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How Does Water Stress and Nitrogen Fertilizer Affect the Growth and Yield of Upland Rice (*Oryza Sativa* L.)

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Abstract Water stress and inadequate nitrogen (N) fertilizer are important factors that simultaneously limit the growth and yield of upland rice. In this study, we examined the interactive effects of N fertilizer application and water stress timing on the growth and productivity of upland rice. The experiment was set up as a randomized complete block design (RCBD) with 2 replications. Toyohatamochi rice was fertilized with three levels of N (30, 60, and 90 kg/ha) and subjected to water stress at different growth stages (early vegetative, active tillering, maximum tillering stages, and then at 10 and 20 days after heading). We did not find any statistically significant interactive effects of water stress timing and N on growth, yield, and dry matter productivity, although N appeared to increases the sensitivity of upland rice to water stress. Water stress at maximum tillering and 10 days after heading (DAH) both reduced grain yield by 50% and dry matter productivity by 49% and 38% respectively. In contrast, early vegetative stress reduced grain yield by a modest 20% despite decreasing dry matter productivity by 40%. Nevertheless, the grain yield of rice stressed at the early vegetative stage increased with N, suggesting a possibility of salvaging grain yield in rice that has suffered water stress at the early vegetative stage by enhancing N fertilization. However, after maximum tillering but before 20 DAH water stress caused irrecoverable grain yield loss, even with more N.

Keywords: *aerobic rice, drought sensitivity, nitrogen fertilizer, water stress*

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1. Introduction

Rice (*Oryza Sativa* L) is the staple food for more than two-thirds of the world's population. About 13% of the world's 147 million hectares of rice are cultivated under upland conditions [1] where moisture stress and inadequate nitrogen affect growth and grain yield.

Water is a major constituent of plant tissue, a reagent in a chemical reaction, a solvent for and mode of translocation of metabolites and minerals, as well as an essential component for cell enlargement through increasing turgor pressure. The occurrence of moisture stress affects many of the physiological processes such as photosynthesis and transpiration resulting in reduced growth and eventual yield loss. The effect of water stress varies with the variety, duration of water stress, and timing of water stress, and the stage growth of rice.

Nitrogen (N) on the other hand is an essential nutrient used in relatively large amounts by plants. It is critically important in plants because it is a fundamental component of the chlorophyll molecule and is essential in the formation of amino acids and proteins. Chlorophyll is the molecule that absorbs sunlight and uses its energy to synthesize carbohydrates from carbon dioxide (CO2) and water. Amino acids are joined together to form proteins that act primarily to control plant growth processes through enzymatic action [2].

Water and N often interact in affecting the growth and yield of rice, and their interaction has received immense attention from several workers. Nitrogen and water stress have been shown to interact and affect photosynthesis and transpiration, with a high N level making plants more sensitive in their response to water stress [3]. Rice plants treated with higher N levels rapidly developed stress symptoms and suffer greater growth reduction than those treated with less N [4]. Even so, rice yields consistently increase with nitrogen application even in the presence of water deficit [5], in particular under conditions of moderate water deficit. Under severe stress when water is the most limiting factor of growth, yields are extremely low and the rice does not respond to increased nitrogen applications [6].

The main purpose of this study was therefore to examine the interactive effects of nitrogen and the timing of water stress (regarding the different growth stages of rice) on the growth and yield of upland rice. Findings from this study may contribute knowledge necessary for planning yield-stabilizing interventions such as supplementary irrigation and fertilizer use in the context of Africa where rainfall patterns are erratic and render fertilizer use risky. Throughout this paper, the terms “moisture stress” and “water stress” are used interchangeably to refer to the experience that plants go through when the water supply to their roots becomes limiting as a result of drought [7].

2. Materials and Methods

The experiment was conducted in a rain-out shelter at Tsukuba International Center (TBIC) of the Japan International Cooperation Agency (JICA) in Japan (latitude 36°01’N, longitude 140°07’E, elevation 24 meters above sea level) from April to September 2008. It was set up in plots of 1 m^2. The soil type was silt clay loam, and the rice variety used was Toyohatamochi rice planted at a spacing of 20 cm by 20 cm (2 Seeds per hill). Toyohatamochi is a glutinous Japonica upland rice variety that matures in 120 days [8]

The experiment was laid out as a two-factor randomized complete block design (RCBD) with two replications. The two factors that were varied in the experiment were 3 levels of N and 5 moisture stress treatments. The N levels were 30, 60, and 90 kg ha-1 (N-1, N-2, and N-3) applied in split doses (60% as basal and 40% as top-dressing). Phosphorous and potassium fertilizers were applied to all treatments at a rate of 100 kg ha-1 and 110 kg ha-1 respectively. In the moisture stress treatments, rice was subjected to moisture stress at five different growth stages; early vegetative/seedling (S-1), active tillering (S-2), maximum tillering (S-3), and in two phases (S-4 and S-5) after heading the 50% heading date. S-4 was initiated 10 days after heading (DAH) and S-5 at 20 days after heading. A well-watered treatment (S-0) was maintained as a control. In the control (no stress) plots, a normal watering regime of 30 mm per week was adopted. The 30 mm was divided into 3 equal parts and applied 3 times within the week. Stress was induced in the stress treatments by withholding watering throughout the stress period. The duration of stress in all the stress treatments was 4 weeks, with exception of the last stress treatment which only lasted 3 weeks. Outside the stress period, all treatments received the same amount of water as the no-stress treatment.

To accurately distinguish between the different growth stages for the application of moisture stress, a crop growth staging system based on plant morphogenesis was adopted [9]. According to this system, the beginning of the early vegetative stage was indicated by the emergence of the first complete leaf and ended with the emergence of leaf 6. The active tillering stage started and ended with the emergence of leaves 6 and 10 respectively. Likewise, the start and end of the maximum tillering stage were indicated by the emergence of leaf 10 and the flag leaf respectively. Based on this system, S-1, S-2, and S-3 stresses were initiated at 11, 32, and 53 days after sowing (DAS) to correspond with the start of the early vegetative, active tillering and maximum tillering stages respectively.

2.1. Monitoring Soil Moisture

The volumetric water content of the soil in the stressed and non-stressed plots was monitored throughout the stress period at weekly intervals using a moisture meter-type *HH2* (Delta-T Devices Ltd, UK). Due to large variations in soil moisture measurements within plots as a result of substantial heterogeneity within soils, 10 measurements were taken plot and the average values considered. The moisture meter was calibrated with the experimental soil samples and the gravimetric method was used to generate a calibration curve that was used to transform the moisture meter readings to true soil moisture values [10].

2.2. Growth Measurements

On the last day of each stress, plant heights were measured and tiller number determined. Three hills were also harvested from each treatment and shoot (leaves plus culms) fresh and dry weights were measured. At harvest, panicles and straw were taken from 9 central hills (0.36m2) of each plot. The panicles were counted, threshed and grains separated into filled and unfilled spikelets by floatation using ordinary water (specific gravity 1.0). After drying, 1000 grain weight and the total number of filled and unfilled spikelets were determined and the latter two parameters were used for determining the grain filling ratio. The moisture content of the grains was measured (Riceter Grain Moisture Meter, Kett Electric Laboratory, Tokyo, Japan) and yield (kg ha-1 at 14% Moisture content) calculated from the weight of the filled grains. Dry matter weight was taken after drying at 70℃ for 72 h.

2.3. Leaf Relative Water Content (LRWC)

LRWC of the stressed and unstressed rice plants were compared at the end of each stress treatment. To determine LRWC, three of the youngest fully developed leaves (new leaf with visible ligule) were sampled, immediately weighed (fresh weight), and then enclosed to float in a container filled with distilled water until fully re-hydrated. The turgid fully rehydrated leaves were weighed (turgid weight). The same leaves were dried in an oven until a constant oven-dry weight was attained. LRWC was then calculated according to Turner (1981) as follows;

$$LRWC = \frac{Fresh\ Weight - Dry\ Weight}{Turgid\ Weight - Dry\ Weight} \times 100$$

2.4. Statistical Analysis

All the data collected was summarized in Microsoft excel and subjected to a two-way analysis of variance (ANOVA) in randomized blocks using GENSTAT tenth-edition (VSN International Limited, 2011). Means among treatments were separated using Fisher’s least significant difference (LSD) method.

3. Results

3.1. Soil Moisture Contents during Stress

To determine the actual soil moisture content, a calibration curve was generated by first measuring soil moisture content using the moisture meter (Type HH2) and then again directly using gravimetric measurements, in which a known volume of soil was extracted and weighed, and then dried and reweighed. The moisture meter readings were then plotted against actual soil moisture contents (determined gravimetrically) and the regression equation arising from the plot (y=0.6091x+21.607) was used to transform the moisture meter readings (y) into actual soil moisture values (x). The transformed values showed that volumetric soil water content in all the stress treatments decreased gradually from over 40% to below 30% and less within 2 – 3 weeks (Figure 1).

This ensured the slow development of water stress in the rice plants allowing for various steps of adjustment until the expression of symptoms such as leaf rolling, leaf tip drying, and death of leaves. Figure 1 clearly shows that the reduction in soil moisture during stress was similar in all the stress treatments, with exception of the last stress treatment (S-5) which only lasted 3 weeks, rather than 4 weeks like in the other stress treatments.

3.2. Yield and Yield Components

Overall, the interaction between N and stress (S) did not produce any significant differences in yield and dry matter productivity. Similarly, there were no significant differences in yield and yield components as a result of N treatment (Figure 2).

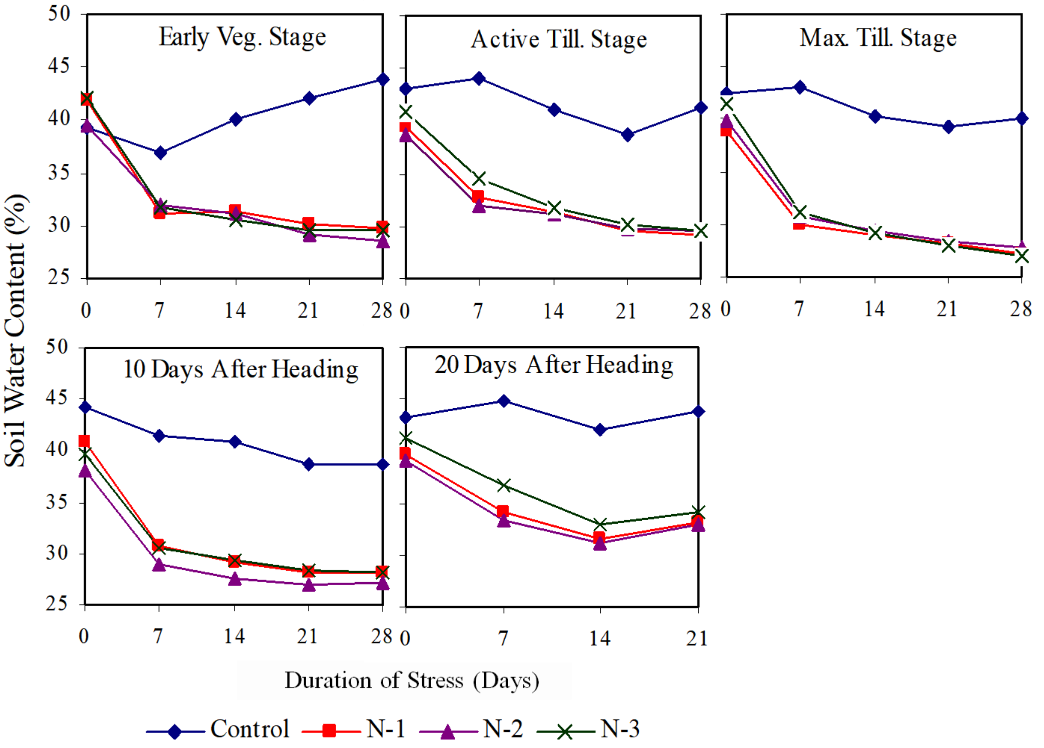

Figure 1. Changes in volumetric soil water content during water stress at different growth stages of upland rice. The line markers ◇, □, △ and × represent the control, N-1, N-2, and N-3 respectively

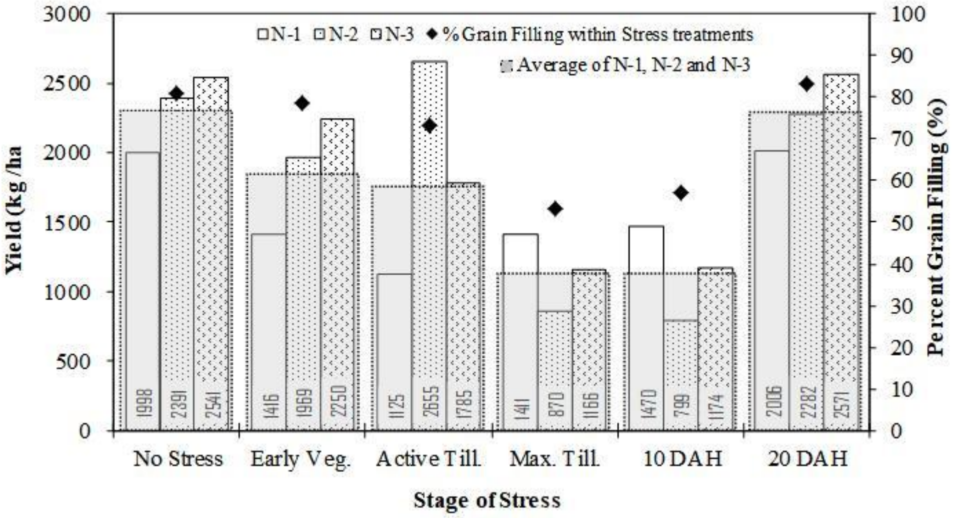

Figure 2. Yield and grain filling ratio of Toyohatamochi rice treated with 3 N levels and subjected to moisture stress at different growth stages

Nevertheless, N application generally increased yield as indicated by a strong positive correlation (r = 0.96) between N and yield. Related to yield also, the number of panicles per hill increased, although not significantly with N application (r = 0.87). In contrast, N reduced the percentage of filled grains (r = -0.63), 1000 grain weight (r = -0.92) and consequently harvest index (r = -0.69).

Figure 2 also shows that there were significant grain yield differences (P<0.01) among the different stress treatments. The lowest yield was recorded when moisture stress occurred at the maximum tillering stage and at 10 days after heading, while stress at the early and active vegetative stages and at 20 days after heading did not have any significant effects on yield. Consequently, grain yields were reduced by 18.7%, 19.7%, 50.3%, and 50.3% when moisture stress occurred at the early vegetative stage, active tillering stage, maximum tillering stage, and 10 and 20 days after heading respectively.

Average grain yields for the different stress treatments were also found to be strongly correlated with yield components, specifically the grain filling ratio (r = 0.97), 1000 grain weight (r = 0.83), and the number of panicles per hill (r = 0.78). For example, the highest yield among the stressed treatments recorded in S-5 (stress at 20 days after heading) corresponded with the highest grain filling ratio of 83.2%. Similarly, the low yield realized in S-3 (stressed at maximum tillering) and S-4 (stressed 10 days after heading) corresponded with poor grain filling (53.4% and 57.1% respectively).

3.3. Dry Matter (DM)

In the same way as to yield and yield components, the interaction between N and stress (S) did not produce any significant differences in the final DM yield (Table I). Similarly, the application of N did not have any statistically significant effect on the final DM yield, although it was quite clear that the DM yield increased with N (r = 0.94). Water stress on the other hand significantly affected final DM production, with stress at maximum tillering and 10 days after heading producing the lowest DM yields. However, the earliest (S-1) and latest (S-5) stresses had negligible effects on the final DM yield. Compared to water stress at the early vegetative stage and active tillering stage, which reduced DM yield by only 44% and 37% respectively, stress at maximum tillering decreased DM yield by up to 49%.

3.4. Plant Height and Tiller Number

No significant interactive effects of N application and water stress were observed in plant height and tiller number measured at the end of S-1, S-2, and S-3. In the same way, no significant differences in plant height and tiller number were found between the treatments as a result of N treatment, yet N seemed to increases plant height and tiller number (Table 1. The strongest association between N and growth (plant height and tiller number) was found at the end of S-2 (active vegetative stage) and the least association was observed in the seedling stage (S-1/early vegetative stage). For instance, the correlation between N, and plant height and tiller number at the end of S-2 were 0.87 and 0.96 respectively as compared to 0.58 and 0.88 at the end of S-1.

It can be seen from Table 1 that moisture stress had highly significant effects on plant height and tiller number. Moisture stress at the active tillering stage (S-2) had the greatest effect on tiller number, decreasing tillering by 39.6% compared to 23.6% and 30.5% for stress occurring at the early vegetative stage (S-1) and maximum tillering stage (S-3) respectively. However, plant height was most affected by the moisture stress that occurred in the early vegetative stage (S-1). Moisture stress in the early vegetative stage reduced plant height by 42.3% while moisture stress at the active tillering stage (S-2) and maximum tillering stage (S-3) decreased plant height by 28.2% and 19.0% in that order.

Table 1. Yield and yield components of Toyohatamochi rice treated with 3 levels of nitrogen and subjected to moisture stress at different growth stages

Nitrogen (Kg/Ha)	Stress Treatment	1000 Grain Weight (g)	Percent filled grains/panicle	Panicle Length (cm)	Panicles/ hill	Dry Matter (g/m^2)	Harvest Index (%)
30	No Stress	27.5	50.2	16.9	5.8	95.9	51.5
	Early Veg.	26.7	40	16	4.9	75.2	45.6
	Active Till.	26.4	33.7	15	4.9	66.9	40.8
	Max. Till.	25.5	50.7	18.7	4.4	76.9	45.2
	10 DAH	25.9	33.2	14.8	6.8	82.4	43.9
	20 DAH	28.5	46.5	17.2	6.3	111.4	44.5
60	No Stress	26.7	59.2	17.2	6.1	118.8	50.1
	Early Veg.	28.9	43.4	15.9	6.3	93.3	52.9
	Active Till.	27	41.9	16.9	9.4	134.8	49.4
	Max. Till.	25.1	29.4	17.1	4.7	59.7	31.2
	10 DAH	24.9	27.3	17.8	4.9	57.6	28.1
	20 DAH	27.5	38.9	15.6	8.6	136.4	40.1
90	No Stress	26.8	52.8	17	7.2	132.6	47.7
	Early Veg.	27.7	48	18	6.9	110.3	50.9
	Active Till.	25.3	39.3	16.2	7.2	99.2	44.6
	Max. Till.	23.9	36.1	17.9	5.3	70	33
	10 DAH	26.4	32.2	17.6	5.4	74	34.8
	20 DAH	26.9	48.1	17	8	137.3	46.6
LSD (5%)	Nitrogen (N)	0.9	7.8	0.8	1.3	18.4	5
	Stress (S)	1.2**	11.0**	1.1	1.8	26.0**	7.1**
	N x S	2.2	19.1	1.8	3.2	45	12.3
CV (%)		3.8	21.7	5.2	23.7	22.2	13.5

3.5. Time to Heading

The heading of rice was delayed by moisture stress that occurred at the vegetative stage. Stress in the advanced stages of vegetative growth delayed heading even more. For instance, when stress was subjected at the maximum tillering stage (S-3), the heading was delayed by 19 days as compared to 13 and 16 days delay when stress was applied in the early vegetative (S-1) and active tillering (S-2) stages respectively (Figure 3). S-4 and S-5 matured one week earlier than the control treatment despite heading at the same time. Time to heading was little affected by N, with 6, 4, and 6 days delay for 30 kg N ha-1, 60 kg N ha-1 and 90 kg N ha-1 respectively.

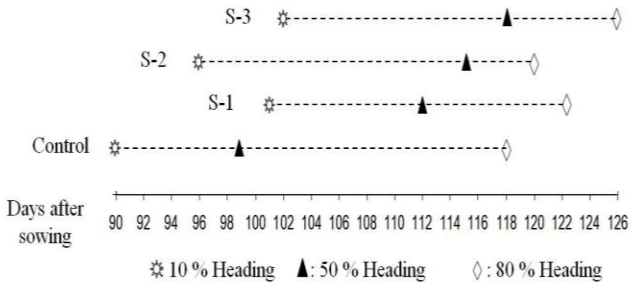

Figure 3. Heading time of Toyohatamochi rice subjected to soil moisture stress at early vegetative/seedling stage (S-1), active tillering (S-2), and maximum tillering stages (S-3). The control treatment was not stressed from planting until harvest

3.6. Leaf Relative Water Content (LRWC)

LRWC of the stressed plants at the end of S-1 (early vegetative stage) was only slightly lower than LRWC in the control plants (Table 2). This observation corresponded with the development of water stress effects (leaf rolling and tip drying), which occurred slowly and at quite low volumetric soil moisture content. The effects of water stress such as leaf rolling and leaf tip drying were also less severe in plants that were subjected to moisture stress earlier during vegetative growth (Figure 4).

Table 2 shows that the differences in LRWC between the stressed and unstressed plants at the end of S-2 and S-3 were much higher than the differences in LRWC at the end of S-1. Correspondingly, the effects of water stress showed quicker in the S-2 plants when compared to the S-1 plants, and almost immediately after the the onset of stress for the S-3 plants (Figure 4). A higher degree of leaf senescence was observed in S-3 than in S-2. On the other hand, the LRWC generally increased with N in both the stressed and unstressed plants, although only slightly.

Table 2. Leaf Relative Water Content (LWRC) % at the end of S-1, S-2, and S-3

Stage of stress	30 kg ha^{-1}		60 kg ha^{-1}		90 kg ha^{-1}	
	S-1	S-0	S-2	S-0	S-3	S-0
28 DAS	77	89	71	87	71	88
56 DAS	62	90	51	89	50	91
80 DAS	57	87	50	91	48	90

4. Discussion

4.1. Effects of N and Moisture Stress Timing on Productivity

This study set out with the aim of examining the interactive effects of N application and soil moisture stress timing on the growth and productivity of upland rice, specifically Toyohatamochi rice. We did not find any statistically significant interactive effect of moisture stress timing and N on the growth, yield, and dry matter productivity of Toyohatamochi. A similar study also found inconsistencies in the combined effects of water stress and N on yield among different rice cultivars [11]. Nevertheless, we were able to show in our study that the response of upland rice to soil moisture stress depends on the timing of moisture stress and the level of N fertilization (Figure 1). For instance, when we stressed Toyohatamochi rice at the early vegetative/seedling and active tillering stages, N application increased grain yield and dry matter productivity. Similarly, when we stressed rice beyond 20 DAH, N increased the grain yield and dry matter productivity. On the contrary, when we applied soil moisture stress at maximum tillering stage and 10 DAH, we realized less and less grain yield and dry matter productivity with more N. Our results suggest that it may be possible to salvage the yields of upland rice that has undergone soil moisture stress at the early vegetative/active tillering stage by enhancing N nutrition. Although N application caused greater growth reduction in the water-stressed plants, it was found to be effective in boosting vegetative growth recovery after the termination of water stress by increasing dry matter productivity [4]. Our observations, together with those of another similar study [4] allude to the finding that nitrogen and water stress interact to cause a significant effect on photosynthesis and transpiration with high N plants being more sensitive to water stress, concerning photosynthesis and transpiration compared with low N plants [3]. The same study showed that water stress causes a greater reduction in photosynthesis in plants grown with high N levels, although plants grown with lower N levels still maintained superior photosynthetic performance. And since over 90% of crop biomass is derived from photosynthetic products [12], maintaining high photosynthetic performance through N fertilization can improve the yields of upland rice that has been water-stressed in the early and active vegetative stages. However, that assertion may not hold for upland rice that suffers water stress from the maximum tillering stage into the heading. In this study, we obtained the lowest grain and dry matter yields in rice that was stressed at the maximum tillering stage and 10 DAH, and not even N could boost productivity in the stressed plants. Instead, we found a negative relationship between N and grain/dry matter productivity, implying that N fertilization at that time increases the sensitivity of upland rice to soil moisture stress. This is in contrast with the finding that N application consistently increases yield even when rice is exposed to water deficit [4]. This is possibly because of differences in the severity of applied moisture stress in the two studies. In severe stress when water is the most limiting factor of growth, rice yields become extremely low and do not respond to increased N applications [6]. Hence severe water stress at this critical stage of rice growth may have irreversibly damaged panicle development by reducing the number of filled grains per panicle (Table 1) and causing high spikelet sterility (Figure 2) through pollen sterility or abortion of embryos or even poor panicle exertion [13,14,15], thereby eliminating the possibility of yield recovery with N. Another study suggested that the use of high N doses should be avoided under severe water stress because it increases spikelet sterility and decreases the grain/straw ratio [11]. However, at 20 DAH, grain filling was almost complete and was therefore not affected much by both soil moisture stress and N fertilization (Table 1), although it seemed to decrease with N. As photosynthesis becomes inhibited by drought, grain filling relies more on stem reserve utilization [16,17].

4.2. Effect of Moisture Stress Timing on Productivity

In this study, we found the timing of water stress to have a significant effect on the yield and dry matter productivity of upland rice (P≤0.01). Concerning the growth stages of rice, the timing of water stress brought out three productivity outcomes (Figure 2), which seemed to be associated with the sequential development of yield components. In rice, the potential number of tillers, and hence panicles per unit area, is determined earliest followed by the number of grains per panicle and finally grain size. Consequently, the timing of moisture stress dictates which of the yield components are affected [18]. In this study, the lowest number of tillers was recorded in rice that was subjected to moisture stress in the active tillering stage, although that did not directly translate into a significantly lower number of panicles, yet grain yield was reduced by 19.7%. On the other hand, moisture stress at the early vegetative stage reduced grain yield by about 18.7%. Hence moisture stress at the early vegetative/seedling and active tillering stages pretty much had the same effect on grain yield (Figure 2), decreasing it by approximately 20%. In the same way, moisture stress at the early vegetative/seedling and active tillering stages equally reduced dry matter productivity by approximately 40%. Our finding that water stress in the vegetative stage reduces grain yield by approximately 20% replicates findings of another study [19] that showed that a yield reduction of 21%. That same study however found a smaller effect moisture stress at the vegetative-stage on dry matter productivity (23.2% reduction), than in our study, perhaps because of differences in the intensity of applied water stress and the fact that they worked with transplanted lowland rice, which had an advance start in vegetative growth before initiation of water stress. Our findings suggest that despite causing a relatively large decrease in dry matter productivity, water stress in the vegetative stage has a moderate effect on grain yield, possibly because it allows time for growth recovery after relief of stress. Grain yield reductions from early droughts (occurring during vegetative growth, after establishment but before maximum tillering) are minimal, resulting largely from a reduction in the number of tillers [13].

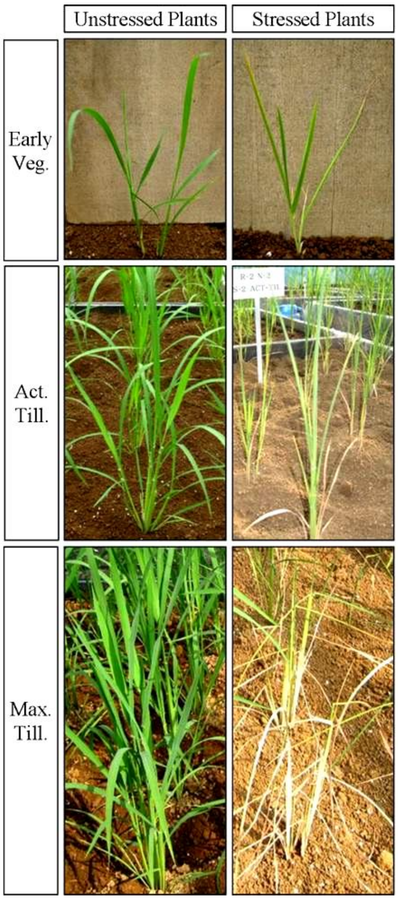

Figure 4. Response of upland rice to water stress occurring during vegetative growth after establishment up to maximum tillering

It was also clear from this study that the most sensitive developmental stage of upland rice to water stress extends from maximum tillering into the heading until about 2 weeks after heading (Figure 2). The severity of stress was expressed by an almost immediate appearance of leaf rolling and tip drying followed by a high degree of leaf senescence (Figure 4) because of a greater effect of water stress on LRWC. Consequently, over 50% of grain yield was lost to water stress at maximum tillering, and 10 DAH respectively, despite producing different effects on dry matter productivity. Water stress at maximum tillering shrunk dry matter productivity by 49% while stress initiated at 10 DAH reduced dry matter by 38%. A possible explanation for this might be the end of vegetative growth at maximum tillering, which triggers the start of reproductive development. On the other hand, the similarity in yield loss due to water stress at maximum tillering and 10 DAH might have been the result of possible overlap between the maximum tillering stage and the beginning of reproductive development, as seen in some short-duration varieties. The variety Toyohatamochi, used in this experiment matures in 120 days, which qualifies it as a short duration variety (IRRI, 1992) with a possible overlap of maximum tillering and start of the reproductive stage. These results confirm previous reports on the response of rice genotypes to soil moisture gradients and water stress during the reproductive stage. In a similar study, the average yield of rice decreased by over 50% when rice was stressed at the reproductive stage, making it the most sensitive developmental stage to water stress [11,20,21]. Water stress commenced at 10 DAH (early grain filling) may have resulted in the abortion of developing grains due to a reduction in assimilates for grain filling [22]. However, water stress at 20 DAH may have found grain filling almost complete hence the minor effect on grain yield.

4.3. Effect of Moisture Stress Timing on Heading

Stress in the vegetative stages prolonged the vegetative growth and subsequently delayed heading. The greatest delay was observed when moisture stress was experienced near the reproductive growth phase (Figure 3). The results indicate that heading was delayed by 14 days in earlier stress (early vegetative and active tillering) and about 21 days in later stress (maximum tillering). A similar study reported heading delays of 18, 22, and 28 days for 4-week drought stress initiated at 23, 42, and 63 days after sowing [13], while another study reported a delay in the heading of 11 to 15 days by stress subjected during vegetative growth (35-66 days after sowing) [4]. Therefore the delays in heading observed in this study are generally consistent with those of other studies [4,13], albeit with minor variations possibly arising from differences in the conditions and varieties used in each of the studies.

4.4. Effect of N on Productivity

Growth, yield and dry matter productivity of Toyohatamochi were not significantly affected by N application A possible explanation for the minor differences in growth and productivity between the N treatments may have been due to the narrow range between the N amounts (i.e. 30, 60, and 90 kg ha^{-1}), which could not bring out appreciable differences in growth and productivity of the treated rice. Perhaps a wider spread between the N treatments such as 0, 60, and 120 kg/ha would result in significant growth and productivity gains from N application. Hence Future research should consider comparing the effects of 0, 60, and 120 kg of N per hectare. The insignificant effects of N observed in this study may also be related to poor utilization of N fertilizer in upland soils, which brought out only subtle differences in the growth, yield, and dry matter production. N uptake is low in aerobic soil conditions [23] and it use efficiency improves when water is not limiting [24].

5. Conclusion

The purpose of this study was to determine the response of upland rice to moisture stress timing under different levels of N fertilization. The study showed that upland rice is most sensitive to water stress from maximum tillering into heading/flowering, thereby underscoring the importance of supplementary irrigation at this stage in the event of drought. The study also showed that N fertilization is effective in boosting vegetative recovery and therefore grain yield in rice that suffers water stress during early vegetative growth.. However, if upland rice is severely water-stressed after maximum tillering, application of N fertilizer, even after relief of stress, would be largely a waste.

Acknowledgments

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