15*, 309–323. [CrossRef]
22. Gardner, R.C. Genes for magnesium transport. *Curr. Opin. Plant Biol.* **2003**, *6*, 263–267. [CrossRef]
23. Maguire, M.E.; Cowan, J.E. Magnesium chemistry and biochemistry. *Biometals* **2002**, *15*, 203–210. [CrossRef]
24. Hussain, M.; Shah, S.H.; Nazir, M.S. Effect of foliar application of calcium cum magnesium on different agronomic traits of three genotypes of Lentil (Lens culinaaris Medic). *Pak. J. Agric. Sci.* **2002**, *39*, 123–125.

25. Fageria, V.D. Nutrient interactions in crop plants. *J. Plant Nutr.* **2001**, *24*, 1269–1290. [CrossRef]
26. Gupta, R.K.; Naresh, R.K.; Hobbs, P.R.; Jiaguo, Z.; Ladha, J.K. Sustainability of post-green revolution agriculture: The rice–wheat cropping systems of the Indo-Gangetic Plains and China. In *Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts*; Ladha, J.K., Hill, J.E., Duxbury, J.M., Gupta, R.K., Buresh, R.J., Eds.; American Society of Agronomy: Madison, WI, USA, 2003; pp. 1–25.
27. Khalifa, R.; Shaaban, K.M.S.; Rawia, A. Effect of foliar application of zinc sulfate and boric acid on growth, yield and chemical constituents of iris plants. *Ozean J. Appl. Sci.* **2011**, *4*, 129–144.
28. Dobermann, A.; Fairhurst, T. *Rice: Nutrient Disorders & Nutrient Management*; Potash & Phosphate Institute: Atlanta, GA, USA, 2002.
29. Sharma, P.K.; Bhushan, L.; Ladha, J.K.; Naresh, R.K.; Gupta, R.K.; Balasubramanian, B.V.; Bouman, B.A.M. Crop-water relations in rice-wheat cropping under different tillage systems and water management practices in a marginally sodic, medium-textured soil. In *Water-Wise Rice Production*; International Rice Research Institute: Los Baños, CA, USA, 2002; pp. 223–235.
30. Alam, S.S.; Moslehuddin, A.Z.M.; Islam, M.R.; Kamal, A.M. Soil and foliar application of nitrogen for Boro rice (BRRI dhan 29). *J. Bangladesh Agril. Univ.* **2010**, *8*, 199–202. [CrossRef]
31. Rajakumar, D.; Gurumurthy, S. Effect of plant density and nutrient spray on the yield attributes and yield of direct sown and polybag seedling planted hybrid cotton. *Agric. Sci. Digest* **2008**, *28*, 174–177.
32. Marschner, H. *Mineral Nutrition of Higher Plants*; Elsevier: Amsterdam, The Netherlands, 2012.
33. Patrick, W.H., Jr.; Mahapatra, I.C. Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. *Adv. Agron.* **1968**, *20*, 323–356.
34. Hunt, R. *Plant Growth Analysis*; Edward Arnold: London, UK, 1978; pp. 26–28.
35. Yoshida, S.; Forno, D.A.; Cock, D.H.; Gomez, K.A. *Laboratory Manual for Physiological Studies of Rice*, 3rd ed.; IRRI: Los Banos, CA, USA, 1976.
36. Ramanathan, K.M.; Krishnamoorthy, K.K. Nutrient uptake by paddy during the main three stages of growth. *Plant Soil* **1973**, *39*, 29–33. [CrossRef]
37. Gransee, A.; Führs, H. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant Soil* **2012**, *368*, 5–21. [CrossRef]
38. Huang, J.W.; Grunes, D.L. Effects of root temperature and nitrogen form on magnesium uptake and translocation by wheat seedlings. *J. Plant Nutr.* **1992**, *15*, 991–1005. [CrossRef]
39. Brohi, A.R.; Karaman, M.R.; Topbaş, M.T.; Aktaş, A.; Savaşli, E. Effect of Potassium and Magnesium Fertilization on Yield and Nutrient Content of Rice Crop Grown on Artificial Siltation Soil. *Turk. J. Agric. For.* **2000**, *24*, 429–435.
40. Peng, S.; Bouman, B.; Visperas, R.M.; Castaneda, A.; Nie, L.; Park, H.K. Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight season experiment. *Field Crops Res.* **2006**, *96*, 252–259. [CrossRef]