# CHAPTER 2
# VARIATION OF SILICON UPTAKE IN UPLAND RICE GENOTYPES UNDER DROUGHT CONDITION

## 2.1 Introduction

Rice is particularly susceptible to soil water deficit (Inthapan and Fukai, 1988) and drought affects its growth in about 50% of the word production area (Hanson *et al*., 1990). Drought occurs frequently in rainfed uplands and limits crop growth and yield which are directly proportional to the amount of water transpired (Yambao and Ingram, 1988). Water uptake by rice decreases as soil matric potential drops below zero, leading to reduced leaf water potential. Rice plants respond to drought by reducing production of new tillers and leaves, reducing leaf elongation, rolling existing leaves and promoting leaf death (Cutler *et al*., 1980; O′Toole and Cruz, 1980; Hsiao *et al*., 1984; Turner *et al*., 1986). These responses reduce interception of photosynthetically-active radiation (PAR) (Inthapan and Fukai, 1988). Stomata are particularly sensitive to drought, leaf conductance decreasing sharply with decrease in leaf water potential (Tomar and O′Toole, 1982; O′Toole *et al*., 1984) which reduces the rate of photosynthesis and radiation-use efficiency (RUE) (Inthapan and Fukai, 1988). These responses reduce dry matter production and eventually grain yield.

Drought can occur during any stage of the crop. The adverse effects of drought depend on the timing, severity and duration of stress. Water stress at the vegetative stage reduces the plant height, tiller number and leaf area. However, the plants can recover once water is applied sufficiently before the onset of flowering and resume growth rates similar to those if non-stressed plant (Tuong *et al*., 1995). Although the vegetative phase is prolonged and the reproductive phase is delayed, grain yield is not reduced significantly due to delayed canopy senescence after recovery. Rice plants are most sensitive to deficit moisture during the period from

about 10 days before flowering to the end of flowering (Yoshida, 1981). Water stress during this stage inhibits panicle exertion and spikelet filling and causes high sterility, leading to decreased grain yields (Ekanayake *et al*., 1989). The sterility is irreversible and water supply at later stages does not help the crop. Pre-anthesis accumulation of carbohydrates in stem and leaf sheath contributes substantially to grain filling under water stress (Chaturvedi *et al*., 1996).

High levels of sugar act as osmotic agent and help in maintaining higher leaf area and dry weight. Translocation is less affected by water stress than photosynthesis. While carbohydrates are remobilized relatively faster in tolerant than in susceptible varieties, therefore, high carbohydrate levels at anthesis and their faster translocation are desirable for tolerance to drought during the reproductive stage. However, Sudhakar *et al*. (1987) reported that stress that occurred during tillering and panicle development stages resulted in lowering of the grain yield more than that at ripening stage (Sudhakar *et al*., 1987). Ghildayal and Jana (1968) observed that at tillering stage of rice was most susceptible to moisture stress.

One way for the growth and survival of plants in dry habitats is drought resistance. It is the generic term used to cover a range of mechanisms whereby plants withstand periods of dry weather. Three primary types of drought resistance have been identified (Jones *et al*., 1981). (i) Drought escape: the ability of a plant to complete its life cycle before a serious plant water deficit develops, (ii) Drought tolerance at high tissue water potential: the ability of a plant to endure periods of rainfall deficit while maintaining a high tissue water potential, and (iii) Drought tolerance at low tissue water potential: the ability of a plant to endure rainfall deficits at low tissue dehydration. Drought escape can be achieved by matching variety duration with rainfall distribution, such that the crop passes critical development stages, especially panicle emergence, before or after the periods of probable water shortage. This is an important mechanism to ensure stable rice yield.

Drought-tolerance plant responded to dehydration by either avoidance or tolerance mechanisms. Dehydration avoidance is the ability of the plant to maintain a high water potential when soil available water is reduced whereas dehydration tolerance is their inherent ability to sustain reduced internal water potential with least injury (Jones *et al*., 1981). Rice plants avoid dehydration either through increased

water uptake by producing deep and extensive root systems or through reduced water losses by stomatal closure, leaf rolling, leaf waxiness and leaf abscission (Ingram *et al*., 1994).

However, drought resistance is a complex of many morphophysiological and biochemical characteristics, and it is doubtful that any one criterion will be adequate for selection of drought-resistant genotypes. Leaf rolling is one of traits which is used as a selection criterion for selection of drought-resistant genotypes because leaves of many crop plants frequently roll when stressed. This passive movement reduces the radiation effect, thereby counteracting the increase in leaf temperature arising from stomatal closure and preventing further development of leaf water deficit. Leaf conductance and transpiration rates decrease sharply with leaf rolling. Rice varieties with erect leaves also roll their leaves and are suitable for upland cultivation (Gupta, 1997). The leaf rolling score is very useful for the purpose of recording when the crop begins to be stressed. Rolling occurs when the cells lose turgor and the leaf wilts, and it is a very clear visual symptom of plant water deficit. In general, if a certain cultivar does not show leaf rolling while others do, this is an indication that this cultivar has a relatively better status. That may be a result of deep roots that allow continued water uptake, effective osmotic adjustment that maintains turgor at a given leaf water status, or less leaf area and slower water use. Because rolling can reflect many different mechanisms, it is not generally correlated with yield under stress (Lafitte *et al*., 2003).

Transpiration is the loss of water vapor from a plant which causes stomata closure and therefore, decreases the photosynthetic rate. Transpiration from the leaves is made mainly through the stomata and partly through the cuticle (Ma and Takahashi, 2002). Under soil moisture stress, the stomata partially or entirely close, conserving water and, hence, preventing loss of internal plant moisture. When stomata are completely closed, whether during the night time or because of moisture stress, most of the water lost by the plant is through cuticle transpiration (Yoshida, 1975). A thick and impermeable cuticle layer on the leaf surface minimizes water loss, thereby increasing plant resistance to drought (Yoshida and Reyes, 1976). Si can alleviate water stress by decreasing transpiration. Rice plants have a thin cuticle and the formation of a cuticle-Si double layer significantly decreases cuticular

transpiration. The transpiration of rice decreases with increasing Si content in the shoot (Ma *et al*., 2001). The transpiration rate in rice is negatively correlated with the Si content of the shoot (Ma and Takahashi, 2002).

As mentioned above, breeding upland rice genotypes with greater ability of Si uptake has been proposed. However, genotypical difference in Si uptake has been reported to be smaller than that of other nutrients while genetic variability is the raw material of plant breeding, and its existence and nature must first be established before exploitation of trait can be considered. Therefore, some upland rice genotypes have been evaluated for variability of Si uptake under drought.

The objective of this study was to determine if upland rice genotypes varied in their Si uptake when grown under drought condition at tillering stage. However, high accumulation of Si in rice has been attributed to the ability of the root to take up Si (Takahashi *et al*., 1990; Richmond and Sussman, 2003; Ma *et al*., 2004), therefore, this study was to determine Si uptake by investigating from Si content in different parts of rice.

## 2.2 Materials and methods

An experiment was conducted at Rajamangala University of Technology Lanna - Nan during June to November 2003. Fifty-two upland rice genotypes (listed in Table 2.1) were analysed for silicon content. Four seeds of each genotype were planted into 25-cm-diameter pots containing loam soil, and each genotype was planted in four pots. Prior to planting, soil was amended with $(NH_4)_2SO_4$ (0.5 g $kg^{-1}$ soil), KCl (0.2 g $kg^{-1}$ soil), and $KH_2PO_4$ (0.2 g $kg^{-1}$ soil). The experiment was laid out in Randomized Complete Block Design with three replicates. The rice plants were established by watering with drip irrigation. For drought condition manipulation, water was withheld to impose stress at tillering stage for 15 days, starting 31 days after the emergence of seedling. After finishing of drought-stage treatment, water was applied regularly until reaching physiological grain-maturing stage.

**Data collection**

The performance of fifty-two rice genotypes were recorded through Si content in tissues of rice plants at tillering (45 days after emergence) and harvesting stage, recorded on yield and yield components.

1) Si content in rice plants tissues at tillering (45 days after emergence) and harvesting stage: It was determined by the autoclave-induced digestion (AID) method (Elliott and Snyder, 1991). Rice plant samples were taken randomly from 4 plants of each genotype which were grown in the same pot. Then, these plant samples were separated into three parts. First part was leaf blades, second part was stem (stem and leaf sheath), and third part was roots only. Except at harvesting stage, hulls were added for determination. AID method was described by the following procedures. Plant samples were dried at 70°C for 48 h and ground in a stainless steel mill to pass a 20-mesh screen. 100 mg of each sample of rice part tissues then was wetted with 2 mL of 50% $H_2O_2$ in 150 mL polytetrafluoroethylene bottles which had been rinsed with 0.1 M NaOH and demineralized water (DM). Each bottle was added 4.5 g of 50% NaOH and the suspension was autoclaved at 138 kPa for 1 h. After atmospheric pressure was reached, the contents were brought to 50 mL with DM. Si in dilution of samples was determined colorimetrically by the blue silicomolybdous acid procedure, which was a modification of the colorimetric procedure described by Horwitz (1970). Color development was accomplished by adding 35 mL of 20% acetic acid, 10 mL of ammonium molybdate solution, 5 mL of 20% tartaric acid and 1 mL reducing solution. After mixing, absorbance at 650 nm was determined. The Si content was determined using a standard curve and expressed as mg Si $g^{-1}$ dry weight.

2) Leaf rolling score: Rice plants from the remainder pots of each genotype were then scored visually for drought damage, which included leaf rolling and leaf drying. A visual score of leaf rolling was done on an arbitrary scale of 0, 1, 3, 5, 7 and 9 at midday after finishing of drought treatment, where 0 corresponded to leaves healthy (drought tolerant) and 9 to leaves tightly rolling (drought-intolerant), following the IRRI scoring system (IRRI, 1996).

3) Yield and yield components: Rice plant samples were taken from the remainder pots of each genotype for recording yield and yield components.

**Statistical analysis**

Data were analysed statistically by analysis of variance (ANOVA), with subsequent comparison of means by the least significant difference (LSD) test.

## 2.3 Results

### 2.3.1 Leaf rolling score

As shown in Table 2.1, the leaf rolling score of rice plants which were treated with drought condition at tillering stage were significantly different among the upland rice genotypes ($P < 0.01$). The upland rice genotypes ranged in leaf rolling score from 5.0 to 8.3 and the mean of leaf rolling score for genotypes was 6.8.

### 2.3.2 Si content in rice plant tissues

Analysis of variance of Si content in upland rice tissues which plants were treated with drought condition at tillering stage, Si content in leaf blade and stem tissues varied greatly and significantly ($P < 0.01$) among the upland rice genotypes, both at tillering and harvesting stages. The data from Tables 2.1 and 2.2 showed that Si content in leaf blade tissues at tillering and harvesting stage ranged form 26.4 to 75.0 mg $g^{-1}$ and 28.1 to 62.5 mg $g^{-1}$, respectively while Si content in stem tissues ranged from 29.2 to 63.9 mg $g^{-1}$ and 25.8 to 64.9 mg $g^{-1}$, respectively. The means of Si content in leaf blade tissues at tillering and harvesting stage for genotypes were 56.4 mg $g^{-1}$ and 39.7 mg $g^{-1}$, respectively, and the means of Si content in stem tissues at tillering and harvesting stage for genotypes were 37.7 mg $g^{-1}$ and 34.7 mg $g^{-1}$, respectively. Si content in hull tissues was significant among the upland rice genotypes ($P < 0.05$) which ranged from 28.5 to 56.8 mg $g^{-1}$ and the mean was 39.3 mg $g^{-1}$ (Table 2.2). But Si content in root tissues was not significant among the upland rice genotypes, both at tillering and harvesting stages. The means of Si content in root tissues at tillering and harvesting stage for genotypes were 40.4 mg $g^{-1}$ and 44.2 mg $g^{-1}$, respectively. These results showed that under drought condition, some genotypes were better in uptaking Si than others. However, the genotypes, for

example, Hao (No.26), SPT93034-SMG-9-2-4 (No.14), SPT91068-3-SMG-6-2-1-1-1 (No.20), SMGC90001-11 (No.41), Khao Peek (No.46) etc. which showed the highest Si content in plant tissues were not consistent at both stages of growth.

**Table 2.1** Mean of leaf rolling score and silicon content (dry weight basis) in rice plant tissues of 52 upland rice genotypes recorded at tillering stage (45 days after emergence) when grown under drought condition.

| No. | Genotype | Leaf rolling score | Mean of Si content in rice plant tissues (mg $g^{-1}$) | | |
|---|---|---|---|---|---|
| | | | leaf blade | stem | Root |
| 1. | FNUR8506-2-3-1-1-2 | 7.7 | 50.5 | 32.5 | 39.6 |
| 2. | Ja Taw Gu | 5.0 | 60.9 | 52.8 | 44.5 |
| 3. | Jao Hor | 5.0 | 66.9 | 40.3 | 34.5 |
| 4. | IURON92#37 | 6.3 | 56.5 | 36.0 | 38.2 |
| 5. | FNUR8017-3 | 7.7 | 52.8 | 29.9 | 39.4 |
| 6. | SMG9004-2-1-1-1 | 6.3 | 55.8 | 40.4 | 34.1 |
| 7. | SMG9037-2-1-1-2 | 7.7 | 46.3 | 29.2 | 39.2 |
| 8. | SMG9058-1-1-1-1 | 7.7 | 49.4 | 34.3 | 42.7 |
| 9. | SMG9058-1-1-1-2 | 5.7 | 65.3 | 46.4 | 44.3 |
| 10. | SMGHR89003-4-3-1-1 | 6.3 | 60.7 | 42.4 | 36.0 |
| 11. | Khao Horm Pamar | 7.0 | 53.1 | 37.6 | 42.9 |
| 12. | SMGH89028-3-1-1-1 | 7.7 | 54.7 | 35.9 | 37.6 |
| 13. | Jao Li Saw | 7.0 | 56.3 | 33.9 | 37.6 |
| 14. | SPT93034-SMG-9-2-4 | 5.0 | 69.3 | 49.2 | 42.4 |
| 15. | GT6947-1-9-1-1-1-1P | 6.3 | 58.6 | 38.9 | 39.2 |
| 16. | SPT91026-1-SMG-6-2-1-1-1 | 8.3 | 45.4 | 34.3 | 34.6 |
| 17. | SPT91026-1-SMG-6-2-1-2-2 | 6.3 | 59.5 | 38.2 | 44.0 |
| 18. | Rouang Pueng | 7.0 | 53.8 | 35.7 | 41.9 |
| 19. | SPT91026-5-SMG-2-4-1-2-3 | 7.0 | 55.2 | 37.1 | 41.5 |
| 20. | SPT91068-3-SMG-6-2-1-1-1 | 5.7 | 68.8 | 45.9 | 42.2 |
| 21. | SPT90021-SMG-1-2-1-1-1 | 6.3 | 61.4 | 36.0 | 44.0 |

**Table 2.1** (continued)

| No. | Genotype | Leaf rolling score | Mean of Si content in rice plant tissues (mg $g^{-1}$) | | |
|---|---|---|---|---|---|
| | | | leaf blade | stem | root |
| 22. | Plaw Sew Tawng | 5.7 | 59.8 | 31.5 | 38.5 |
| 23. | Plasew 1 | 7.7 | 52.1 | 37.8 | 44.8 |
| 24. | Khao Niaw Maew | 8.3 | 47.5 | 31.8 | 33.0 |
| 25. | Nam Ton Lai | 6.3 | 61.2 | 32.9 | 39.7 |
| 26. | Hao | 5.0 | 75.0 | 35.9 | 45.4 |
| 27. | Daw Prae | 6.3 | 57.2 | 38.2 | 37.8 |
| 28. | Horm Rai 5 | 7.7 | 51.0 | 30.4 | 42.2 |
| 29. | Prae | 6.3 | 57.5 | 32.9 | 40.1 |
| 30. | Khao Sa | 6.3 | 63.7 | 35.5 | 34.8 |
| 31. | Sew Luang | 6.3 | 60.7 | 35.3 | 46.1 |
| 32. | Khao Luang | 6.3 | 63.9 | 34.3 | 31.5 |
| 33. | Sew Mae Jan | 8.3 | 45.9 | 38.9 | 35.3 |
| 34. | Daw Thai 3 | 7.0 | 55.2 | 38.9 | 34.6 |
| 35. | SMGC90002-4 | 7.0 | 54.0 | 63.9 | 40.3 |
| 36. | SMG9101-1-1-1 | 8.3 | 50.3 | 32.0 | 39.4 |
| 37. | SPT91068-3-SMG-1-1-1 | 8.3 | 47.1 | 35.3 | 42.0 |
| 38. | SPT90020-SMG-1-2-1-1-1 | 7.0 | 52.4 | 36.7 | 38.0 |
| 39. | Lang Gah | 7.7 | 53.3 | 38.5 | 36.0 |
| 40. | Khao Dang | 5.7 | 62.8 | 37.8 | 34.8 |
| 41. | SMGC90001-11 | 6.3 | 68.1 | 45.7 | 44.7 |
| 42. | SMGC89001-6 | 8.3 | 43.3 | 34.3 | 44.5 |
| 43. | Khao Sew | 7.0 | 61.6 | 44.8 | 40.1 |
| 44. | Khao Non Lek | 6.3 | 61.2 | 40.4 | 43.1 |
| 45. | Khao Non Yai | 6.3 | 57.2 | 46.6 | 38.0 |
| 46. | Khao Peek | 5.0 | 67.7 | 38.2 | 49.2 |
| 47. | Khao Ma Naum | 7.0 | 58.4 | 32.0 | 42.0 |
| 48. | Makok Pee | 7.0 | 56.6 | 30.8 | 42.2 |
| 49. | IR55411-53 | 7.0 | 55.8 | 37.5 | 44.1 |
| 50. | IRAT191 | 8.3 | 26.4 | 30.2 | 45.7 |

**Table 2.1** (continued)

| No. | Genotype | Leaf rolling score | Mean of Si content in rice plant tissues ($mg\ g^{-1}$) | | |
|---|---|---|---|---|---|
| | | | leaf blade | stem | root |
| 51. | Douradao | 7.0 | 55.9 | 40.1 | 45.6 |
| 52. | IR57893-70 | 7.7 | 50.0 | 36.2 | 44.7 |
| | Mean† ± SE | 6.8 ± 1.3 | 56.4 ± 9.2 | 37.7 ± 7.5 | 40.4 ± 5.6 |
| | *F*-test | * | ** | ** | ns |
| | $LSD_{0.05}$ | 2.15 | 14.94 | 12.15 | - |
| | $LSD_{0.01}$ | - | 19.74 | 16.06 | - |

† Data are the means of three replications.

**, * and ns = significant at the 0.01, 0.05 probability level and not significant by ANOVA, respectively.

**Table 2.2** Mean of silicon content (dry weight basis) in rice plant tissues of 52 upland rice genotypes recorded at harvesting stage when grown under drought condition at tillering stage.

| No. | Genotype | Mean of Si content in rice plant tissues ($mg\ g^{-1}$) | | | |
|---|---|---|---|---|---|
| | | leaf blade | Stem | root | hull |
| 1. | FNUR8506-2-3-1-1-2 | 47.3 | 34.8 | 43.4 | 49.4 |
| 2. | Ja Taw Gu | 36.7 | 28.1 | 50.1 | 51.5 |
| 3. | Jao Hor | 43.3 | 40.8 | 39.0 | 33.4 |
| 4. | IURON92#37 | 43.1 | 32.0 | 43.6 | 29.9 |
| 5. | FNUR8017-3 | 35.5 | 34.1 | 38.2 | 37.3 |
| 6. | SMG9004-2-1-1-1 | 39.6 | 28.8 | 46.6 | 38.3 |
| 7. | SMG9037-2-1-1-2 | 62.5 | 36.0 | 45.6 | 42.0 |
| 8. | SMG9058-1-1-1-1 | 28.1 | 29.9 | 48.5 | 40.3 |
| 9. | SMG9058-1-1-1-2 | 37.1 | 25.8 | 51.5 | 45.0 |

**Table 2.2** (continued)

| No. | Genotype | Mean of Si content in rice plant tissues ($mg\ g^{-1}$) | | | |
|---|---|---|---|---|---|
| | | leaf blade | Stem | root | hull |
| 10. | SMGHR89003-4-3-1-1 | 32.7 | 35.9 | 44.3 | 33.4 |
| 11. | Khao Horm Pamar | 53.1 | 29.9 | 46.3 | 34.1 |
| 12. | SMGH89028-3-1-1-1 | 41.5 | 44.1 | 44.7 | 41.9 |
| 13. | Jao Li Saw | 41.7 | 29.9 | 38.7 | 39.2 |
| 14. | SPT93034-SMG-9-2-4 | 49.6 | 41.1 | 51.5 | 43.3 |
| 15. | GT6947-1-9-1-1-1-1P | 30.4 | 33.9 | 48.9 | 43.4 |
| 16. | SPT91026-1-SMG-6-2-1-1-1 | 38.7 | 47.7 | 44.8 | 46.3 |
| 17. | SPT91026-1-SMG-6-2-1-2-2 | 43.3 | 32.2 | 40.1 | 36.0 |
| 18. | Rouang Pueng | 34.6 | 28.1 | 46.1 | 44.8 |
| 19. | SPT91026-5-SMG-2-4-1-2-3 | 47.7 | 32.2 | 47.3 | 40.6 |
| 20. | SPT91068-3-SMG-6-2-1-1-1 | 42.6 | 30.4 | 48.4 | 38.7 |
| 21. | SPT90021-SMG-1-2-1-1-1 | 40.1 | 28.5 | 42.6 | 40.8 |
| 22. | Plaw Sew Tawng | 50.7 | 35.5 | 40.6 | 43.8 |
| 23. | Plasew 1 | 52.1 | 30.1 | 41.7 | 37.3 |
| 24. | Khao Niaw Maew | 34.1 | 34.8 | 38.7 | 42.0 |
| 25. | Nam Ton Lai | 37.8 | 39.2 | 44.5 | 37.3 |
| 26. | Hao | 39.9 | 36.6 | 47.5 | 37.8 |
| 27. | Daw Prae | 32.7 | 29.4 | 44.1 | 36.6 |
| 28. | Horm Rai 5 | 39.2 | 25.8 | 46.6 | 30.1 |
| 29. | Prae | 32.0 | 33.0 | 42.4 | 28.5 |
| 30. | Khao Sa | 41.0 | 41.3 | 41.7 | 34.3 |
| 31. | Sew Luang | 41.5 | 64.9 | 42.9 | 36.7 |
| 32. | Khao Luang | 30.8 | 30.1 | 45.0 | 35.3 |
| 33. | Sew Mae Jan | 32.2 | 33.2 | 44.7 | 39.9 |
| 34. | Daw Thai 3 | 35.5 | 32.5 | 38.2 | 41.0 |
| 35. | SMGC90002-4 | 36.2 | 33.6 | 44.7 | 36.2 |
| 36. | SMG9101-1-1-1 | 41.9 | 35.0 | 43.3 | 28.8 |
| 37. | SPT91068-3-SMG-1-1-1 | 32.9 | 32.7 | 43.1 | 34.1 |
| 38. | SPT90020-SMG-1-2-1-1-1 | 38.0 | 32.7 | 45.2 | 43.8 |

**Table 2.2** (continued)

| No. | Genotype | Mean of Si content in rice plant tissues (mg $g^{-1}$) | | | |
|---|---|---|---|---|---|
| | | leaf blade | Stem | root | hull |
| 39. | Lang Gah | 37.1 | 29.7 | 45.0 | 42.6 |
| 40. | Khao Dang | 37.8 | 30.6 | 44.1 | 33.6 |
| 41. | SMGC90001-11 | 44.5 | 34.5 | 48.5 | 45.6 |
| 42. | SMGC89001-6 | 37.5 | 50.7 | 44.1 | 37.5 |
| 43. | Khao Sew | 34.8 | 34.5 | 43.3 | 35.0 |
| 44. | Khao Non Lek | 32.7 | 29.4 | 42.9 | 41.1 |
| 45. | Khao Non Yai | 36.4 | 40.1 | 47.1 | 41.9 |
| 46. | Khao Peek | 38.9 | 36.0 | 48.0 | 45.9 |
| 47. | Khao Ma Naum | 49.2 | 35.3 | 46.4 | 29.9 |
| 48. | Makok Pee | 31.1 | 41.9 | 38.3 | 32.5 |
| 49. | IR55411-53 | 36.6 | 35.2 | 46.8 | 41.7 |
| 50. | IRAT191 | 46.1 | 34.5 | 36.0 | 40.1 |
| 51. | Douradao | 48.7 | 35.0 | 42.9 | 56.8 |
| 52. | IR57893-70 | 33.4 | 33.2 | 40.6 | 46.3 |
| | Mean† ± SE | 39.7 ± 5.84 | 34.7 ± 5.89 | 44.2 ± 6.93 | 39.3 ± 7.54 |
| | *F*-test | ** | ** | ns | * |
| | $LSD_{0.05}$ | 9.45 | 9.52 | - | 12.18 |
| | $LSD_{0.01}$ | 12.48 | 12.59 | - | - |

† Data are the means of three replications.

**, * and ns = significant at the 0.01, 0.05 probability levels and not significant by ANOVA, respectively.



### 2.3.3 Yield and Yield Components

Table 2.3 shows that upland rice genotypes varied significantly ($P < 0.01$) for grain yield, number of panicles per pot, number of spikelets per panicle, spikelet fertility and 100-grain weight when grown under drought condition at tillering stage. The ranges of these recorded data were 27.44 to 66.96 g $pot^{-1}$, 10 to 26

panicles pot$^{-1}$, 75 to 186 spikelets panicle$^{-1}$, 46.28 to 90.35% and 1.846 to 4.531 g, respectively. The means for grain yield, number of panicles per pot, number of spikelets per panicle, spikelet fertility and 100-grain weight for genotypes were 47.6 g pot$^{-1}$, 16.7 panicles pot$^{-1}$, 128.4 spikelets panicle$^{-1}$, 72.0% and 3.1 g, respectively. These results showed that under drought, some genotypes were better in yield or yield components than others.

**Table 2.3** Yield and yield components of 52 upland rice genotypes recorded at harvesting stage when grown under drought condition at tillering stage.

| No. | Genotype | Grain yield (g pot$^{-1}$) | Number of panicles per pot | Number of spikelets per panicle | Spikelet fertility (%) | 100-grain weight (g) |
|---|---|---|---|---|---|---|
| 1. | FNUR8506-2-3-1-1-2 | 45.71 | 17 | 171 | 71.44 | 2.270 |
| 2. | Ja Taw Gu | 61.24 | 17 | 76 | 85.28 | 3.630 |
| 3. | Jao Hor | 59.71 | 18 | 173 | 78.49 | 2.433 |
| 4. | IURON92#37 | 54.67 | 26 | 99 | 66.82 | 2.832 |
| 5. | FNUR8017-3 | 39.17 | 17 | 177 | 60.48 | 2.174 |
| 6. | SMG9004-2-1-1-1 | 33.12 | 16 | 79 | 68.81 | 3.048 |
| 7. | SMG9037-2-1-1-2 | 35.37 | 13 | 107 | 69.30 | 3.653 |
| 8. | SMG9058-1-1-1-1 | 45.63 | 16 | 75 | 71.70 | 3.822 |
| 9. | SMG9058-1-1-1-2 | 50.02 | 15 | 130 | 70.87 | 3.403 |
| 10. | SMGHR89003-4-3-1-1 | 45.11 | 13 | 96 | 68.65 | 4.531 |
| 11. | Khao Horm Pamar | 47.56 | 16 | 155 | 72.10 | 2.759 |
| 12. | SMGH89028-3-1-1-1 | 47.3 | 15 | 122 | 65.87 | 3.804 |
| 13. | Jao Li Saw | 58.09 | 17 | 89 | 83.98 | 3.735 |
| 14. | SPT93034-SMG-9-2-4 | 59.89 | 14 | 118 | 79.32 | 3.709 |
| 15. | GT6947-1-9-1-1-1-1P | 66.96 | 18 | 144 | 76.37 | 2.390 |
| 16. | SPT91026-1-SMG-6-2-1-1-1 | 52.56 | 17 | 84 | 77.62 | 4.157 |
| 17. | SPT91026-1-SMG-6-2-1-2-2 | 61.81 | 15 | 109 | 80.30 | 4.436 |
| 18. | Rouang Pueng | 40.36 | 20 | 177 | 64.05 | 1.846 |
| 19. | SPT91026-5-SMG-2-4-1-2-3 | 55.70 | 16 | 129 | 70.61 | 3.648 |
| 20. | SPT91068-3-SMG-6-2-1-1-1 | 56.63 | 16 | 121 | 72.98 | 3.660 |

**Table 2.3** (continued)

| No. | Genotype | Grain yield (g pot$^{-1}$) | Number of panicles per pot | Number of spikelets per panicle | Spikelet fertility (%) | 100-grain weight (g) |
|---|---|---|---|---|---|---|
| 21. | SPT90021-SMG-1-2-1-1-1 | 54.81 | 15 | 109 | 78.62 | 4.076 |
| 22. | Plaw Sew Tawng | 36.23 | 17 | 129 | 61.03 | 2.934 |
| 23. | Plasew 1 | 37.76 | 18 | 89 | 73.42 | 3.116 |
| 24. | Khao Niaw Maew | 42.14 | 17 | 148 | 67.81 | 2.514 |
| 25. | Nam Ton Lai | 40.85 | 16 | 147 | 67.79 | 2.603 |
| 26. | Hao | 27.44 | 19 | 121 | 46.28 | 2.426 |
| 27. | Daw Prae | 28.74 | 16 | 164 | 49.03 | 2.409 |
| 28. | Horm Rai 5 | 40.69 | 18 | 186 | 61.00 | 1.992 |
| 29. | Prae | 48.24 | 18 | 177 | 54.75 | 2.592 |
| 30. | Khao Sa | 46.14 | 19 | 115 | 68.31 | 2.723 |
| 31. | Sew Luang | 46.64 | 13 | 110 | 78.89 | 4.093 |
| 32. | Khao Luang | 46.98 | 17 | 147 | 63.78 | 2.986 |
| 33. | Sew Mae Jan | 58.45 | 16 | 172 | 79.41 | 2.597 |
| 34. | Daw Thai 3 | 53.11 | 18 | 152 | 69.52 | 2.553 |
| 35. | SMGC90002-4 | 51.6 | 13 | 125 | 86.74 | 3.323 |
| 36. | SMG9101-1-1-1 | 50.13 | 16 | 83 | 87.37 | 4.372 |
| 37. | SPT91068-3-SMG-1-1-1 | 47.19 | 10 | 132 | 76.97 | 4.186 |
| 38. | SPT90020-SMG-1-2-1-1-1 | 57.19 | 18 | 82 | 74.33 | 4.193 |
| 39. | Lang Gah | 48.14 | 18 | 154 | 67.75 | 2.385 |
| 40. | Khao Dang | 44.18 | 15 | 158 | 74.86 | 2.454 |
| 41. | SMGC90001-11 | 44.06 | 13 | 107 | 80.23 | 3.402 |
| 42. | SMGC89001-6 | 44.07 | 18 | 104 | 65.63 | 2.877 |
| 43. | Khao Sew | 36.52 | 17 | 137 | 63.77 | 2.542 |
| 44. | Khao Non Lek | 48.18 | 16 | 180 | 73.79 | 2.386 |
| 45. | Khao Non Yai | 40.45 | 16 | 131 | 68.06 | 2.545 |
| 46. | Khao Peek | 53.45 | 16 | 170 | 79.04 | 2.330 |
| 47. | Khao Ma Naum | 40.46 | 13 | 156 | 72.77 | 2.658 |
| 48. | Makok Pee | 42.72 | 14 | 160 | 69.91 | 2.690 |
| 49. | IR55411-53 | 55.82 | 24 | 133 | 75.45 | 2.301 |
| 50. | IRAT191 | 48.67 | 20 | 95 | 81.97 | 3.156 |

**Table 2.3** (continued)

| No. | Genotype | Grain yield (g pot$^{-1}$) | Number of panicles per pot | Number of spikelets per panicle | Spikelet fertility (%) | 100-grain weight (g) |
|---|---|---|---|---|---|---|
| 51. | Douradao | 43.72 | 19 | 87 | 82.50 | 3.282 |
| 52. | IR57893-70 | 54.03 | 23 | 87 | 90.35 | 3.285 |
| | Mean† | 47.6 | 16.7 | 128.4 | 72.0 | 3.1 |
| | ± SE | ± 11.07 | ± 3.39 | ± 23.64 | ± 9.31 | ± 0.21 |
| | *F*-test | ** | ** | ** | ** | ** |
| | $LSD_{0.01}$ | 23.65 | 7.25 | 50.52 | 19.90 | 0.44 |

† Data are the means of three replications.

** = significant at the 0.01 probability level by ANOVA.

## 2.4 Discussion

These studies revealed that under drought condition at tillering stage, upland rice genotypes varied significantly for leaf rolling score, Si content in rice plant tissues, yield and yield components. Leaf rolling occurs after the cells lose turgor pressure and the leaf wilts, and it is a very clear visual symptom of plant water deficit. In general, if a certain variety does not show leaf rolling while others do, this is an indication that this variety has a relatively better water status. Therefore, leaf rolling score is useful as a selection criterion for drought tolerance (Lafitte *et al*., 2003). Based on these facts, it might be concluded that studied upland rice genotypes varied in drought tolerance. These results could be further explained that drought tolerance, Si content in rice plant tissues, yield and yield components were influenced greatly among upland rice genotypes when treated with drought at tillering stage.

Moreover, result also showed that the mean of Si content in leaf blade was higher than in stem at both growth stages, indicating that the distribution of Si within the rice plant organs is determined by the transpiration rate of organ. These results

**Table 2.4** Correlations among leaf rolling score, Si content in rice plant tissues, yield and yield components.

| Trait† | Si-YL | Si-ML | Si-YS | Si-MS | Si-YR | Si-MR | Si-H | Y | P | S | SF | G | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Si-YL | - | -0.033 | 0.390** | -0.019 | 0.062 | 0.399** | 0.004 | 0.028 | -0.150 | 0.161 | -0.175 | -0.072 | -0.778** |
| Si-ML | | - | -0.113 | 0.098 | 0.210 | 0.022 | 0.028 | -0.104 | -0.054 | -0.219 | 0.139 | 0.176 | 0.100 |
| Si-YS | | | - | -0.128 | 0.098 | 0.451** | 0.239 | 0.281* | -0.203 | -0.150 | 0.315* | 0.141 | -0.323* |
| Si-MS | | | | - | 0.054 | -0.144 | -0.077 | -0.026 | -0.141 | -0.134 | 0.067 | 0.182 | 0.065 |
| Si-YR | | | | | - | 0.227 | 0.162 | 0.042 | 0.014 | -0.147 | 0.235 | 0.105 | -0.189 |
| Si-MR | | | | | | - | 0.201 | 0.084 | -0.175 | -0.079 | -0.036 | 0.067 | -0.451* |
| Si-H | | | | | | | - | 0.304* | 0.169 | -0.274 | 0.340* | 0.085 | -0.021 |
| Y | | | | | | | | - | 0.117 | -0.132 | 0.655** | 0.320* | 0.119 |
| P | | | | | | | | | - | -0.068 | -0.105 | -0.411** | 0.084 |
| S | | | | | | | | | | - | -0.418** | -0.741** | -0.028 |
| SF | | | | | | | | | | | - | 0.469** | 0.162 |
| G | | | | | | | | | | | | - | 0.071 |

† Si-YL = Si content in leaf blade at tillering stage  Si-ML = Si content in leaf blade at harvesting stage
Si-YS = Si content in stem at tillering stage  Si-MS = Si content in stem at harvesting stage
Si-YR = Si content in root at tillering stage  Si-MR = Si content in root at harvesting stage
Si-H = Si content in hull at harvesting stage  Y = grain yield  P = number of panicles per pot
S = number of spikelets per panicle  SF = spikelet fertility  G = 100-grains weight  L = leaf rolling score

** and * = significant at the 0.01 and 0.05 probability levels, respectively.

agreed with Jones and Handreck's (1967). However, both means of leaf blade and stem Si content at tillering stage were markedly higher than harvesting stage. In addition, correlation of Si content between leaf blade at tillering stage and leaf blade at harvesting stage was not identified, the same as correlation of Si content of stem at both growth stages was not found either. Furthermore, correlation between leaf blade and stem of Si content among genotypes at tillering stage showed a positive significance ($r$ = 0.390**) (Table 2.4) but was not found at harvesting stage. These revealed that distribution of Si in the rice shoot did not only depend on the transpiration rate of organ but also might depend on other factors, especially different plant growth and development of each genotype. However, under drought condition at tillering stage, leaf rolling score showed negative correlation with Si content in leaf blade and stem at tillering stage and Si in root at harvesting stage ($r$ = -0.778**, -0.323* and -0.451** respectively) (Table 2.4). These results demonstrated that under drought condition at tillering stage, Si also exerted alleviative effect on drought stress. These effects were mainly attributed to the high accumulation of Si in rice shoot. These results agreed with Ma and Takahashi (2002), Ma (2004) who reported that Si content in the shoot could alleviate water stress by decreasing transpiration through the cuticle of leaves. For relationship between drought tolerance at tillering stage and Si in root at harvesting stage, that may be a result of high water uptake for drought tolerance that allows continued Si uptake and accumulation in root.

For relationship analysis among leaf rolling score, yield and yield components (Table 2.4), it was found that there were positive correlations between grain yield and spikelet fertility ($r$ = 0.655**), grain yield and 100-grain weight ($r$ = 0.320*) while 100-grain weight showed negative correlation with both number of panicles per pot ($r$ = -0.411**) and number of spikelet per panicle ($r$ = -0.741**), and positive correlation with spikelet fertility ($r$ = 0.467**). Number of spikelets per panicle showed negative correlation with spikelet fertility ($r$ = -0.418**). These results suggested that grain yields were increased by yield components such as spikelet fertility and 100-grain weight but decreased by the number of panicles per pot. These results agreed with Yoshida (1983). The competition between panicles was strong with increasing number of panicles per pot, thereby, 100-grain weight and spikelet fertility was reduced by the increased number of panicles per pot. However, the leaf

rolling score did not show any correlation with grain yield or yield component. These results could be explained that upland rice genotypes showed differently in recovering of growth when received sufficient water before the onset of flowering and resumed growth rate similar to those of non-stressed plants (Tuong *et al*., 1995). Although the vegetative phase was prolonged and the reproductive phase was delayed, grain yield was not reduced significantly due to delayed canopy senescence after recovery (Sharma and Singh, 1999). The more rapid recovery abilities of genotypes will cause more spikelet fertility and grain weight, resulting in higher grain yields. In addition, grain development will be increased by photosynthesis activities of young leaves after recovering since most of assimilates will be translocated to young spikelets during the grain-filling period.

Results from the relationship analysis among Si content in rice plants, yield and yield components (Table 2.4) indicated that grain yield showed significant positive correlation with Si content in stem at tillering stage ($r$ = 0.281*) and Si in hulls at harvesting stage ($r$ = 0.304*). In addition, spikelet fertility was positively correlated to both Si in stem at tillering stage ($r$ = 0.315*) and Si in hull at harvesting stage ($r$ = 0.340*). These results revealed that Si in hulls could increase the grain yield through decreasing spikelet sterility because if moisture deficiency occured during post-flowering stage, it would enhance the spikelet sterility (Sharma and Singh, 1999). The function of Si in hulls may be to retain a high moisture condition within hull and decreasing the transpiration from the hull for the normal development of the spikelets (Ma, 2004). Si content in stem at tillering stage might be beneficial to grain yield by increasing spikelet fertility because after drought stress was over, some Si in the young stem would be translocated to panicles in order to enhance spikelet development and maintain moisture condition within the hull (Ma, 2004). A high moisture condition within the hull could reduce the percentage of spikelet sterility (Ma *et al*., 2001), so Si content in young stem tissues was related positively to the yield. However, Si content in leaf blade and stem at harvesting stage was not significantly correlated with yield and yield components. These results indicated that the rice growth after recovery did not depend on the Si content in leaf blade and stem only, but might be due to the other factors, such as resumption of growth rates of rice

plant, retention of green leaf, prolongation of grain-filling period and etc. (Sharma and Singh, 1999).

Results of this study could be concluded that variations of Si content notably existed among the upland rice genotypes, and Si uptake and accumulation in different parts of upland rice could alleviate drought stress. Thereby, analysis of Si content in young leaf blade and stem tissues could be possibly employed and helpful as a criterion of selection for breeding and improvement of drought tolerance in upland rice crops.