Chapter 5

Manganese utilization in Mn efficient and inefficient rice genotypes

5.1 Introduction

The definition of nutrient utilization efficiency used in this study has been suggested by Graham (1984), the nutrient efficiency of genotype (for each element separately) as the ability to produce a high yield in a soil that is limiting in that element for a standard genotype. Accordingly, Mn efficiency has been defined as a genotype's ability to produce high yield in a soil whose Mn content is limiting for a standard genotype (Ascher-Ellis *et al*., 2001). Wheat cv. Maris butler was judged to be relatively Mn efficient as it could produce high grain yield (Jiang and Ireland, 2005) and dry mater yield (Jiang and Ireland, 2001) when grown in Mn deficiency condition. The presence of Maris butler is clearly Mn use efficiency trait (Jiang, 2008), there is a higher internal use of Mn expressed as an improved photosynthetic efficiency. This result showed that Maris butler produced 0.0089 g dry matter yield from a 1 µg Mn whereas it was 0.0067 g in Paragon (Mn inefficient genotype).

Beside, mineral nutrition of plants affects the partitioning of carbohydrates between shoots and roots. Manganese deficiency has the most severe effect on the content of nonstructural carbohydrate (Marschner, 1995). Manganese decreased the concentration of soluble carbohydrate in plants, particularly in roots (Mukhopadhyay and Sharma, 1991) due to its role in photosynthesis. Manganese deficiency reduced photosynthesis and carbohydrate production in leaves, thus may also affect the stability of the chloroplast lamellar system (Burnell, 1988). Recently, Pearson and Rengel (1997) demonstrated reduced producing of carbohydrate under Mn deficiency in wheat.

Therefore, this study set out to evaluate mechanisms of the production and partitioning of carbohydrates and to evaluate grain yield of Mn efficiency and inefficiency genotypes. That Mn efficiency genotypes cloud be produce carbohydrate and grain yield better than Mn inefficiency ones in low availability of Mn.

5.2 Materials and Methods

5.2.1 Experiment 5.2.1 Genotypic differences in the production and partitioning of carbohydrates between root and shoot of rice grown under Mn deficiency

Two rice genotypes, PSL1 (Mn inefficiency) and KDML105 (Mn efficiency) were grown in solution culture with two levels of applied Manganese (0 and 0.5 mg Mn/L). Ten days after germination, five plants of each variety were transplanted to plastic pots containing nutrient solution (10 L). The solution was modified by Insalud (2006) (Table 2.3). The solution was renewed every week and pH values were adjusted daily to 5.5±0.05 with 1N HCl or 1N NaoH. There are three replicates per treatment. Data were recorded at 30 day after transplanting including: dry weight, shoot and root and concentration of soluble carbohydrates in root and shoot by analyse total nonstructural carbohydrate (TNC) (Smith *et al*., 1964).

TNC analysis

The TNC analysis was modified from Nelson's reducing sugar procedure (A.O.A.C., 1990). Shoot and root portion of 0.05 g from each repicate pot was placed in a 250-mL volumetric flask and digested in 0.2 N H_2SO_4 (40 ml) and oven drying at 100 ºC for 1 hrs. The sample solution were adjusted pH values to 7.0±0.05 with 1N HCl or 1N NaoH, the solution was then brought to 50-mlL volume and filtrate with filter Whatman no 5 and then separated into approximately 1 ml for analyze TNC by Nelson's reducing sugar procedure.

Nelson's reducing sugar

Sample solution 1 ml was placed into a 10-mL test tube

↓

Alkaric copper reagent 1 ml

↓

The samples were placed in a hot water bath for 20 min and then in a cold water bath

↓

Arsenomolybdic reagent 1 ml

↓

Shaking for solve of silt

↓

Adjust the volume to 10 ml with De-ionized water

↓

Absorbance of sample solution were determined with a spectrophotometer at 540 nm

The measurement of sample solution was compared with standard solution of D-glucose was 0.01-0.1 %.

Preparation of TNC reagent

Nelson's alkaline copper reagent

Nelson's reagent A (20 ml) was mixed with Nelson's reagent B (0.8 ml).

Nelson's reagent A: Anhydrous sodium carbonate (Na_2CO_3) 25 g, potassium sodium tartrate ($C_4H_4KNaO_64H_2O$) 25 g, sodium bicarbonate ($NaHCO_3$) 25 g and anhydrous sodium sulfate (Na_2CO_4) 25 g were solved with distill water and adjusted to 200 ml

Nelson's reagent B: Copper sulfate ($CuSO_4\ 5H_2O$) 7.5 g, drop wise addition of sulfuric acid (H_2SO_4) 2 min and then adjusted to 200 ml with distill water.

Arsenomolybdic acid reagent

Ammonium molybdate $(NH_4)_6Mo_7O_{24}4H_2O)$ 25 g was solved by distill water 450 ml and sulfuric acid 21 ml as reagent 1. Disodium hyfrogen arsenate ($Na_2HAsO_47H_2O$) 3 g and distill water 25 ml as reagent 2 and then were mixed in reagent 1.

$$TNC = \frac{\text{mg glucose equivalent x Volume make}}{\text{Weight of sample x Volume take}}$$

5.2.2 Experiment 5.2.2 Genotypic differences in the producing of grain yield of rice grown under Mn deficiency

Two rice genotypes, PSL1 (Mn inefficiency) and KDML105 (Mn efficiency) were grown in solution culture with two levels of applied Manganese (0 and 0.5 mg Mn/L). Ten days after germination, five plants of each variety were transplanted to plastic pots containing nutrient solution (10 L). The solution was modified by Insalud (2006) (Table 2.3). The solution was renewed every week and pH values were adjusted daily to 5.5 ± 0.05 with 1N HCl or 1N NaoH. There are three replicates per treatment.

Data were recorded at 30, 60 day after transplanting and mature stage including: chlorophyll content in YEB-1, number of leaves plant^{-1} and tillers plant^{-1}. Then, harvest measurements including: shoot dry weight (g plant^{-1}), root dry weight (g plant^{-1}) and grain yield (g plant^{-1}). The samples were analysed for Mn concentration in all plant part by dry-ashing and atomic absorption spectrometry (Delhaize *et al*., 1984).

5.2.3 Statistic analysis

Analysis of variance was conducted based on a factorial model with treatment arranged in a Completely Randomized Design (CRD). Data were analyzed using two-way analysis of variance (ANOVA) to determine the main effects and interactions among genotype, Mn treatment. The comparison of mean was used with Least Significant Difference (LSD) at $P<0.05$.

5.3 Results

Experiment 5.3.1 Genotypic differences in the production and partitioning of carbohydrates between root and shoot of rice grown under Mn deficiency

Chlorophyll content

Mn deficiency affected on YEB-1 chlorophyll content at 15 and 30 days after transplanting (Table 5.1). At 15 days after transplanting, YEB-1 chlorophyll content in Mn_0 of PSL1 decreased, excepted in KDML105 when compared to $Mn_{0.5}$. In Mn_0, YEB-1 chlorophyll content of KDML105 was higher than PSL1.

At 30 days after transplanting, YEB-1 chlorophyll content in Mn_0 of KDML105 increased, whereas it was decreased in PSL1when compared to $Mn_{0.5}$. In Mn_0, YEB-1 chlorophyll content of KDML105 was the highest but in $Mn_{0.5}$, KDML105 was lower than PSL1.

Number of leaves

At 15 and 30 days after transplanting, significant differences in number of leaves were found between genotypes and Mn levels (Table 5.2). At 15 days after transplanting, number of leaves in Mn_0 of PSL1 decreased, excepted in KDML105 when compared to $Mn_{0.5}$. In Mn_0, number of leaves of KDML105 was higher than PSL1. In $Mn_{0.5}$, number of leaves of KDML105 and PSL1 were not significantly different.

At 30 days after transplanting, number of leaves in Mn_0 of KDML105 increased, whereas it was decreased in PSL1when compared to $Mn_{0.5}$. In Mn_0, number of leaves of KDML105 was the highest but in $Mn_{0.5}$ was lower than PSL1.

Number of tillers

At 15 and 30 days after transplanting, significant differences in number of tillers were found between genotypes and Mn levels (Table 5.3). At 15 days after transplanting, number of tillers in Mn_0 of PSL1 decreased, excepted in KDML105 when compared to $Mn_{0.5}$. In Mn_0, number of leaves of KDML105 was higher than PSL1. In $Mn_{0.5}$, number of leaves of KDML105 was lower than PSL1.

At 30 days after transplanting, number of tillers in Mn_0 of PSL1 decreased, whereas KDML105 increased when compared to $Mn_{0.5}$. In Mn_0, number of leaves of KDML105 was the highest but in $Mn_{0.5}$, KDML105 was lower than PSL1.

Dry weight

There was a highly significant between Mn levels in their effect on the shoot dry weigh. Mn deficiency reduced shoot dry weight of all genotypes compared with Mn sufficiency. However, shoot dry weight of KDML105 had the highest in all Mn levels. While, root dry weight in Mn_0 of PSL1 decreased, whereas KDML105 was similar when compared to $Mn_{0.5}$. Root dry weight of KDML105 and PSL1 did not differ in all Mn levels (Table 5.4).

The relative shoot and root dry weight was significantly different between genotypes. Relative shoot dry weight of all genotypes was higher than relative root dry weight. However, relative shoot and root dry weight of KDML105 was higher than PSL1 (Table 5.5).

Total nonstructural carbohydrate concentration (TNC)

The concentration of TNC in shoot at Mn_0 of KDML105 increased, excepted in PSL1, it was decreased when compared with $Mn_{0.5}$. In Mn_0, TNC concentration in shoot of all genotypes did not differ but in $Mn_{0.5}$, KDML105 was lower than PSL1.

TNC concentration in root of KDML105 and PSL1 decrease when grown in Mn_0. PSL1 had TNC concentration in root higher than KDML105 in Mn_0 (Table 5.6).

The relative TNC concentration in shoot of all genotypes were higher than relative TNC concentration in root. Relative TNC concentration in shoot of KDML105 was higher than PSL1, whereas relative TNC concentration in root of KDML105 was lower than PSL1 (Table 5.7).

The root /shoot ratio of TNC concentration were significantly different between genotypes and Mn levels. Root /shoot ratio of TNC concentration of all genotypes decreased when grown in Mn_0. In Mn_0, root /shoot ratio of TNC concentration of KDML105 and PSL1 was not differ but in $Mn_{0.5}$, PSL1 was lower than KDML105 (Table 5.8).

The relative dry weight and TNC concentration in shoot and root were significantly different between genotypes. Relative dry weight and TNC concentration in shoot of KDML105 was the highest. Relative dry weight in root of PSL1 was the lowest, whereas relative TNC concentration was the highest. While, relative dry weight in root of KDML105 was higher than PSL1 but relative TNC concentration in root was the lowest (Figure 5.1).

Table 5.1 Response to Mn of YEB-1 chlorophyll content (SPAD unit) and relative chlorophyll content in YEB-1 at 15 and 30 days after transplanting.

Variety	Mn level (ppm)			Relative of chlorophyll content in YEB-1
	0	0.5	Mean	
15 Days				
PSL1	26.17bB	30.02aA	28.10	87.12B
KDML105	29.46aA	29.33aA	29.40	100.48A
Mean	27.81	29.68	28.75	93.80
F-test	V*	Mn*	VxMn**	V**
$LSD_{0.05}$			1.8363	5.5013
30 Days				
PSL1	23.81bB	28.78aA	26.29	82.79B
KDML105	28.22aA	26.78bB	27.50	105.36A
Mean	26.02	27.78	26.90	94.07
F-test	V*	Mn**	VxMn***	V**
$LSD_{0.05}$			1.5326	8.7906

*, ** and *** Significant at $P < 0.05$, $P < 0.01$ *and* $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.2 Response to Mn of number of leaves (plant^{-1}) and relative number of leaves at 15 and 30 days after transplanting.

Variety	Mn level (ppm)			Relative of number
	0	0.5	Mean	of leaves
15 Days				
PSL1	3.47bB	5.67aA	4.57	61.05B
KDML105	4.27aA	4.07aB	4.17	105.00A
Mean	3.87	4.87	4.37	83.03
F-test	V*	Mn***	VxMn***	V**
$\text{LSD}_{0.05}$			0.5435	16.076
30 Days				
PSL1	12.17bB	13.87aA	13.02	87.75B
KDML105	15.83aA	12.89bB	14.36	122.88A
Mean	14.00	13.38	13.69	105.31
F-test	V***	Mn**	VxMn***	V***
$\text{LSD}_{0.05}$			0.4766	6.4089

*, ** and *** Significant at $P < 0.05$, $P < 0.01$ *and* $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.3 Response to Mn of number of tillers (plant^{-1}) and relative number of tillers at 15 and 30 days after transplanting.

Variety	Mn level (ppm)			Relative of number
	0	0.5	Mean	of tillers
15 Days				
PSL1	3.47bB	5.67aA	4.57	61.05B
KDML105	4.27aA	4.07aB	4.17	105.00A
Mean	3.87	4.87	4.37	83.03
F-test	V*	Mn***	VxMn***	V**
LSD$_{0.05}$			0.5435	16.076
30 Days				
PSL1	12.17bB	13.87aA	13.02	87.75B
KDML105	15.83aA	12.89bB	14.36	122.88A
Mean	14.00	13.38	13.69	105.31
F-test	V***	Mn**	VxMn***	V***
LSD$_{0.05}$			0.4766	6.4089

*, ** and *** Significant at $P < 0.05$, $P < 0.01$ *and* $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.4 Response to Mn of shoot and root dry weight (g $plant^{-1}$) at 30 days after transplanting.

Variety	Mn level (ppm)				Mean
	0		0.5		
	Shoot	Root	Shoot	Root	
PSL1	1.30bB	0.13dA	2.15aB	0.37cA	0.99
KDML105	2.15bA	0.25cA	2.56aA	0.37cA	1.33
Mean	1.72	0.19	2.36	0.37	1.16
F-test	V***	Mn***	VxMn *		
LSD0.05			0.1208		

* and *** Significant at $P < 0.05$ *and* $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.5 Response to Mn of relative shoot and root dry weight at 30 days after transplanting.

Variety	Relative Dry weight		Mean
	Shoot	Root	
PSL1	60.72aB	34.31bB	47.52
KDML105	83.72aA	67.70bA	75.71
Mean	72.22	51.01	61.61
F-test	V***	E***	VxE*
$LSD_{0.05}$			7.3664

* and *** Significant at $P < 0.05$ *and* $P < 0.001$, respectively. V, E and VxE indicated F-test for variety, plant part and variety and plant part interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.6 Response to Mn of TNC concentration (mg glucose equivalent g^{-1} dry weight) at 30 days after transplanting.

Variety	Mn level (ppm)				Mean
	0		0.5		
	Shoot	Root	Shoot	Root	
PSL1	4.40dA	7.05bA	5.48cA	13.13aA	7.52
KDML105	4.51bA	3.44cB	4.21bcB	12.55aA	6.18
Mean	4.46	5.25	4.84	12.84	6.85
F-test	V***	MN***	VxMn***		
LSD0.05			1.0713		

^{ns}, *** Non significant, significant at *P* < 0.001. V, Mn and VxMn indicated F-test for varity, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same colume is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.7 Response to Mn of relative TNC concentration at 30 days after transplanting.

Variety	Relative TNC concentration		Mean
	Shoot	Root	
PSL1	80.86aB	53.73bA	67.30
KDML105	107.01aA	27.40bB	67.21
Mean	93.94	40.57	67.25
F-test	Vns	Mn***	VxMn**
$LSD_{0.05}$			20.614

^{ns}, ** and *** Non significant, significant at $P < 0.01$ *and* $P < 0.001$, respectively. V, E and VxE indicated F-test for variety, plant part and variety and plant part interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.8 Response to Mn Root /Shoot ratio of TNC concentration at 30 days after transplanting.

Variety	Mn level (ppm)		Mean
	0	0.5	
PSL1	1.60bA	2.41aB	2.00
KDML105	0.78bB	2.99aA	1.88
Mean	1.19	2.70	1.94
F-test	V^{ns}	Mn***	VxMn*
$LSD_{0.05}$			0.305

^{ns}, * and *** Non significant, significant at $P < 0.05$ *and* $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

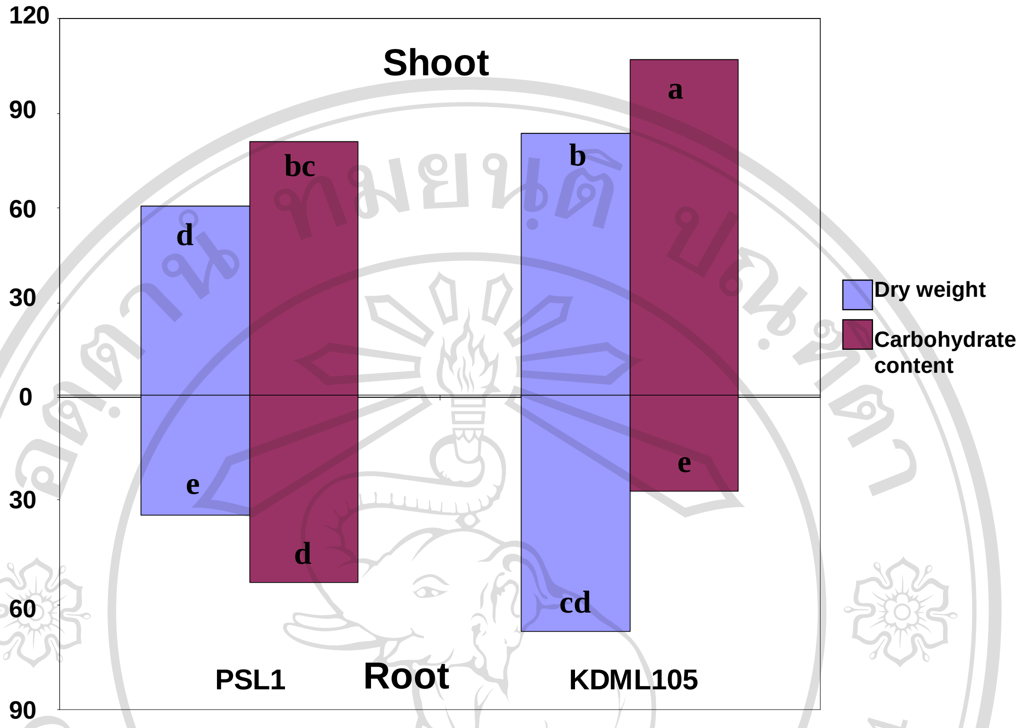

Figure 5.1 Relative dry weight and TNC concentration in shoot and root at 30 days after transplanting.

Experiment 5.3.2 Genotypic differences in the producing of grain yield of rice grown under Mn deficiency

Chlorophyll content

YEB-1 chlorophyll content was significantly different between genotypes and Mn levels (Table 5.9). At 30 days after transplanting, YEB-1 chlorophyll content of KDML105 and PSL1 decreased when grown in Mn_0. In Mn_0, KDML105 was higher than PSL1.

At 60 days after transplanting, YEB-1 chlorophyll content of all genotypes did not differ between Mn levels. However, in Mn_0, YEB-1 chlorophyll content of KDML105 was higher than PSL1.

At maturity, in Mn_0, YEB-1 chlorophyll content of KDML105 was similar to $Mn_{0.5}$, whereas in PSL1, it was decreased when compares to $Mn_{0.5}$.

Beside, relative chlorophyll content in YEB-1 of KDML105 had the highest in all growth stages.

Number of leaves

At 30, 60 days after transplanting, number of leaves of PSL1 increased, excepted in KDML105 did not differ when compared to $Mn_{0.5}$. Number of leaves of KDML105 was higher than PSL1 in Mn_0.

At maturity, number of leaves of KDML105 increased, whereas it was decreased in PSL1when grown in Mn_0. In Mn_0, number of leaves of KDML105 was higher than PSL1.

In all growth stages, relative number of leaves of KDML105 was the highest (Table 5.10).

Number of tillers

Manganese deficiency affected on number of tillers at all growth stages (Table 5.11). At all growth stages, number of tillers in Mn_0 of PSL1 decreased, excepted in KDML105 did not differ when compared to $Mn_{0.5}$. In Mn_0, number of tillers of KDML105 was higher than PSL1.

Beside, relative number of tillers of KDML105 was the highest in all growth stages.

Dry weight

Shoot and total dry weight were not significantly different between genotypes and Mn levels (Table 5.12). Root dry weight of KDML105 decreased when grown in Mn_0. In Mn_0, root dry weight of KDML105 was lower than PSL1.

Relative shoot, root and total dry weight to Mn deficiency were not significantly different between genotypes.

Grain yield of KDML105 and PSL1 increased when grown in $Mn_{0.5}$. However, KDML105 had grain yield higher than PSL1 in Mn_0. Similarly, relative grain yield of KDML105 was higher than PSL1 (Table 5.13).

Manganese concentration

Manganese concentration in YEB and shoot of KDML105 increased, whereas PSL1 was decreased when grown in $Mn_{0.5}$. In Mn_0, KDML105 and PSL1 were similar. The concentration of Mn in root of KDML105 increased, excepted in PSL1 when grown in Mn_0. Root Mn concentration of KDML105 was higher than PSL1 in Mn_0 (Table 5.14).

The concentration of Mn in grain was not significantly different between genotypes and Mn levels (Table 5.15).

Manganese content

Shoot, root and whole plant

Shoot Mn content in Mn_0 of PSL1 decreased, excepted in KDML105 when compared to $Mn_{0.5}$. In Mn_0, Mn content in shoot of KDML105 and PSL1 were similar. The content of Mn in root was not significantly different between genotypes and Mn levels. The content of Mn in whole plant of all genotypes increased when grown in $Mn_{0.5}$. Manganese content in whole plant of KDML105 was higher than PSL1 in Mn_0 (Table 5.16).

Grain

Manganese content in grain of PSL1 decreased, excepted in KDML105 when grown in Mn_0. In Mn_0, Mn content in grain of KDML105 was higher than PSL1 (Table 5.17).

Manganese uptake efficiency

Manganese uptake efficiency in Mn_0 of PSL1 decreased, excepted in KDML105 when compared to $Mn_{0.5}$. In Mn_0, Mn uptake efficiency of KDML105 was higher than PSL1. Moreover, relative Mn uptake efficiency of KDML105 was the highest (Table 5.18).

Table 5.9 Response to Mn of YEB-1 chlorophyll content (SPAD unit) and relative YEB-1 chlorophyll content at 30, 60 days after transplanting and maturity.

Variety	Mn level (ppm)			Relative SPAD
	0	0.5	Mean	
30 Days				
PSL 1	23.07bB	30.75aA	26.91	74.99B
KDML105	28.90bA	30.18aA	29.54	95.74A
Mean	25.98	30.47	28.23	85.37
F-test	V***	Mn***	VxMn***	V***
LSD(0.05)			0.7046	3.0292
60 Days				
PSL 1	29.11aB	39.02aA	34.06	74.65B
KDML105	34.98aA	36.37aA	35.67	96.23A
Mean	32.04	37.69	34.87	85.44
F-test	V**	Mn***	VxMn***	V**
LSD(0.05)			1.5142	7.3219
maturity				
PSL 1	32.58bB	41.69aA	37.14	78.14B
KDML105	39.14aA	39.44aB	39.29	99.25A
Mean	35.86	40.57	38.21	88.70
F-test	V***	Mn***	VxMn***	V***
LSD(0.05)			1.1902	5.2797

*** Significant at $P < 0.001$. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.10 Response to Mn of number of leaves (plant^{-1}) and relative number of leaves at 30, 60 days after transplanting and maturity.

Variety	Mn level (ppm)			Relative number of leaves
	0	0.5	Mean	
30 Days				
PSL 1	9.26bB	11.15aA	10.20	83.01B
KDML105	11.17aA	10.94aA	11.06	102.12A
Mean	10.21	11.05	10.63	92.57
F-test	V***	Mn***	VxMn***	V**
LSD(0.05)			0.4731	8.4905
60 Days				
PSL 1	10.67bB	14.64aA	12.65	73.05B
KDML105	13.37aA	13.11aB	13.24	101.95A
Mean	12.02	13.88	12.95	87.50
F-test	Vns	Mn***	VxMn***	V**
LSD(0.05)			0.8752	11.2
maturity				
PSL 1	14.33bB	16.36aA	15.35	87.57B
KDML105	18.14aA	16.31bA	17.23	111.19A
Mean	16.24	16.34	16.29	99.38
F-test	V**	Mnns	VxMn**	V*
LSD(0.05)			1.5343	14.502

*** Significant at $P < 0.001$. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.11 Response to Mn of number of tillers (plant^{-1}) and relative number of tillers at 30, 60 day after transplanting and maturity.

Variety	Mn level (ppm)			Relative number of tillers
	0	0.5	Mean	
30 Days				
PSL 1	2.11bB	2.61aA	2.36	81.75B
KDML105	2.83aA	2.56aA	2.70	110.97A
Mean	2.47	2.58	2.53	96.36
F-test	V*	Mnns	VxMn*	V*
LSD(0.05)			0.4399	21.468
60 Days				
PSL 1	2.58bB	3.52aA	3.05	73.50B
KDML105	3.39aA	3.39aA	3.39	100.08A
Mean	2.99	3.46	3.22	86.79
F-test	V***	Mn***	VxMn***	V**
LSD(0.05)			0.2282	13.155
maturity				
PSL 1	3.77bB	5.30aA	4.53	71.24B
KDML105	5.41aA	5.56aA	5.49	97.46A
Mean	4.59	5.43	5.01	84.35
F-test	V***	Mn***	VxMn***	V**
LSD(0.05)			0.364	12.525

*** Significant at $P < 0.001$. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.12 Response to Mn of shoot, root and total dry weight (g plant^{-1}) at maturity.

Variety	Mn level (ppm)			Relative dry weight
	0	0.5	Mean	
Shoot				
PSL 1	8.03	9.46	8.75B	85.01
KDML105	8.24	9.85	9.04A	83.75
Mean	8.14	9.66	8.90	84.38
F-test	V^{ns}	Mn***	$VxMn^{ns}$	V^{ns}
LSD(0.05)			0.6979	8.2133
Root				
PSL 1	0.89aA	0.83aA	0.86	107.11
KDML105	0.65bB	0.84aA	0.75	78.47
Mean	0.77	0.83	0.80	92.79
F-test	V^{ns}	Mn^{ns}	VxMn*	V^{ns}
LSD(0.05)			0.166	32.08
Total				
PSL 1	8.92	10.29	9.61B	86.84
KDML105	8.89	10.69	9.79A	83.34
Mean	8.91	10.49	9.70	85.09
F-test	V^{ns}	Mn***	$VxMn^{ns}$	V^{ns}
LSD(0.05)			0.7149	9.9184

^{ns}, * and *** Non significant, significant at $P < 0.05$ and $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.13 Response to Mn of grain yield (g plant^{-1}) and relative grain yield at maturity.

Variety	Mn level (ppm)			Relative grain yield
	0	0.5	Mean	
PSL1	1.59bB	3.22aA	2.41	49.13B
KDML105	2.70bA	3.42aA	3.06	79.20A
Mean	2.15	3.32	2.73	64.17
F-test	V***	Mn***	VxMn***	V***
LSD0.05			0.3822	9.3475

*** Significant at $P < 0.001$. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.14 Response to Mn of Mn concentration in YEB, shoot and root (mg Mn kg^{-1}) at maturity.

Variety	Mn level (ppm)		
	0	0.5	Mean
YEB			
PSL 1	34.77bA	37.49aA	36.13
KDML105	33.71aA	28.03bB	30.87
Mean	34.24	32.76	33.50
F-test	V***	Mn*	VxMn***
LSD(0.05)			1.5839
Shoot			
PSL 1	92.38bA	97.77aA	95.07
KDML105	92.59aA	83.86bB	88.23
Mean	92.48	90.82	91.65
F-test	V***	Mn^{ns}	VxMn***
LSD(0.05)			3.5581
Root			
PSL 1	15.25aB	15.54aB	15.40
KDML105	23.50aA	19.52bA	21.51
Mean	19.38	17.53	18.45
F-test	V***	Mn*	VxMn*
LSD(0.05)			2.306

^{ns}, * and *** Non significant, significant at $P < 0.05$ and $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.15 Response to Mn of Mn concentration in seed (mg Mn kg^{-1}) at maturity.

Variety	Mn level (ppm)		
	0	0.5	Mean
PSL 1	42.99	42.32	42.66
KDML105	42.40	42.44	42.42
Mean	42.70	42.38	42.54
F-test	V^{ns}	Mn^{ns}	$VxMn^{ns}$
LSD(0.05)			3.2305

ns Non Significant. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.16 Response to Mn of Mn content in YEB, shoot and root (mg Mn plant^{-1}) at maturity.

Variety	Mn level (ppm)		
	0	0.5	Mean
Shoot			
PSL 1	0.743bA	0.925aA	0.83
KDML105	0.763aA	0.826aB	0.79
Mean	0.753	0.875	0.81
F-test	V*	Mn***	VxMn*
LSD(0.05)			0.0678
Root			
PSL 1	0.013	0.013	0.013B
KDML105	0.015	0.016	0.016A
Mean	0.014	0.015	0.014
F-test	V*	Mn^{ns}	VxMn^{ns}
LSD(0.05)			0.003394
Whole plant			
PSL 1	0.068bB	0.137aA	0.103
KDML105	0.115bA	0.145aA	0.130
Mean	0.092	0.141	0.116
F-test	V**	Mn***	VxMn*
LSD(0.05)			0.0215

ns, *, ** and *** Non significant, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.17 Response to Mn of Mn content in seed (mg Mn plant^{-1}) at maturity.

Variety	Mn level (ppm)		
	0	0.5	Mean
PSL 1	0.96bB	1.16aA	1.06
KDML105	1.03aA	1.11aA	1.07
Mean	1.00	1.14	1.07
F-test	V^{ns}	Mn***	VxMn*
LSD(0.05)			0.0748

^{ns}, * and *** Non significant, significant at $P < 0.05$ and $P < 0.001$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

Table 5.18 Response to Mn of Mn uptake efficiency (mg Mn g^{-1} root DW) at maturity.

Variety	Mn level (ppm)			Relative SPAD
	0	0.5	Mean	
PSL 1	0.87bB	1.13aA	1.00	76.56B
KDML105	1.20aA	1.01aA	1.10	119.19A
Mean	1.04	1.07	1.05	97.88
F-test	V^{ns}	Mn^{ns}	VxMn*	V*
LSD(0.05)			0.2456	31.159

^{ns} and * Non significant and significant at $P < 0.05$, respectively. V, Mn and VxMn indicated F-test for variety, Mn level and variety and Mn level interaction effects, respectively. The difference between varieties in the same column is indicated by upper case letters. The difference between Mn level in the same row is indicated by lower case letters.

5.4 Discussion

The concentration of soluble TNC in root of PSL1 was the highest under deficient Mn supply but root dry weight was lower than in any other treatments. This relationship between Mn deficiency and TNC partitioning, where export to root increased in PSL1. This may reflect the need for the Mn inefficient genotypes PSL1 to increase root growth for increase the absorptive root surface area to take up the required amount of Mn. Therefore, TNC partitioning to shoot was affected, yet shoot growth was inhibited. However, Mn deficiency impaired essential growth functions and TNC production. According to Pearson and Rengel (1997) demonstrated the reducing content of structural carbohydrates. Besides, Abbott (1967) observed that root growth was reduced under Mn deficiency, predominantly due to inhibition of cell elongation in the lateral roots (Webb and Dell, 1990).

Sadana *et al.* (2002) observed that at the same shoot Mn concentration, the Mn-efficient of wheat genotype PBW343 produced more dry matter than Mn-inefficient wheat genotype PDW233 grown in Mn deficient soil. In this study, KDML105 produced 1.49 g of grain weight from 1 g Mn whereas, PSL1 produced 0.93 g grain weight from 1 g Mn when grown under Mn deficient. This is consistent with the earlier introduction expressed that 1 µg Mn produced 0.0089 g dry matter yield in Mn efficient genotype but in Mn inefficient genotype produced 0.0067 g dry matter yield (Jiang, 2008). This suggests that Mn efficiency in KDML105 is more likely to be related to a higher internal Mn use efficiency, such as a more efficient internal redistribution of Mn under Mn deficiency.

Moreover, efficiency is defined as the ability of a genotype to utilize them in the production of plant biomass or utilizable plant yield (seed or grain). The response is the capacity of the genotype to increase yield as the supply of the nutrient to the root is increased. The present of difference in final yields in plots with and without Mn fertilizer is used effectively to determine Mn efficiency (Graham *et al*., 1992; McDonald *et al*., 2001). This study found that KDML105 is able to produce higher yield than PSL1 when grown on the same condition of limited Mn supply. This responsible accorded to the classification of Gerloff (1977) into 2 response groups (Figure 5.2). KDML105 is Mn efficient responders, plants which produces high yields at low Mn levels and which respond to Mn additions. PSL1 is Mn inefficient responders, plants with low yields at low levels of Mn which have a high response to added nutrients.

From the results, it indicates the Mn use efficiency of KDML105. It is most clearly on Mn efficiency trait in KDML105 because there is high Mn acquisition and uptake efficiency genotype, yet Mn utilization efficiency genotype.

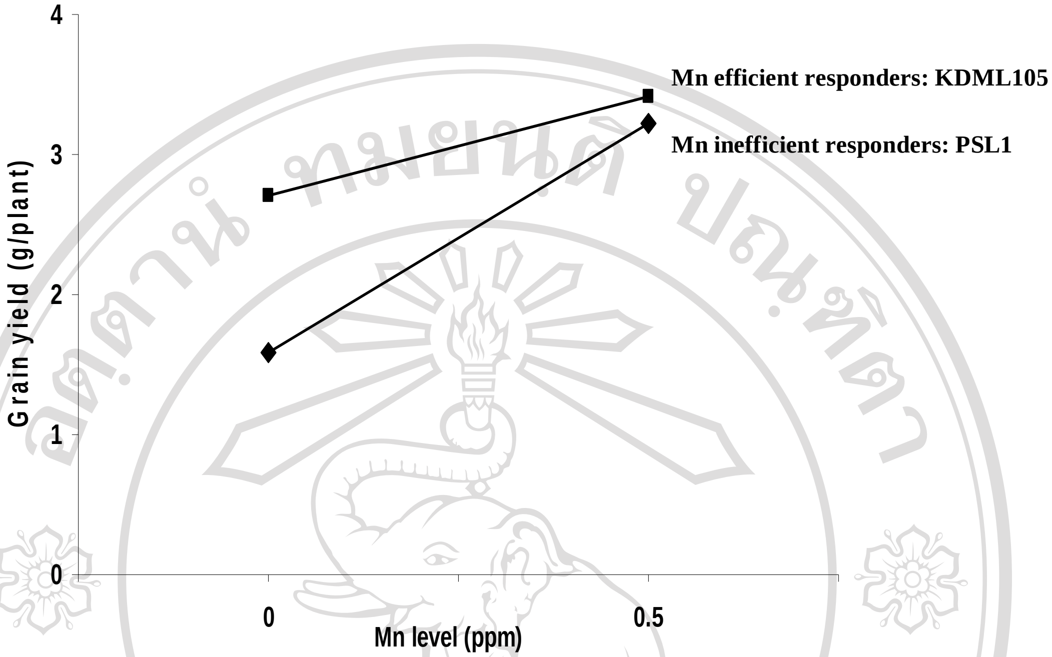

Figure 5.2 Diagrammatic representation of Mn response modified from Gerloff (1977).