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Submergence MEDIATES Leaf Blast Resistance in Sub1 and Non-Sub1 Rice Genotypes

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Abstract
An experiment was conducted to study the effect of submergence on leaf blast, caused by *Magnaporthe oryzae*, at the seedling stage in two Sub1 and two non-Sub1 rice genotypes during 2012 and 2013 at Regional Agricultural Research Station, Tarahara, Nepal. A split-plot design was followed using submergence periods as main-plots and genotypes as sub-plots. Four submergence periods during 2012 and five periods in 2013 were employed. Submergence periods varied significantly for leaf blast as measured by area under disease progress curve (AUDPC) during 2013. Seven days submerged plants produced the lowest AUDPC values. Rice genotypes differed significantly for AUDPC values during both the years. Disease development decreased with increasing submergence periods, with a greater reduction in Sub1 genotypes. With or without submergence, Swarna Sub1 recorded the lowest disease severity and could be promoted in the flash floods affected and other rainfed areas in Nepal terai where blast is a problem.

Key words: Leaf blast resistance, *Magnaporthe oryzae*, mediates, Sub1 rice, submergence

1. Introduction
Current climate risks (IRRI, 2006) suggests that to meet the demand for rice in Asia, yields will have to be doubled over the next 50 years, but changes in rainfall pattern and disease intensity have been making rice crops less productive. Nepal is the fourth most climate vulnerable country in the world for its extraordinary geography, a largely resource-poor population, and weak institutional capacity to manage the climate challenges. Such risk-management measures result in lower crop yields even during seasons of average rainfall. In Nepal, about 15% rice area is often prone to flash floods and 30% to drought out of 1.5 million hectare land devoted to rice crop (ABPSD, 2012).

It is difficult to predict when floods or drought may occur. Sometimes, floods occur in any stages of the crop alone either once or more than once in a crop season. Floods and droughts often occur in the same crop season. In flash floods affected areas, seedlings of traditional varieties are destroyed when they are complete submerged for ≥5 days. Traditional genotypes also suffer from diseases in the seedling stages and especially leaf blast damages the rice seedlings resulting in partial to complete seedling loss (Chaudhary and Sah, 1998).

Identification of submergence tolerance gene was started since 1987 and subsequently *SUB1A* gene was identified as the major determinant of submergence tolerance (Xu *et al*., 2006; Septiningsih *et al*., 2008; Bailey-Serres *et al*., 2010; Singh *et al*., 2010). Using marker assisted backcrossing, the *SUB1A* gene was introgressed to eight rice varieties, including the five mega rice varieties of India and Bangladesh (Collard *et al*., 2013). Nepal received the seeds of these varieties in 2008 and released Swarna Sub1 and Samba Mahsuri Sub1 (by the name of Samba Masuli Sub1 in Nepal) for flash floods affected areas in 2011 after testing in collaboration with IRRI (Singh et al., 2013). The Sub1 varieties have a small segment of the donor genome containing *SUB1A*, while retaining the entire genome of the original varieties (Singh *et al*., 2009; Bailey-Serres *et al*., 2010; Iftekharuddaula *et al*., 2011; Sarkar and Bhattacharjee, 2011). In Nepal, these Sub1 varieties are gaining popularity among the farming communities even in flash flood non-affected lowland areas. Especially Swarna Sub1 produces equally as good yield as or even better than original variety because *SUB1A* gene also controls tolerance to drought in rice.

Among biotic factors, blast, caused by *Magnaporthe oryzae*, is the widespread and destructive disease in Nepal (Manandhar, 1987). It affects plant growth and yields in the transplanted field in terms of quality and quantity (Ou, 1980; Chaudhary, 1999). Rice growers often face shortage of seedlings for transplanting in the areas where blast susceptible varieties are grown (Chaudhary *et al*., 1994; Chaudhary *et al*., 2005). Popular varieties become susceptible after a few years of release when cultivated in a large scale (Bonman *et al*., 1992) because the blast pathogen is highly variable for genetic adaptation to cause the disease on newly released popular varieties (Chaudhary *et al*., 2004). Seed treatments (Manandhar, 1984; Chaudhary and Sah, 1998) and foliar sprays with chemicals (Manandhar *et al*., 1985; Chaudhary, 1999) have been recommended to reduce its damage. Use of chemical is not practical for resource-poor farmers and affects environment adversely. Thus, the rice growers often suffer with crop loss. In this study two Sub1 and two non-Sub1 genotypes were evaluated under different submergence periods to study the effect of submergence on leaf blast development in those rice genotypes.

2. Materials and Methods
The experiment was laid out in a split-plot design with three replications during the 2012 and 2013 wet seasons at

Regional Agricultural Research Station, Tarahara, Nepal. Submergence durations were used as main-plots and rice genotypes as sub-plots. Four different submergence durations (0, 1, 3 and 5 days) in 2012 and five submergence durations (0, 1, 3, 5 and 7 days) in 2013 were evaluated using four rice genotypes (Swarna, Swarna Sub1, Samba Mahsuri and Samba Mahsuri Sub1). The experiment was repeated thrice to subject the rice seedlings to the variable blast pathogen population from August to October in the 2013 wet season.

Sprouted seeds of the rice genotypes were grown in plastic trays @ 100g m^{-2}. The trays (56 cm × 36 cm × 11 cm) were filled with a mix of farm soil and farm yard manure (3:1) and fertilized with 150:22:0 $N:P_2O_5:K_2O$ kg ha^{-1}. The trays were watered whenever necessary. Two rows of each genotype were seeded and replicated thrice within each tray. The seedlings were submerged for different periods as per assigned in a submergence tank 15 days after sowing. The trays were taken out of the tank and kept for 7 days near the tank for recovery of the seedlings. The trays were transferred in the rice blast nursery where natural epiphytotic conditions were created following the procedure of Chaudhary and Sah (1998). The trays were watered daily in the evening before sunset if rainfall did not occur. Rain water was drained out of the tray daily in the evening and morning to avoid high soil moisture and to favor longer dew period in the seedlings. Because, moisture stress under upland condition maintains longer leaf wetness duration (Ou, 1980).

First scoring was begun on the 7th day after placing the trays in the rice blast nursery using 0-9 scale (IRRI, 1996) and second and third scoring on the 10th and 13th day. Scores were converted into disease severity as follows.

$$\text{Leaf blast severity (\%)} = \frac{\text{Score recorded}}{9} \times 100$$

AUDPC values were calculated as per the procedure of Shanner and Finney (1977) using the following formula.

$$AUDPC = \sum_{i=1}^{n} \left[\frac{(y_{i+1} + y_i)}{2}\right] \times (x_{i+1} + x_i)$$

Where,

y_i = disease severity at the i^{th} observation, x_i = time at the i^{th} observation, and n = total number of observations

Analysis of variance (ANOVA) was performed using MSTATC to compare the effect of submergence duration and genetic differences for leaf blast development. The treatments were compared using Duncan's Multiple Range Test (DMRT).

3. Results and Discussion

Submergence duration significantly affected leaf blast development on rice seedlings during 2013 though it did not differ statistically for disease development during 2012 (Table 1). Over all disease development was lower in 2012 as compared to 2013. Insignificant differences might be attributed to less favorable environment (Fig. 1 & Fig. 2) and only four submergence periods were considered for testing during 2012. Especially rainfall and relative humidity influenced the leaf blast development. These reasons resulted in high error mean square and less chances of being statistically different AUDPC values among the submergence periods though the values were numerically different. Seven days of submergence period produced the lowest AUDPC values in all three tests while in two tests, rice plants submerged for 3-7 days had lower AUDPC values, suggesting that leaf blast might be reduced when rice seedlings were submerged, at least for three days, before transplanting. The combined analysis also showed the similar results and further partitioned the AUDPC values among 3-7 days submergence duration, 7 days submerged plants exhibited the lowest disease. Several studies have demonstrated that flooding induced resistance to many pathogens (Sah, 1989; Singh *et al*., 2004; Hsu *et al.*, 2013). Rice plants are less severely infected with blast pathogen when grown in continuous flood irrigation than when grown in an intermittent flood or an upland condition (Lee and MacMinn, 1996). Kim *et al*. (1986) found that flooding reduced the number of blast infections, the rate of lesion expansion and resulted in slower disease development. In general, hypoxia (oxygen limited condition) in the flooded root zone signals the plant defense mechanisms conferring rice blast field resistance, likely through increased ethylene production (Singh *et al*., 2004). The flooding restricts the rate of fungal mycelium growth on rice plants, limiting overall lesion development. This restriction of invasion can be attributed to structural and physiological in nature (Singh *et al*., 2003).

Table 1: Effect of submergence durations on leaf blast as measured by area under disease progress curve (AUDPC) in Sub1 and non-Sub1 rice at Regional Agricultural Research Station, Tarahara, Sunsari, Nepal during 2012 and 2013 wet seasons

SN	Submergence Days	AUDPC†				
		2012	2013			
			Test 1	Test 2	Test 3	Average
1	0	191.67	351.1 a	362.5 a	458.3 a	390.7 A
2	1	162.96	319.4 a	358.3 a	434.8 a	370.8 A
3	3	188.89	276.3 b	338.8 a	377.8 b	331.0 B
4	5	176.85	265.6 b	323.5 ab	358.4 b	315.7 BC
5	7		262.6 b	294.4 b	352.8 b	303.2 C
	$LSD_{0.05}$	NS	42.51	41.53	32.58	20.22
	CV	24.75%	6.33%	7.06%	5.58%	6.30%
	Interaction		NS	NS	NS	NS

† Values followed by different letters within a column are significantly different at P=0.05; NS= Not Significant

The Sub1 and non-Sub1 rice genotypes differed significantly for AUDPC values irrespective of submergence durations during both the years (Table 2). Among Sub1 rice, Swarna Sub1 had lower AUDPC values than that in Samba Mahsuri Sub1 (Fig. 3). Original Samba Mahsuri showed the highest AUDPC values. The combined analysis of 2013 data also indicated the similar result.

Table 2: Effect of Sub1 and non-Sub1 rice on leaf blast as measured by area under disease progress curve (AUDPC) as influenced by submergence durations at Regional Agricultural Research Station Tarahara, Sunsari, Nepal during 2012 and 2013 wet seasons

SN	Variety	AUDPC†				
		2012	2013			
			Test 1	Test 2	Test 3	Average
1	Swarna	141.7 c	293.4 b	322.1 c	398.9 b	338.1 B
2	Swarna Sub 1	92.59 d	266.7 c	312.2 c	371.2 c	316.7 C
3	Samba Mahsuri	271.3 a	323.1 a	367.7 a	426.7 a	372.6 A
4	Samba Mahsuri Sub 1	214.8 b	296.7 b	340.0 b	388.9 b	341.9 B
	$LSD_{0.05}$	37.56	13.93	17.66	16.49	9.03
	CV (%)	24.75	6.33	7.06	5.58	6.30

† Values followed by different letters within a column are significantly different at P=0.05

Submergence duration had positive effect on reducing leaf blast in the seedbed (Table 1). Disease development was lowered with increased submergence durations, with substantially a greater reduction in Sub1 genotypes (Fig. 3). The Sub1 genotypes can tolerate complete submergence up to two weeks through restriction of carbohydrate consumption, chlorophyll degradation and elongation growth (Fukao *et al*., 2006; Xu *et al*., 2006). The *SUB1* locus encodes VII ethylene response factor genes that limit ethylene production during submergence. The *SUB1* also dampens responsiveness to gibberelic acid (GA) through up-regulation of genes negative signaling to GA (Fukao and Xiong, 2013). Because of activation of Sub1 gene, the plants accumulated more carbohydrate and in turn the Sub1 rice showed relatively higher level of leaf blast resistance after de-submergence. The similar results for increased resistance to stalk rot of maize were reported by Dodd (1980), when source to sink ratio was greater.

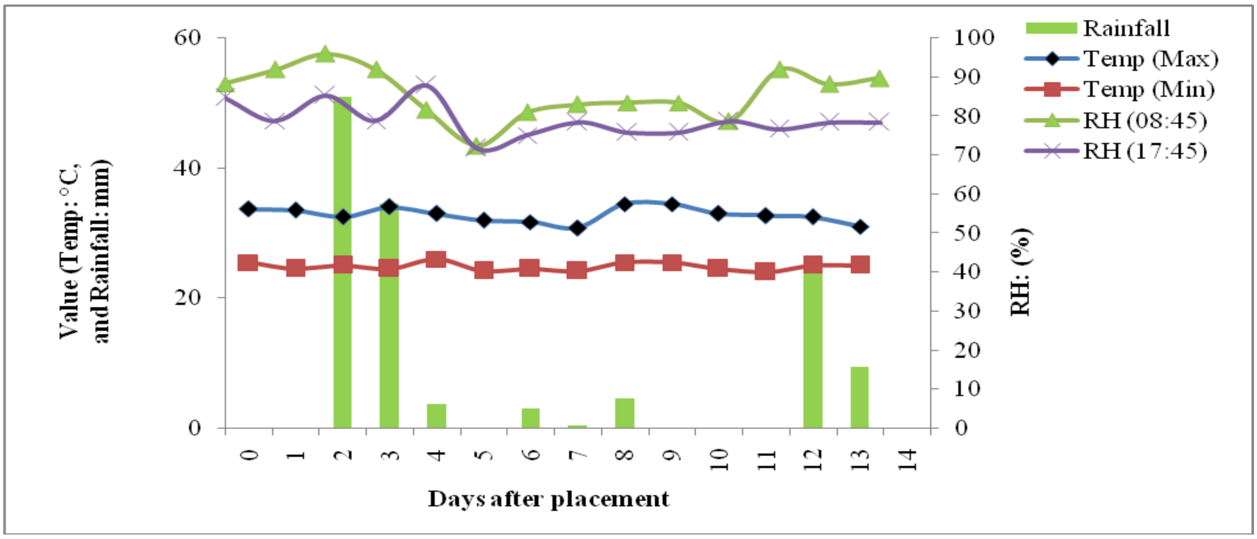

Figure 1: Daily temperature (°C), rainfall (mm) and relative humidity (%) during 30 August to 11 September 2012 at Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Sub1 mediated postponement of leaf senescence is likely to aid in prompt recovery from submergence and drought stress. This helps a lot to build and accumulate more carbohydrate in the source (vegetative parts) influenced by increased photosynthetic rate because of less degradation of chlorophyll (Panda and Sarkar, 2012). When maize stalks were cut above the first and second internodes, 100% cob rot was recorded (Dodd, 1980). The least disease was observed when less or no foliage was removed, indicating source (carbohydrate reserve) mediated resistance to disease.

Due to their immobility, plants have evolved complex sensing mechanisms and response pathways that help them adapt to diverse environmental conditions and ensure their survival (Bailey-Serres and Voeseneck, 2008). Transcriptional regulation is one of the mechanisms used by plants to protect against biotic and abiotic stresses. Two rice chromosomal regions were reported to be associated with biotic stress and submergence tolerance based on in silico data (Kottapalli *et al*., 2006). Defense responses in abiotic and biotic stresses are regulated by groups of cross-communicating signal transduction pathways. Hormones, such as abscisic acid, jasmonic acid, and salicylic acid mediate signaling pathways required for both pathogen resistance and tolerance to abiotic stresses (Xiong and Yang, 2003; Chini *et al*., 2004).

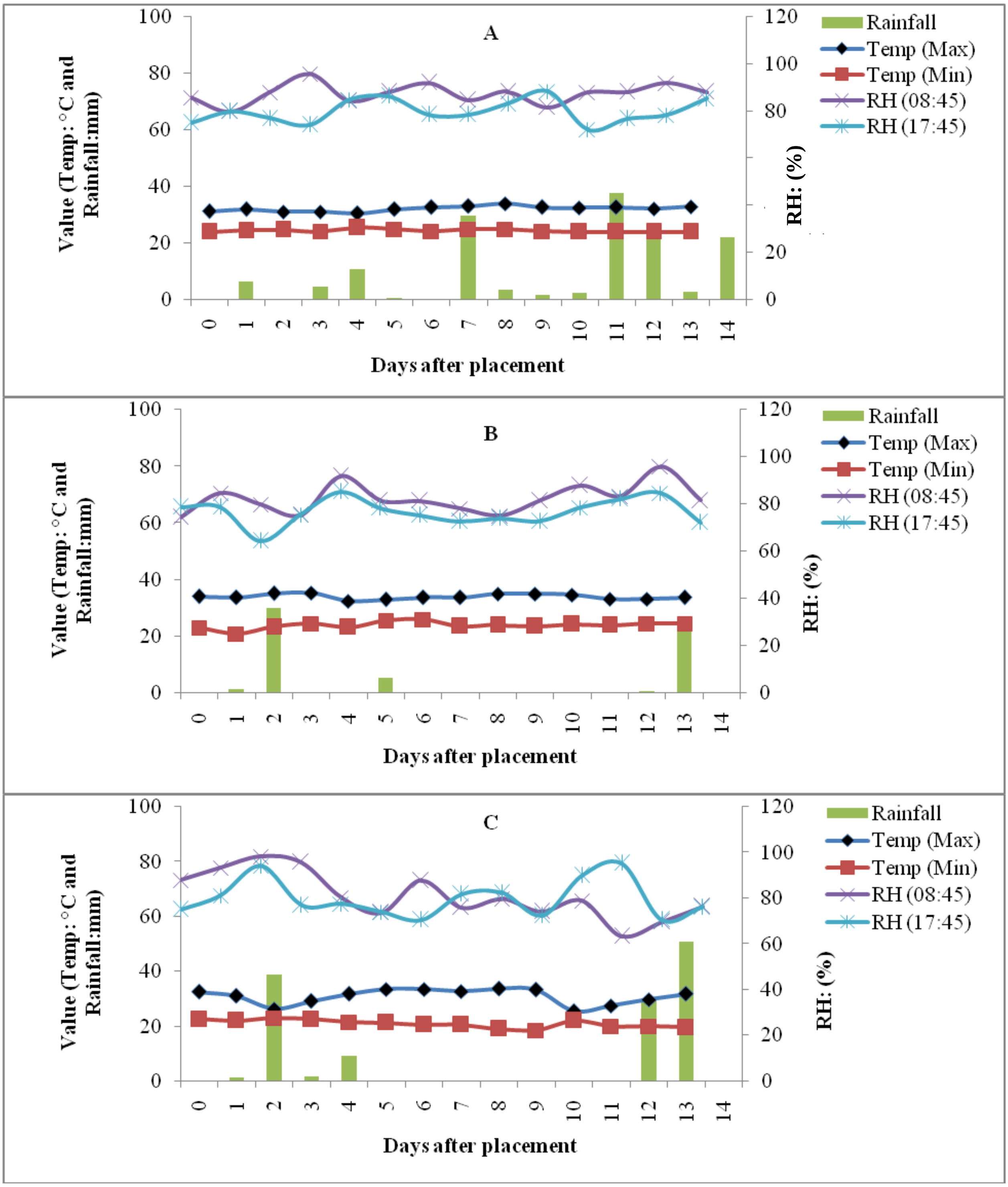

Figure 2: Daily temperature (°C), rainfall (mm) and relative humidity (%) during (A) 6-20 August (B) 15-29 September and (C) 3-17 October 2013 at Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Recently, Rushton et al. (2010) reported that WRKY transcription factors (TFs) are induced upon submergence in *Arabidopsis* and these are involved in the regulation of gene expression during biotic stress, abiotic stress, senescence, and several developmental processes. In addition, many TFs mediate disease defense and abiotic stresses in tobacco (Zhang *et al*, 2007) and rice (Liu *et al*, 2008). A review also discussed about the central roles of some WRKY TFs in mediating both abiotic and biotic stresses (Friedel *et al*., 2012). Submergence activates innate immunity markers and

WRKY TFs to confer higher disease resistance to plants (Hsu *et al*., 2013). They identified a key TF, WRKY22 that mediates this response. The results not only showed the induction of WRKY genes and innate immunity marker genes in response to flooding, but also showed that pathogen resistance could be triggered by flooding. In natural conditions, flooding leads to a higher probability of pathogen infection and faster disease development (Kottapalli *et al*., 2006). Thus, plants have evolved disease defense in response to submergence in anticipation of a higher risk of pathogen attack during and post-submergence (Hsu *et al*., 2013). It happened because pathogen associated molecular patterns and pattern recognition receptors are expressed and trigger a defense response (Boller and Felix, 2009).

Our studies demonstrated that when Sub1 rice genotypes were subjected to submergence for 3-7 days at the seedling stage, the stress conferred not only tolerance to submergence but also resistance to leaf blast. Thus, *SUB1A* locus could be used in flash flood affected areas where rice seedlings are damaged by flooding and leaf blast so that healthy and quality seedlings can be raised and transplanted for increased rice production.

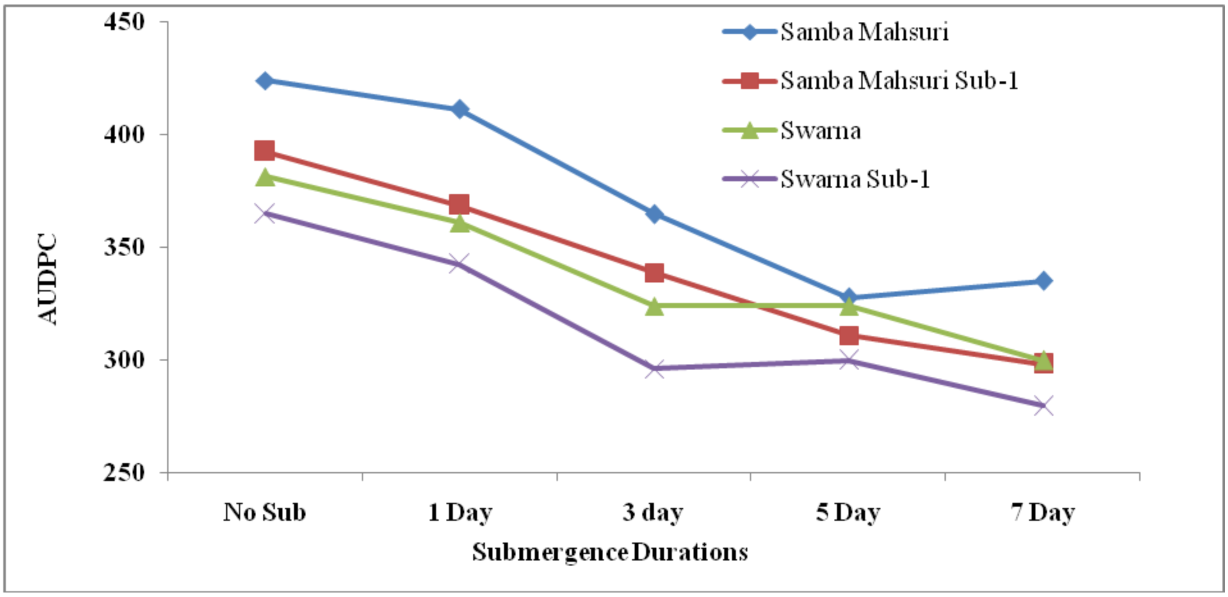

Figure 3: Effect of Submergence durations on leaf blast as measured by AUDPC in Sub1 and non-Sub1 rice genotypes during the 2013 wet season at Regional Agricultural Research Station, Tarahara, Nepal

4. Conclusions

Considering current climate risk and rice leaf blast, climate resilient technologies are needed to develop and disseminate for increased rice production and productivity in Nepal. Attempt was made during the 2012 and 2013 wet seasons to find out suitable water management practice and rice genotypes for leaf blast management in the seedbed to raise enough healthy rice seedlings for transplanting. Submergence reduced leaf blast at the seedling stage; 3-7 days submerged plants showed higher level of disease resistance. Rice genotypes had lower disease severity on post submerged plants with a significantly greater reduction on Sub1 rice. Swarna Sub1 was better compared to Samba Mahsuri Sub1 with respect to leaf blast under with or without submergence. So, rice genotypes with *SUB1A* QTL like Swarna Sub1 could be promoted in flash flood affected and blast prone areas where these biotic and abiotic stresses occur during the seedling stage in Nepal.

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