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Variable rate inorganic foliar fertilization effect on paddy leaves chlorosis, plant growth and yield performance

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ABSTRACT

Foliar feeding has been growing in popularity and has been used to supplement the soil-based fertilizer applications to enhance the growth and yield of crops. However, spraying a high concentration of foliar fertilizer can cause a leaf burn effect while a low concentration of fertilizer application can show symptoms of nutrient deficiencies on the leaf. This study was conducted to determine the effect of foliar fertilization on paddy leaf chlorosis and its impact on plant growth and yield performances between variable rate application (VRA) and uniform rates of supplying the fertilizer. The experiment was performed for two planting seasons and had four nitrogen (N) treatments (50% fixed rate, 100% fixed rate, 150% fixed-rate, and VRA) that arranged in a randomized complete block design (RCBD) with four replications. Paddy leaf chlorosis counts, plant growth (plant heights, number of tillers, number of panicle and flower), and yield performances (grain yield, number of grains, 1000-grain weight, and number of spikelets) were collected and recorded. The results showed no sign of leaf burns, however, showed chlorosis condition on the paddy leaves for all the treatments. VRA had the lowest chlorosis counts and had the highest SPAD readings at every planting stage for both planting seasons. While for plant growth performance, VRA showed moderate plant heights however had a higher number of tillers, panicle, and flowers compared to uniform rate treatments. So, VRA significantly produced more yield compared to uniform rates in both planting seasons. Therefore, foliar fertilization of VRA performed better compared to the uniform rate treatments.

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chlorophyll-N content; leaf burn; nutrient's deficiency; precision farming; SPAD chlorophyll meter

1. Introduction

Today, the wave of the agriculture technique known as precision farming (PF) is inevitably in the agriculture sector as part of the Agriculture Industrial Revolution 4.0. Precision farming is a term that has been used in managing the variability within the crop planting system. PF is a comprehensive system designed to optimize agricultural production by carefully tailoring soil and plant management to fit the different conditions found in each field while maintaining environmental quality (Shi et al. 2020). One of the most promising site-specific management is variable rate application (VRA) for farm inputs. VRA emphasized in improving the farm's economic efficiency and environmental protection through the precise application of agronomic inputs at the right

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place, in the right amount, and at the right time (Athanasios et al. 2017). It has been applied within paddy cultivation around the globe including in the Malaysia region.

VRA of N fertilizer has been extensively studied worldwide for the paddy cultivation. The main reason is due to the limiting factor of N that becomes a major issue in maintaining the sufficiency level of N within the planting system (Yasuyuki 2016). Shortage of N could lead to chlorotic conditions, affecting the crop growth and limiting the yield. N deficiency symptoms on paddy plants can be observed during vegetative and reproductive growth by exhibiting the leaf yellowing to yellow-brown color if the deficiency is too severe (Abd. Kharim et al. 2020). In fact, some of the plants showed dwarf physical conditions, leaves wilting and poor yield physical performance if the fertilizer rates used are low (Abd. Kharim et al. 2019). The variable rate of N application can offer the potential in improving the planting growth and increase the yield production, while minimizing the input and wastage application within the planting operation and reducing the environmental impacts.

Apart from that, foliar fertilization is an alternative fertilizer application in paddy cultivation by spraying the liquid fertilizer directly onto the leaf (Zahanggir et al. 2015). Foliar fertilization is widely used practice to correct nutritional deficiencies in plants caused by improper supply of nutrients to roots. Thus, foliar fertilizer application may not be able to completely replace soil fertilization, but it is a way to promote the efficiency of nutrient absorption into plant cells, which would certainly have an effect on yield and quality in rice grains. This technique has been reported as an efficient method as it allows the absorption to occur rapidly into the inner cell layers of the leaf and other reproductive organs (Al-Khuzai and Al-Juthery 2020). This method is also considered an effective technique in boosting the yield which recently draws researcher's attention for its less dependency on soil-based fertilizer with low volume of application that suit for the UAV aerial spraying technique. It was proven that the efficiency of foliar application is three- to fivefolds greater than soil-based fertilizers, and can thus significantly reduce the amount of fertilizer usage (Sandhya, Ghiridara, and Munirathnam 2014). Furthermore, it is an economical way of supplementing the plant's nutrients when they are in short supply or unavailable form in the soils. The only issues of foliar fertilization are having leaves burn if a high dosage of fertilizer application is used, improper handling and overlap spraying during the application. Therefore, understanding the accurate amount of nutrients required by the plant before application of fertilizer is essential to prevent leaf burn incidences due to inaccurate application of fertilizer rates to the plant.

Therefore, in this experiment, VRA of foliar fertilization was applied accordingly to PF principles by using SPAD chlorophyll meter to formulate an accurate amount of N to fertilize the paddy plant without the application of granular fertilizer. The objective of the study was to determine the effect of VRA and uniform rates of foliar fertilization on paddy leaves chlorosis, growth morphology, and its impact on yield performances. The VRA was hypothesized capable to supply precise amount of N rates according to the actual requirement of the paddy plant based on the spatial reflectance of paddy leaves at different growth stages. Since N is one of the key limiting nutrients in paddy cultivation, knowing the precise N level required by the paddy plant is crucial in fertilizer management to optimize plant growth and increase the yield.

2. Materials and methods

2.1. Site, treatment, and cultural operations

The experiment was conducted in two planting seasons (1st season: 1 January to 30 April 2017, and 2nd season: 8 May to 4 September 2017) at Ladang 2, Universiti Putra Malaysia with coordinates 3.0087° N, 101.7037° E. MR219 paddy cultivar was planted in the pot (40 cm heights; 34 cm diameter) filled with 10 kg of uniformly mixed soil. The experimental soil used was sandy clay loam with pH 6.2, soil organic matter 4.31%, total N 0.19%, available phosphorus 254.1 kg/ha, available potassium 299.7 kg/ha, and CEC 17 cmol/kg soil.

The experiment was laid out in a randomized complete block design (RCBD) with four treatments and four replications for each treatment. The treatments were uniform rate (50% fixed rate, 100% fixed rate, and 150% fixed rate) and VRA that used SPAD chlorophyll meter to measured chlorophyll content in the paddy leaf to calculate foliar fertilization amount. The experiment used an inorganic nitrogen (N), phosphorus (P), and potassium (K) foliar fertilization (21:21:21) as solely fertilizer source without application of any granular fertilizer and was given according to supplier recommendation during early plant establishment 15 days after transplanting (DAT), mid-tillering stage (35 DAT), panicle initiation stage (55 DAT), and flowering stage (65 DAT). The amount of NPK foliar fertilization to every treatment can be seen in Table 1 on various DAT for both planting seasons. A handheld pump sprayer was used to perform the foliar spraying at the top of the canopy of the paddy plant and every plant received a separate session of liquid spraying based on the amount that actually required by the paddy plant until the spraying liquid was finished. The experiment only measured N content in the leaves to determine the right concentration rate and amount of N fertilizer. While other mineral elements were prepared and given according to supplier recommendation. Single seedling sown per pot was performed in the experiment after pre-germinated in a nursery tray for 14 days. The water regime in the pot was set up by maintaining 3 cm water from the topsoil that mimics the actual planting condition as planting at the main field. Other control measures such as pest and disease control were performed accordingly to the local agricultural department's recommendation methods to prevent experimental variability.

2.2. SPAD measurement

A SPAD-502 chlorophyll meter was used to measure chlorophyll content within the paddy leaf to determine the precise calculation of N fertilizer required by the paddy plant. SPAD readings of paddy leaves were performed on outermost and fully expanded leaves where triplicate readings were taken on the tip, midway between the leaf base, and one side of the leaf's midrib leaf; all these readings were averaged (Zhaofeng et al. 2016). SPAD readings for the paddy leaves were measured before and after fertilizer application; at the early plant establishment (15 and 18 DAT), mid-tillering (35 and 38 DAT), panicle initiation (55 and 58 DAT), and flowering (65 and 68 DAT). Apart from that, SPAD reading for every 10 DAT until 95 DAT was also measured to observe the relation of chlorophyll content of the paddy plant at every growth stage.

2.3. N Application formula

The N application formula was developed according to formulation that has been created by Gholizadeh et al. (2011) for the threshold level of chlorophyll content in the Malaysian areas of paddy cultivation. The formulation was developed to determine the amount of N that required for the foliar feeding to the plant. At early crop establishment (15 DAT) until mid-tillering (35 DAT), formula N (mg/L) $= 0.80 + 0.93*\text{SPAD}$ [1] was used to determine the N content. Then, at panicle initiation (55 DAT) and flowering (65) stages, formula N (mg/L) $= -2.61 + 0.98*\text{SPAD}$ [2] was used to determine the N content. The final formula (mL) $= [A$ – (formula (1) or (2)/ 1000)]/C [3] was applied to determine the precise amounts of foliar fertilization (mL) needed for liquid spraying, where: A is the threshold level of N in the rice leaves in mg/mL while C is the N amount in percentage of the foliar fertilization used.

Table 1. N, P, K spray amount (mg/L) per paddy plant on various DAT in two planting seasons.

Treatment	N spray amount (mg/L)/plant								P spray amount (mg/L)/plant								K spray amount (mg/L)/plant							
	1st season				2nd season				1st season				2nd season				1st season				2nd season			
DAT	15	35	55	65	15	35	55	65	15	35	55	65	15	35	55	65	15	35	55	65	15	35	55	65
50% fixed rate	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8
100% fixed rate	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6
150% fixed rate	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2	185.2
VRA	16.3	46.3	41.7	7.2	17.2	47.3	42.2	8.5	16.3	46.3	41.7	7.2	17.2	47.3	42.2	8.5	16.3	46.3	41.7	7.2	17.2	47.3	42.2	8.5

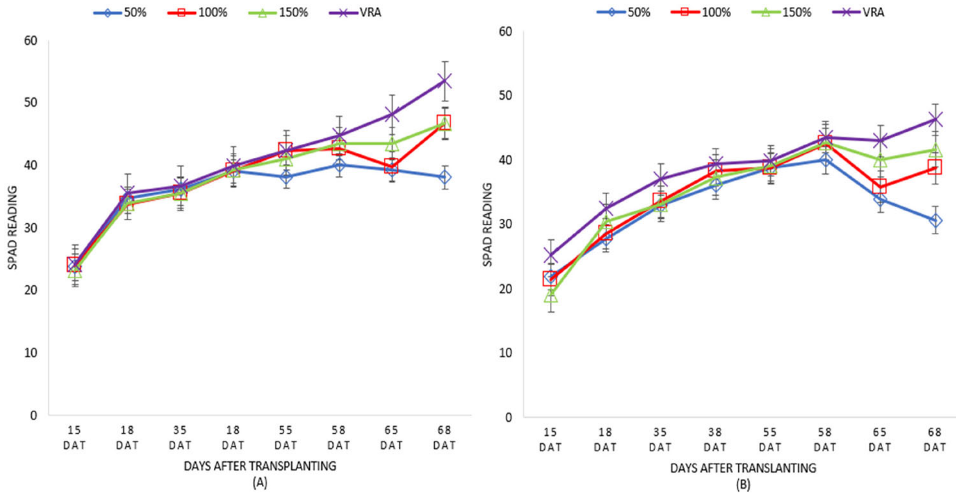

Figure 1. SPAD readings for all the treatments during four split time of foliar fertilization in two planting seasons; (A) 1st season, (B) 2nd season.

2.4. Plant sampling

In terms of plant growth performance, sampling for plant height and number of tillers was recorded for every 10 DAT until 95 DAT. While for the number of panicles and flowers was taken during the 55 DAT, 65 DAT, 75 DAT, and 85 DAT. Hence, the yield performance of paddy plant was recorded accordingly taken by the samples of the number of grains, grains yield, 1000-grain weight, and the number of spikelets after the harvesting process. Sampling for chlorosis counts of the paddy leaves was performed by conducting the visual observation of the young and old leaves conditions through the experiment. Under N deficiency, young leaves usually were still in green color but slightly showed lemon-yellowish color, with narrow and short leaves, compared to old leaves where usually all the leaves looked light pale green, and chlorotic at the tip. Observation and sampling of the leaf burn effect were done right way after the process of foliar fertilization since the effect only can be visually observed on the leaf after the spraying process. Sampling to measure the chlorosis counts and leaf burn on paddy leaves were conducted every 10 days from 15 DAT until 95 DAT for all treatments. All the sampling was collected and recorded as parameter data to determine the effect of VRA over uniform rates of foliar fertilization.

2.5. Statistical analysis

In the experiment, data were analyzed using Statistical Analysis System Software (SAS 9.1, SAS, USA). All data recorded and collected were subjected to a two-way of analysis of variance (ANOVA) and means values of every treatment were compared by using Tukey's honest significant difference (HSD) test at a 0.05 probability level.

3. Results and discussion

3.1. SPAD readings

SPAD readings of all the treatments in both planting seasons were shown in Figure 1. VRA shows the highest SPAD readings in both planting seasons compared to other treatments followed by 150%, 100%, and 50% fixed rates, respectively. SPAD readings of all the treatments represent a sigmoid curve according to the lifespan of the paddy plant which has similar patterns as shown in the experiment performed by Abd. Kharim et al. (2019). From Figure 1, 50% fixed rates of fertilizer treatments showed an increment in SPAD readings until 55 DAT however kept decreasing until 68 DAT even though liquid spraying was performed for later planting stages in both planting seasons. This indicated that a 50% fixed rate was unable to supply enough N fertilizer amount to the paddy plant as the SPAD reading pattern shows a decrement trend during the planting stages from 58 DAT until 68 DAT.

While during the 58 DAT until 65 DAT, there was a sharp decrement in SPAD readings for treatments 50%, 100%, and 150% fixed rates. This shows that there was a decline in the chlorophyll content and N amount within the paddy leaves. During this period, paddy plants were in a phase of reproduction phase for the panicle and flowering initiation thus require another N fertilizer supplement to avoid N nutrient deficiency that later could affect yield production (Hu et al. 2014). Therefore, during the period of 58 DAT until 65 DAT, split foliar fertilization should be applied to prevent a sharp decline in the SPAD readings to elevate the reproduction phase of the paddy plant. It was proven that other previous research studies showed that SPAD threshold level below 35 during the period of 55 DAT until 68 DAT could affect later yield production, especially the panicle initiation process (Abd. Kharim et al., 2019). It was undeniable that higher panicle initiation was crucial for high production of the flowering process which directly reflects higher grain yield produces. VRA showed superior trends of SPAD reading compared to other treatments by showing no decrement of SPAD readings from early planting until 68 DAT. This indicates that VRA treatment manages to supply sufficient N to the paddy plant due to high SPAD readings that reflect sufficient green color of the paddy leaves since the contribution for the greenness of plant leaves came from a high level of chlorophyll- N content in the plant. The main reason why VRA treatment showed better SPAD readings compared to other treatments is the VRA's ability to supply the N fertilizer to the paddy plant based on the actual need of the plant according to its specific growth stages. This proves that VRA of foliar fertilization by using the SPAD chlorophyll meter is capable to predict accurately the chlorophyll-N content in the paddy plant thus helping effectively in supplying a precise amount of N fertilizer to the plant with better monitoring of the fertilizer management regime.

3.2. Chlorosis effect on paddy leaves

In the experiment, chlorotic conditions were monitored through visual observation to detect discoloration on the leaves. The discoloration on the paddy leaf was determined based on the changing color from green to yellow whether on certain leaf regions or complete region of the leaf which usually exhibit earlier at older leaf compared to new leaf since N was a mobile type of nutrient deficiency (Chen et al. 2014). Decoloration of the green leaf could be a sign of the reduction in photosynthesis that has a close relationship to the reduction of N content in the leaf. All the treatments showed chlorosis conditions on paddy leaves in the experiment. At the early stages (15 DAT) of the paddy plant, only VRA showed no chlorosis sign on the paddy leaves during the first planting season however showed a sign of chlorosis on the leaf during the second planting season. On the other hand, all the uniform treatment rates have begun to show visible chlorosis signs on the leaves at the early stages (15 DAT) in both planting seasons. During the planting stages from 35 DAT until 95 DAT for both planting seasons, all the treatments showed significant differences in terms of chlorosis counts where treatment of VRA had the lowest chlorosis counts compared to uniform treatment rates. As mentioned by Fageria and Santos (2015), a large number of nutrients N was crucial for the development of tiller and panicle, especially during the period of active tillering (35 DAT) and panicle initiation (65 DAT). Therefore, a high number of leaf chlorosis could be observed as the N was supplied insufficiently. Treatments of 50%, 100%,

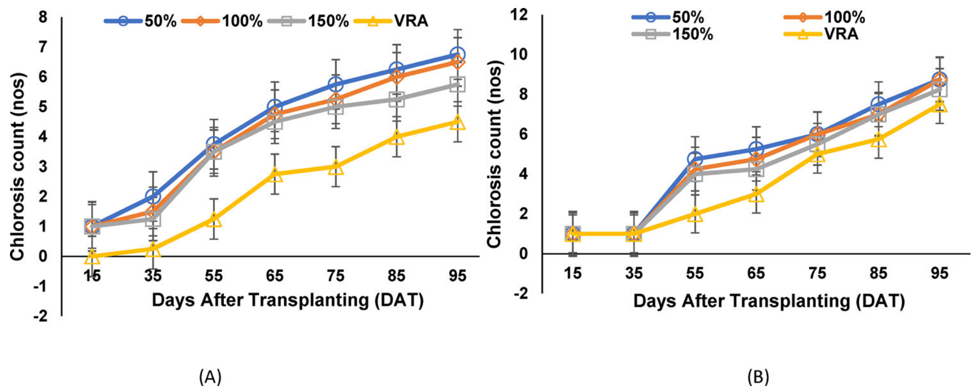

Figure 2. Chlorosis counts on paddy leaves between all the treatments on various DAT in two planting seasons, (A) 1st season, (B) 2nd season.

Table 2. Comparison of paddy growth characteristics between different treatment rates in two planting seasons.

Treatments	Plant height (cm)		Number of tillers per hill		Number of panicles per hill		Number of flowers per hill	
Season	1st	2nd	1st	2nd	1st	2nd	1st	2nd
50%	83.50a*	82.70a*	3.25a*	3.00a*	1.25a*	1.00a*	1.25a*	1.00a*
100%	98.30a*	97.50a*	4.50a*	4.25a*	2.75a*	2.50a*	2.75a*	2.50a*
150%	104.75a*	103.5a*	4.25a*	4.00a*	3.25a*	2.00a*	3.25a*	2.00a*
VRA	93.50a*	92.25a*	5.50a*	5.25a*	4.50a*	4.25a*	4.50a*	4.25a*

*Means separation in each column followed by the same letter are not significantly different at $p = 0.05$; 50% = 50 % fixed fertilizer rate; 100 % = 100 % fixed fertilizer rate; 150 % = 150% fixed fertilizer rate; VRA = variable rate application of fertilizer.

and 150% fixed rates had higher counts of leaves chlorosis during those periods compared to VRA.

While during the period of 65 DAT until 75 DAT (flowering stage), the chlorosis counts of all the treatments showed a slight increase as well as SPAD readings. A slow increase of chlorosis counts and SPAD readings during the flowering stage has happened because this stage required more K and P elements instead of N to promote early flowering and produce bearing spikelets per panicle for grain production and grain filling (Wang et al. 2017). However, during the grain filling and maturity period (75 DAT until 95 DAT), chlorosis counts for all the treatments showed rapid increase because no foliar fertilization was performed which make less available N to take up by the paddy plant. As shown in Figures 1 and 2, it was clearly stated that uniform rates of foliar fertilization especially 50% and 100% fixed rates were unable to provide sufficient nutrients for the plant growth during active growth (35 DAT), panicle initiation (55 DAT), flowering stage (65 DAT) and until at the end of harvesting stage (95 DAT) due to high accumulation of chlorosis counts and had lower SPAD readings. An insufficient supply of nutrients could lead to chlorosis conditions on the paddy leaves since chlorosis was an indicator of the plant failing to produce the normal amount of chlorophyll to sustain effective food manufacture through the photosynthesis process. Therefore, an insufficient supply of nutrients can also reduce the yield performances since chlorosis can reduce food supply in the plant and make the plant unable to function effectively to grow and produce grains.

3.3. Effect of chlorosis on plant growth performance

A comparison of paddy plant growth performance between all the treatments can be seen in Table 2. The mean number of tillers, number of panicles, and the number of flowers were higher

Table 3. Comparison of paddy's yield components between all the treatments in two planting seasons.

Treatments	Number of grains per hill		Grain yield per hill (g)		1000-gram weight per hill (g)		Number of spikelets per hill	
Season	1st	2nd	1st	2nd	1st	2nd	1st	2nd
50%	573.3b*	547.50b*	7.33b*	6.22b*	11.49b*	11.02b*	5.50b*	5.25b*
100%	637.5b*	620.25b*	7.72b*	7.10b*	11.74b*	11.43b*	6.00b*	5.50b*
150%	730.25b*	677.75b*	9.75b*	8.92b*	13.57b*	13.44b*	6.75ab*	6.25b*
VRA	1106.5a	957.50a	26.71a	21.66a	24.07a	22.64a	10.75a	8.75a

*Means separation in each column followed by the same letter are not significantly different at p = 0.05; 50% = 50 % fixed fertilizer rate; 100 % = 100 % fixed fertilizer rate; 150 % = 150% fixed fertilizer rate; VRA = variable rate application of fertilizer.

for VRA treatment compared to uniform rate treatments. The comparison of plant height between all the treatments showed that treatment 150% fixed rate had the higher plant heights followed by treatment of 100% fixed rate, VRA, and 50% fixed rates, respectively for both planting seasons. However, those results were not significantly different for mean values at the probability level of 0.05. The pattern of this finding was similar to Abd. Kharim et al.'s (2019) experimental results where paddy plants that received fertilizer applications with the VRA method demonstrated better growth characteristics compared to paddy plants that received fertilizer through the uniform rate method. One of the main contributions for increasing the plant height is due to the high application of N that trigger efficient plant metabolism to form new cells, increasing the number and size of meristematic cells, producing new shoots, and extending the cell wall for essential development of plant growth which was translated within this experiment (Elhabet 2018).

Apart from that, VRA treatment had higher tiller counts compared to other treatments in both planting seasons. This was due to better optimization of the nutrients from the sufficient supply of N for the metabolic processes to increase the tiller formation of the paddy plant during active vegetative growth (Wang et al. 2017). In terms of the panicle's number and flower per hill of the rice plant, VRA had the highest number of panicle and flower for both planting seasons compared to other treatments even though findings showed there were no significant differences to each of the treatments at 0.05 probability level. This study also noted that numbers of panicles and flowers were closely associated with the amount of tiller production which results showed that VRA had a higher number of tillers together with the number of panicles and flowers. This could be an early indicator to predict the yield productivity of paddy plants by measuring the number of tillers during the tillering stages. Therefore, during the active tillering period, sufficient N supply needs to be applied accordingly to the actual needs of the paddy plant to produce more panicles and flowers since having higher panicles and flowers per plant can lead to higher grain yield productivity (Yoseftabar 2013).

3.4. Effect of chlorosis on yield performance

Throughout paddy cultivation, sufficient application of N fertilizer is one of the important factors that can contribute to higher yield (Hashem 2019). In this study, yield performances of every treatment were varied and can be seen in Table 3. While in Table 4, N supply (g) to the paddy plant from every treatment on various DAT is shown. From Table 4, 150% fixed-rate supply higher N to paddy plant and followed by 100% fixed rate, VRA, and 50% fixed rate respectively. In both planting seasons, VRA showed significant differences and the highest yield performances compared to other treatments. As expected, the 50% fixed rate showed the lowest in yield performances followed by 100% and 150% fixed rates respectively. Even though a 150% fixed rate applied the highest amount of fertilizer compared to other treatments however it produces less yield compared to VRA. This can be likely indicating that 150% fixed rate experienced law of diminishing return which means the yield of the plant will not increase with further addition

Table 4. Comparison of N supply (g) between all the treatments on various DAT in two planting seasons.

Treatments	15 DAT		35 DAT		55 DAT		65 DAT		Total	
Season	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
50%	95.1d	95.1d	95.1d	95.1d	95.1d	95.1d	95.1d	95.1d	380.5d	380.5d
100%	190.3b	190.3b	190.3b	190.3b	190.3b	190.3b	190.3b	190.3b	761.0b	761.0b
150%	285.4a	285.4a	285.4a	285.4a	285.4a	285.4a	285.4a	285.4a	1141.6a	1141.6a
VRA	187.4c	186.2c	185.9c	186.3c	185.6c	183.7c	185.8c	187.2c	744.6c	743.2c

*Means separation in each column followed by the same letter are not significantly different at p = 0.05; 50% = 50 % fixed fertilizer rate; 100 % = 100 % fixed fertilizer rate; 150 % = 150% fixed fertilizer rate; VRA = variable rate application of fertilizer.

of fertilizer amount especially involving N element (Liu et al. 2015). Hence, excessive application of N can cause excessive growth of the plant and had the potential to reduce plant yield due to having higher plant heights with a thin stem that are easy to bend thus easily break and disperse the grain during the strong wind.

If there was a slight reduction of the N element in the plant, it was no surprise that plant growth and yield productivity will be affected since N is the most essential compound in plant molecular development (Amina et al. 2015). This was shown by a 50% fixed rate where it shows the lowest SPAD readings with higher chlorosis counts on the leaves and this led to less yield produced compared to other treatments due to insufficient nutrient supply. While for VRA treatment, it showed higher SPAD readings throughout the planting periods with having fewer chlorosis counts on the paddy leaves and produce better yield performances which likely indicated the optimum usage and sufficiently used nutrients from foliar fertilization. Miraculously, VRA's yield performance was higher compared to 100% fixed rate's yield performance despite the amount of N supply (g) to the paddy plant because both treatments were almost the same. However, statistical analysis in Table 4 showed there was a significant difference between both treatments in terms of N supply (g) to the paddy plant. It can be speculated that the differences in yield performances between VRA and 100% fixed rate might be happened due to reduction in SPAD readings of 100% fixed rate during 58 until 65 DAT (flowering stage) compared to VRA treatment which shows much higher in SPAD readings. Reduction in SPAD readings can be defined as lower N levels in the soil and paddy plant. SPAD readings in this experiment were mainly used as a monitoring tool to notify N levels in the soil and plant at every stage of the paddy life cycle. Therefore, a reduction in SPAD readings of 100% fixed rate during 58 until 65 DAT might indicate that N level in the soil and paddy plant during the particular period was declined and required immediate fertilization to prevent later yield reduction.

Sufficient nutrients supply during the flowering stage was vital for the effective flowering process since this stage was a critical period in increasing the amount of spikelet. Consequently, insufficient nutrients during this period could distort spikelet production and most likely can reduce grain filling rate thus affecting the number of grains per hill and yield mass-produced. This was proven in Table 3 where the 100% fixed rate shows lower counts of spikelets number and the number of grains per hill compared to VRA treatment. In fact, during the flowering period until grain filling and maturity period, sufficient application of macronutrients such as N, P, and K could increase paddy yield contributing characteristics such as more tiller and panicle development, promote early flowering, spikelet number per panicle, percentage filled grains, grain protein content, and 1000-grain weight. Therefore, VRA foliar fertilization in this study shows the importance of precise fertilization according to plant needs at every planting stage instead of depending on conventional uniform rate fertilization. Hence, precise fertilization able to decrease chlorosis conditions on the paddy leaves at every critical planting stage is crucial to improve paddy plant health and later enhancing yield production (Rekani 2020).

4. Conclusion

The precise application of foliar fertilization with measurements of SPAD chlorophyll meter can help to increase chlorophyll-N content in the paddy plant while minimizing the chlorosis condition on the paddy leaves due to sufficient nutrients supply to the plant even though infertile soil was used during the study. Even under infertile soil, treatment of VRA can produce a higher yield compared to treatment of uniform rates. The findings can help in improving the fertilizer management of paddy cultivation with the emphasis on the application of the precision-based treatment and foliar feeding with the UAV liquid fertilization.

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Disclosure statement

The authors declare that they have no conflict of interest.

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References

Abd. Kharim, M. A., W. Aimrun, A. R. Mohamed Shariff, and A. F. Abdullah. 2019. Preliminary study of variable rate application – organic liquid fertilizer by using SPAD chlorophyll meter on System of Rice Intensification (SRI) cultivation. *Communications in Soil Science and Plant Analysis* 50 (5):639–49. doi: 10.1080/00103624.2019.1576717.

Abd. Kharim, M. A., W. Aimrun, A. R. M. Shariff, and A. F. Abdullah. 2020. Effect of variable rate application on rice leaves burn and chlorosis in system of rice intensification. *Malaysian Journal of Sustainable Agriculture* 4 (2):66–70. doi: 10.26480/mjsa.02.2020.66.70.

Al-Khuzai, A. H. G., and H. W. A. Al-Juthery. 2020. Effect of DAP Fertilizer Source and Nano Fertilizers (Silicon and Complete) Spray on Some Growth and Yield Indicators of Rice (Oryza sativa L. cv. Anber 33). *IOP Conference Series: Earth and Environmental Science* 553:012008.

Amina, K., Q. Md. Khairul, S. Md. Hasina, A. B. Md. Khairul, and S. Abu. 2015. Nitrogen fertilizer optimization and its response to the growth and yield of lowland rice. *Research on Crop Ecophysiology* 10 (1):1–6.

Athanasios, B., B. Bert, F. Spyros, V. Jurgen, W. Tamme van der, S. Iria, G. B. Manuel, B. Andrew, and E. Vera. 2017. Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. *Sustainability* 9:1339. doi: 10.3390/su9081339.

Chen, L., L. Lin, G. Cai, Y. Sun, T. Huang, K. Wang, and J. Deng. 2014. Identification of nitrogen, phosphorus, and potassium deficiencies in rice based on static scanning technology and hierarchical identification method. *PLoS One* 9 (11):e113200. doi: 10.1371/journal.pone.0113200.

Elhabet, H. 2018. Effect of organic and inorganic fertilizers on rice and some nutrients availability under different water regimes. *Journal of Agricultural Sciences Food Research* 9:247.

Fageria, N. K., and A. B. Santos. 2015. Yield and yield components of lowland rice genotypes as influenced by nitrogen fertilization. *Communications in Soil Science and Plant Analysis* 46 (14):1723–35. doi: 10.1080/00103624.2015.1043443.

Gholizadeh, A., M. S. M. Amin, A. R. Anuar, W. Aimrun, and M. M. Saberioon. 2011. Temporal variability of SPAD chlorophyll meter readings and its relationship to total nitrogen in leaves within a Malaysian paddy field. *Australian Journal of Basic and Applied Sciences* 5 (5):236–45.

Hashem, I. M. 2019. Studies on the Effect of Foliar Fertilizer Application in Combination with Conventional Fertilizers on Rice Production. *Journal of Plant Production* 10 (6):447–52. doi: 10.21608/jpp.2019.48291.

Hu, Y., Y. Jingping, L. Yamin, and H. Junjun. 2014. SPAD values and nitrogen nutrition index for the evaluation of rice nitrogen status. *Plant Production Science* 17 (1):81–92. doi: 10.1626/pps.17.81.

Liu, K., Y. Li, H. Hu, L. Zhou, X. Xiao, and P. Yu. 2015. Estimating rice yield based on normalized difference vegetation index at heading stage of different nitrogen application rates in southeast of China. *Journal of Environmental & Agricultural Sciences* 2:13. doi: 10.2134/agronj2011.0202.

Rekani, S. I. 2020. Effect of foliar application of high concentrations for some micronutrients on growth and yield of submergence rice grown in calcareous soil. *Journal of Advancements in Plant Science* 3:103.

Sandhya, B. R., T. K. Ghiridara, and P. Munirathnam. 2014. Studies on the effect of foliar fertilization in combination with conventional fertilizers on yield, economics and nutrient uptake of rice (Oryza sativa L.) under K.C. Canal Ayacut area of Andhra Pradesh, India. *Agricultural Science Digest – A Research Journal* 34 (1):15–20. doi: 10.5958/j.0976-0547.34.1.003.

Shi, Y., Y. Zhu, X. Wang, X. Sun, Y. Ding, W. Cao, and Z. Hu. 2020. Progress and development on biological information of crop phenotype research applied to real-time variable-rate fertilization. *Plant Methods*. 16 (1):11. doi: 10.1186/s13007-020-0559-9.

Wang, Y., J. Lu, T. Ren, S. Hussain, C. Guo, S. Wang, R. Cong, and X. Li. 2017. Effects of nitrogen and tiller type on grain yield and physiological responses in rice. *AoB PLANTS* 9 (2):plx012. doi: 10.1093/aobpla/plx012.

Yasuyuki, W. 2016. The relationship between SPAD values and leaf blade chlorophyll content throughout the rice development cycle. *JARQ* 50 (4):329–34. doi: 10.6090/jarq.50.329.

Yoseftabar, S. 2013. Effect nitrogen management on panicle structure and yield in rice (*Oryza sativa L.*). *International Journal of Agriculture and Crop Sciences* 5 (11):1224–7.

Zahanggir, M. A., M. Sadekuzzaman, S. Souvic, and M. R. H. Hafizur. 2015. Reducing soil application of nitrogenous fertilizer as influenced by liquid fertilization on yield and yield traits of kataribhog rice. *International Journal of Agronomy and Agricultural Research* 6 (1):63–9.

Zhaofeng, Y., C. Qiang, Z. Ke, T. A. Syed, T. Yongchao, Z. Yan, C. Weixing, and L. Xiaojun. 2016. Optimal leaf positions for SPAD meter measurement in rice. *Frontier Plant Science* 7:719. doi: 10.3389/fpls.2016.00719.