CHAPTER 5

THEY STAND AMONG EQUALS:
V. DIFFERENTIAL COMPETITIVE ABILITY OF NEW BIOTYPES OF WEEDY RICE (*Oryza sativa* L.) AND CULTIVATED RICE VAR. MR220 IN SELANGOR NORTH-WEST PROJECT, MALAYSIA

5.1 INTRODUCTION

Competition for resources happens between individuals of the same species (intra-specific) or between members of different species (inters-specific) in plant populations or communities. When a new plant is introduced into a community, generally it is expected that it will change the environment of the native species, especially on their growth (Harper 1977). Inter-specific competition is a significant factor in controlling the distribution and abundance of terrestrial plants in a variety of different habitats and it is an important determinant of the structure and dynamics of plant communities (Aerts 1999).

Most studies reported that nutrient availability is one of the most important factors that can limit plant performance in nature. Competition at the seedling stage is extremely important and will, significantly, determine later success (Aerts 1999). For some species their low competitive ability in securing nutrients may become one of the most important factors contributing to the species' narrow distribution.

Competition begins when one or more vital resources such as water, light or nutrients are limited for plant growth. Plants can differ quite significantly in their interaction with each other when they occupy the same site and habitat. Plant competitiveness, consecutively, is determined by the dynamic interaction in the availability of resources and the ability to obtain these limited resources (Van Auken & Bush 1987).

Competition can be also defined as reduction in growth of one plant as the consequences by limitation in resources to that plant because of the presence of a neighbour. There are two factors dependable by the degree of growth suppression for a plant to induce on its neighbours. First, the responsiveness of each species to resource supply. Second, a species' competitiveness will depend on the effectiveness of each species in competing for limiting resources in a specific environment (Beneke *et al.* 1992).

De Wit (1960) developed a mathematical model to describe the interference between two species using a replacement series experiment to study the interference, or competition between species. The overall density of the two species is held constant but the proportion of the two species is changed so that the outcome of competition between the two species can be predicted (Weiner 1980).

This replacement series commonly place weed species together with crop plant species to show any possible interference between them. For example, Weiss & Noble (1984) found that, by using a replacement series experiment, the seedlings of the invasive species *Chrysanthemoids monilifera* had a competitive advantage over the native species *Acacia longifolia* because of its rapid growth, large leaf area, and high use of water. For that reason, it is common to use the replacement experiments to compare the relative efficiency of two species to compete each other in the environment (Daugovish *et al.* 2002).

In a different example, Austin *et al*. (1985) found that *Carthamus lanatus* had the highest yield when grown in a mixed plantation with *Carduus nutans*, *Carduus pycnocephalus*, *Cirsium vulgare*, *Onopordum aff. illyricum*, and *Silybum marianum*. This was not the case for the total dry weight of the species at the medium and high level of nutrients where the species had low yield. Conversely, Mynhardt (1994) found that inter-specific competition lowered the number of lateral tillers per plant and tuft height in *Anthephra pubescens* in a mixed stand when compared to plants in pure stands. This concluded that *Anthephra pubescens* was a poor competitor in these conditions. Obviously, differences among the competitive abilities of plant species can be important factors controlling the distribution and composition of vegetation and crop (Gerry & Wilson 1995).

Various studies of the competitive ability of weedy rice and cultivated rice have been carried out in all over the world. Weedy rice occurs as a serious threat in rice field which causes a lot of loss to the rice production and yield. Generally, rice production in the world is affected by weedy rice such as *Oryza sativa, Oryza barthii, Oryza longistominata, Oryza officinalis, Oryza punctata* and *Oryza rufipogon* (Holm *et al.* 1997).

Weedy rice can be highly competitive against cultivated rice and can cause severe yield losses especially when it counts to the density, population and cultivated variety (Diarra *et al.* 1985). It was estimated that infestation of 5% of weedy rice in Malaysian rice granaries led to reduction of yield production of 64,880 tons of rice valued at MYR 137,876,375/year or US$35,999,053/year (Baki 2004). In Thailand, a crop cut survey found that grain yield reduces linearly with the increment for every percent of the weedy rice infestation (Manneechote *et al.* 2005).

Some studies pointed out that competition effects are also closely related to interference duration (Kwon *et al.* 1991). Combining the effects of weedy rice density and duration of competition, Fischer & Ramirez (1993) observed a yield reduction of 50% when 24 weedy rice plants m^{-2} competed with the crop during the first 40 days after emergence. With the same initial density, the yield loss reached 75% in the case of season-long competition. In a green house experiment, significant effects on rice plant growth were recorded only when the competition had duration longer than 70 days, starting from the emergence (Estorninos *et al.* 2002). In some cases, inter-varietal competition resulted to be more important than intra-varietal competition, with weedy rice acting as the dominant competitor (Pantone & Baker 1991).

Most of weedy rice share important characteristic to become weed in rice granaries such as high competitiveness and easy shattering. Additionally, some of the weedy rice has red pigmented pericarp and this character makes a low quality rice production when it mixed up with cultivated rice. Compared to cultivated rice, weedy rice frequently shows numerous and slender tillers, extra hispid and light green leaves, taller than the cultivated rice and high capacity of seeds shattering (Kwon *et al.* 1992).

Although there are various citations on the relationship between weedy rice density and rice yield loss, it's just a few researches focused on how the rice growth influenced by the existence of weedy rice.

Weedy rice shows wide variations in anatomical, biological and physiological features. At seedling stage, red rice plants are difficult to distinguish from the crop, while after the tillering the identification of the weed is possible. There are many morphological differences in comparison with the rice varieties such as more numerous, longer and more slender tillers, leaves which are often hispid on surfaces, tall plants, pigmentation of the pericarp, and easy seed shattering from the panicle (Noldin *et al.* 1999).

The break off of the weedy rice seeds onto the soil before crop harvesting allows the weed to disseminate and dormant in the soil seed bank. The spread of weedy rice became significant mainly after the shift from rice transplanting to direct seeding and started to be very severe.

Presently, the spread is mainly related to the planting of cultivated rice seeds containing seeds of the weed. The weed affects rice yield because of its high competitive capacity. The red layer of the weed grains harvested with the crop have to be removed with an extra milling but this operation results in broken grains and grade reduction.

Wright (1954) was the first person to introduce path analysis to be used in agronomy, horticulture, ecology and weed science. Path analysis is an extension of the regression model, used to test the fit of the correlation matrix against two or more causal models which are being compared by the researcher. The model is usually depicted in a circle-and-arrow figure in which single arrows indicate causation. A regression is done for each variable in the model as a dependent on others which the model indicates are causes. The regression weights predicted by the model are compared with the observed correlation matrix for the variables, and a goodness-of-fit statistic is calculated. The best-fitting of two or more models is selected by the researcher as the best model for advancement of theory (Cohen *et al.* 2002)

Path analysis model can resolve the crop-weed relationship on yield components of wheat and rice. The relationship can be determined either in monoculture or in mixture (Pentone *et al.* 1992). The path analysis in rice indicated that the number of panicle per plant and grain per panicle were the most important yield components to study the responses of fecundity and grain yield to competition (Baki *et al*. 2005).

The close morphological resemblance between weedy rice and the cultivated rice has “vetoed” the application of herbicides that are able to selectively control other rice weeds. This makes weedy rice hard to control and manage chemically. The other ways to control the weedy rice are by supplying rice growers with clean seeds, chemical or mechanical control in pre- and post-emergence of weedy rice in rice pre-planting or in crop post-planting by cutting the panicle and rotation. In most cases, two or more of these strategies are combined. In some conditions, the weed pressure is so high that the only way to reduce red rice populations is to adopt rotation, although, this practice shows some constraints in particular environmental conditions such as in the presence of saline and hydromorphic soils (Karim *et al.* 2004).

The work reported in this chapter discusses on the competitive relationship between cultivated rice *var.* MR220 with the new biotype of weedy rice (NBWR), the latter was found commonly prevailing in rice farms of Selangor North West Project. The study was initiated with the hope to generate information on an understanding on the competition of

NBWR with the cultivated rice, and how the infestation of this new weed biotype can affect the rice production.

5.2 MATERIALS AND METHODS

A series of pot experiment was conducted in an insect-proof house at Pasir Panjang, Sekinchan, Selangor, Malaysia from November 2007 to March 2008.

Seeds of cultivated rice var. MR220 obtained from Selangor Agriculture Department and seeds of NBWR previously sampled from field were selected for the experiment. These seeds were sown into separate 14.5 diameter petri-dishes with moist Whatman no. 4 filter paper.

Healthy uniform seedlings of these two MR220 and NBWR were selected after ten days of germination. These seedlings with a well-developed radical were selected and transplanted into plastic pots (23cm diameter, 20cm height) previously filled with moist paddy soils of the Java series obtained from the rice granary of Selangor North West Project. The density regimes of cultivated rice var. MR220 and NBWR are as Table 5.1.

Table 5.1. Treatment combinations and ratios accorded in the replacement and additive series experiment.

Treatment	Density of MR220		Density of NBWR	
	(plant/pot)	Estimated (plant/m^2)	(plant/pot)	Estimated (plant/m^2)
T1	1	24		
T2	3	17		
T3	6	144		
T4	9	217		
T5	12	288		
T6	9	217	3	71
T7	6	144	6	144
T8	3	71	9	217
T9	-	-	12	288
T10	-	-	9	217
T11	-	-	6	144
T12	-	-	3	71
T13	-	-	1	24

In T1 treatment or pot, only one plant of rice was planted. Then three plants for T2, six plants for T3, nine plants for T4 and twelve plants for T5 were planted for each pot. For T6 to T8 a mixture of MR220 and NBWR was planted. There are nine plants of MR220 and three plants of NBWR in T6, six plants for each plants of MR220 and NBWR for T7 and for T8 three plants of MR220 and nine plants of NBWR. In all treatment, the maximum number of plants per pot was twelve with ratio either 100% MR220:0% NBWR (T1; T2; T3; T4; T5); 75%MR220:25%NBWR (T6); 50MR220:50NBWR (T7); 75 NBWR:25 MR220 (T8) and 0MR220:100 NBWR (T9; T10; T11; T12; T13). Four replicates were allocated for each treatment.

The arrangement of pots was according to complete randomized design. Positions of the pots were changed alternately twice a week to minimize the edge effect. The plants were kept inundated to a depth of 2-3 cm until the booting stage. After that, the water was drained out but the soil was kept moist. Each treatment was watered twice daily. Standard fertilizer application was given for each pot with urea, TST and MOP 30 days and 60 DAT at the rates of 100:30:20 (N:P:K) per hectare. Records of growth parameters were taken as Table 5.2.

Table 5.2. Selected plant growth parameters and yield components.

Parameters	Record days (days after transplanting - DAT)
Plant height	Every 10 days
Number of tiller	Every 10 days
Panicle length	During harvest
Panicle dry weight	Post harvest
Grain per panicle	During harvest
Filled Grain per panicle	Post harvest
1000 grains weight	Post harvest
Root dry weight	Post harvest
Leaves dry weight	Post harvest
Culm dry weight	Post harvest
Panicle per plant	Post harvest

The analysis of variance (ANOVA) is one of the most used and robust statistical tests devised. But ANOVA requires data sets comply with the three rules; a) samples normally distributed b) variance independent of the mean and c) components of the variance additive. This latter criterion has probably been a bit of a mystery but now all will be revealed in that the ANOVA test breaks down the sources of variance into their components on the assumption that the components are additive (Cohen *et al.* 2002).

Fisher's Least Significant Difference Test (LSD) was used to compare between treatment means. Fisher's Least Significant Difference Test is a statistical procedure that determines if the difference found between two treatments is due to the treatment or if the difference is simply due to random chance. For each set of data a value ($LSD_{0.05}$) is calculated at a chosen level of significance (Young & Young 1998).

Data taken were then calculated to get the quantitative growth indices viz; relative yield (r), relative yield total (RYT), aggressivety index (A), reproductive effort (RE), vegetative effort (VE) and harvest index (HI).

Relative yield is a parameter to measure the yield of one species in association with another species and relative yield total can explain the yield total of two or more different plants (Harper 1977). Aggressivity index (A) is used to indicate the aggressivity between two plants where grown in mixture. Proportion of weight of reproductive organ with the total of plant weight can be determined by Reproductive Effort while proportion of weight of vegetative organ with the total of plant weight can be determined by Vegetative Effort. Harvest Index is a measurement of the proportion of grain yield of total plant weight (Harper 1977). All indices can be calculated by the equation below:

a) Relative Yield (r):

$r_a = X_{ab} / X_{aa}$

Where: r_a = relative yield for species *a*

X_{ab} = yield of species grown in mixture with species *b* (g/plant)

X_{aa} = monoculture of species *a*

b) Relative Yield Total (RYT):

RYT = ra + rb

Where: r_a = relative yield for species a

r_b = relative yield for species b

c) Aggressivity Index (A):

$A = (r_a - r_b) / RYT$

d) Reproductive Effort (RE)

RE = weight of reproductive component / total plant weight

e) Vegetative Effort (VE)

VE = weight of vegetative component / total plant weight

f) Harvest Index (HI)

HI = grain weight / total plant weight

Competition between species and the resultant vegetative and reproductive yield components can be assessed using path analysis. Path analysis can be used to propose a plausible interpretation of the relationship between the variables into direct and indirect effects. In this study, path analysis will be undertaken using SAS 2004 to get the path coefficients, simple correlation coefficients and the undetermined residuals (U_x) of the regression (Williams *et al.* 1990).

5.3 RESULTS AND DISCUSSION

5.3.1 Clonal Growth

The NBWR and cultivated rice MR220 displayed measurable differences in the growth patterns at different density regimes. Fig. 5.1 and Fig. 5.2 show the plant height of MR220 and NBWR in different monoculture. Most of the plants (NBWR and cultivated rice MR220) reached the peak of height 80 days after transplanting (DAT). After 10 DAT, most of the plant showed relatively the same height. The difference in plant height started to manifest at 20 DAT and thereafter. The NBWR or MR220 in monocultures registered shorter plant heights at higher densities than those counterparts also in monoculture but with lesser density. In MR220 monocultures, at 1 plant per pot has *ca.* 30 cm mean height while monoculture with 12 plants per pot has 15 cm mean height. This pattern continues until the plant reach maturity at 100 DAT.

The MR220 reached their peak growth after 70 DAT except for MR220 in 1 plant per pot monoculture which reached the peak much earlier at 50 DAT. After the peak growth, all MR220 grew slowly or have no growth until the harvesting time.

While in NBWR, the monoculture at lesser density (1 and 3 plants per pot) showed delayed late peak time (80 DAT) in plant height. However, other monocultures showed an earlier peak in plant height at 60 DAT.

The cultivated rice (MR220) and weedy rice (NBWR) planted in mixture did not show any significant height difference for MR220 despite increasing proportion of NBWR. The same pattern also occurred in NBWR (Table 5.3). However, different results in plant height occurred in monoculture. The LSD tests indicated significant differences in height with increasing density in monoculture for both MR220 and NBWR (Table 5.3).

The plant height of MR220 was reduced at higher density regimes. The height of plants in T1 was 84 cm, and this was reduced up to 4.17% in T2, 10.42% in T3, 8.33% in

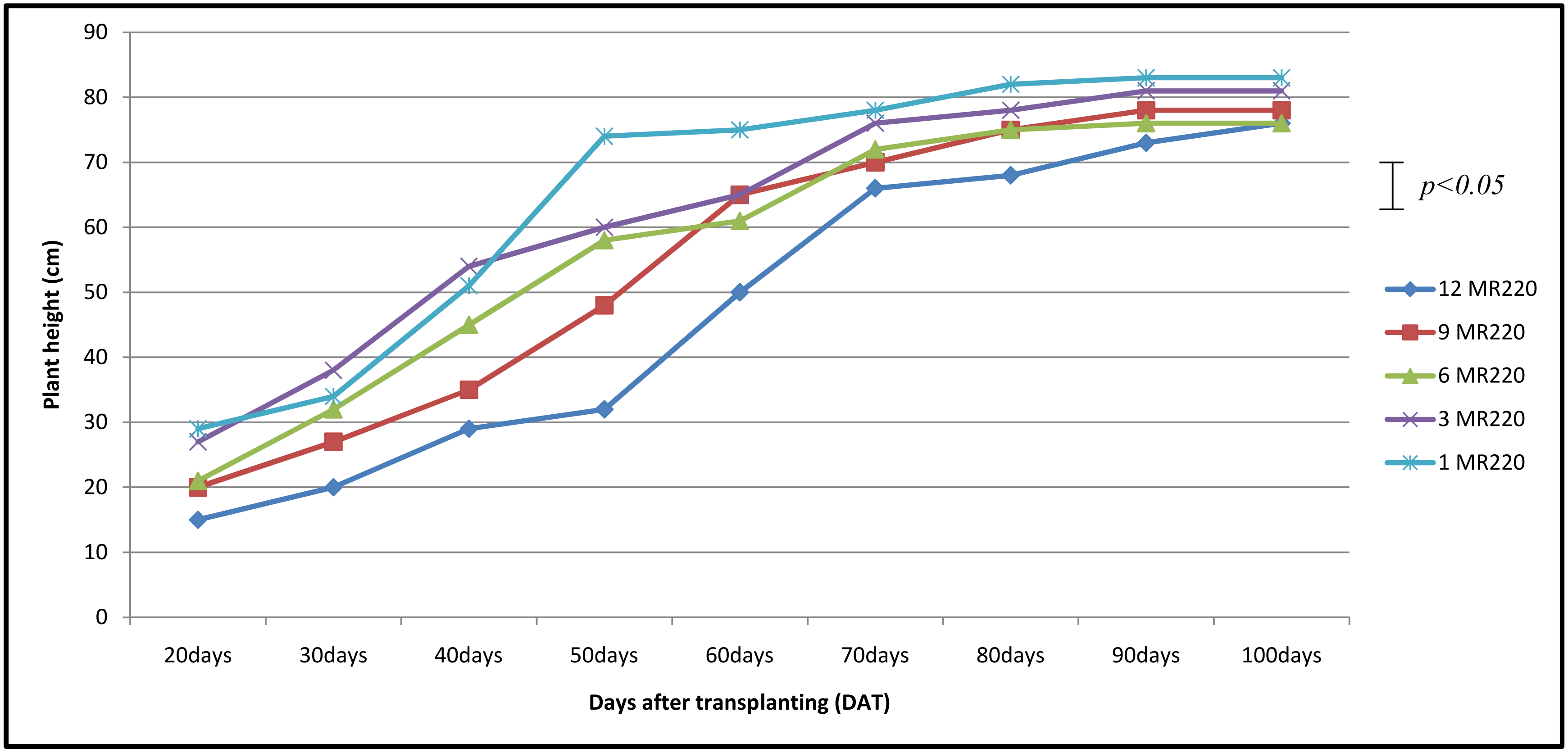

Fig. 5.1. Plant height of cultivated rice *var.* MR220 in monoculture as influenced by different densities and days (after transplanting - DAT). Bar represents LSD value at $p>0.05$.

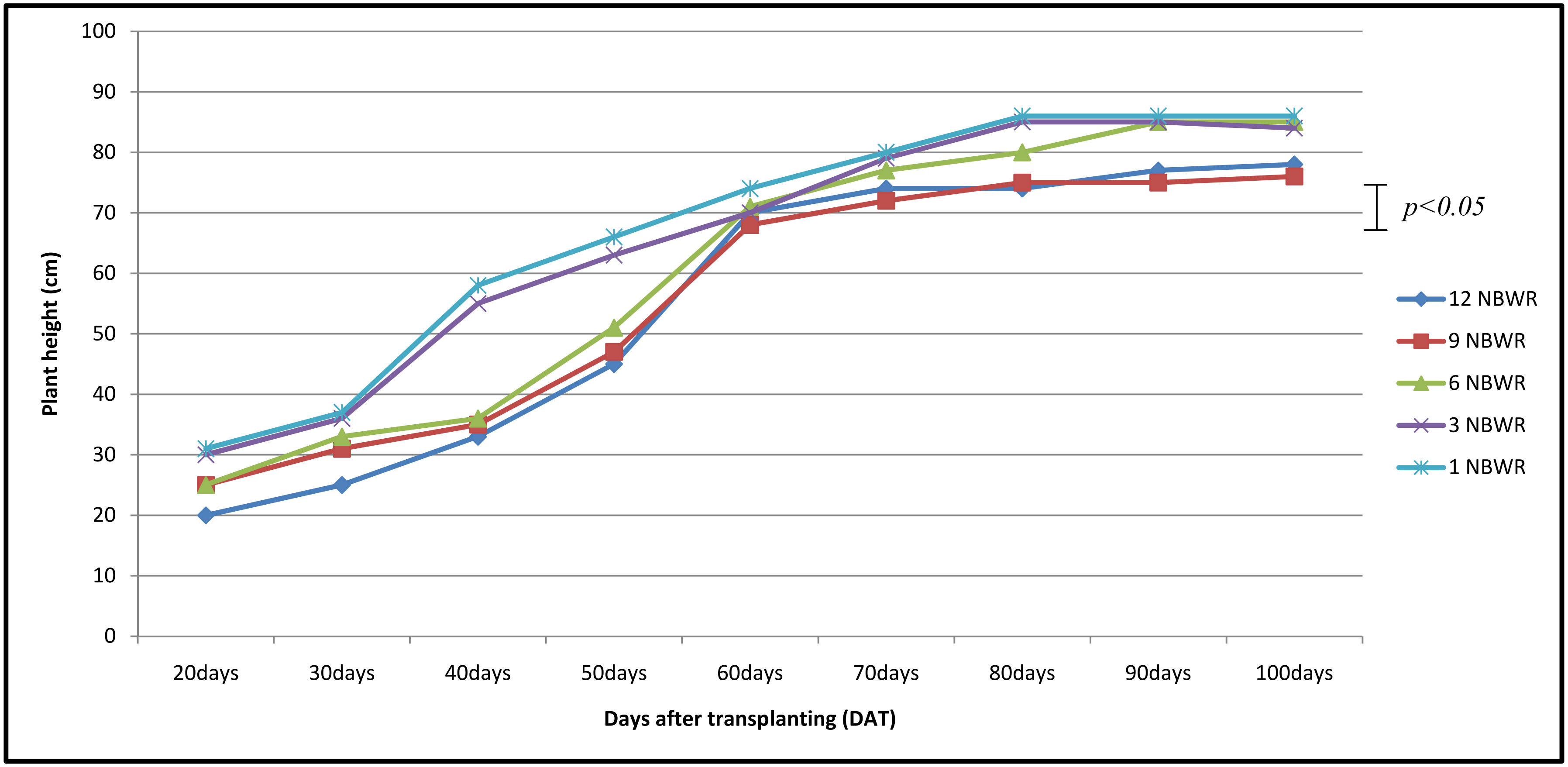

Fig. 5.2. Plant height of new biotype of weedy rice (NBWR) in monoculture as influenced by different densities and days (after transplanting - DAT). Bar represents LSD value at $p<0.05$.

Table 5.3. Final plant height of MR220 and NBWR in different density regimes (monoculture and mixture). * shows the significance value of plant height when grow in different density regimes.

MR220				NBWR			
Density regimes	*Average height*	LSD	Significance*	*Density regimes*	*Average height*	LSD	Significance*
T5	75.75	72.92	b	T6	78.00	76.33	c
T4	77.00	74.17	b	T7	73.00	71.33	d
T3	75.25	72.42	b	T8	76.00	74.33	c
T2	81.50	78.67	a	T9	77.00	75.33	c
T1	84.00	81.17	a	T10	78.00	76.33	c
T6	77.75	74.92	b	T11	83.75	82.09	b
T7	75.50	72.67	b	T12	85.00	83.33	a
T8	75.00	72.17	b	T13	86.25	84.58	a

* Values with the same lowercase letter are not significantly different at $P < 0.05$

T4, and 9.82% in T5. The height of NBWR grown in monoculture was also reduced as the number of plants per pot increased. The height of plants in T12 reduced 1.45% and followed by T11 (2.90%), T10 (9.56%), and T9 (10.72%).

The LSD tests indicated significant differences in final plant height for both MR220 and NBWR plants in monoculture pots (Table 5.3). This shows the effect of intra-specific competition on height was greater in plants grown in monoculture.

The MR220 in monoculture has recorded an increase number of tiller/plant for all density regimes. However, the quanta of increase were different between the different densities (Table 5.4). The MR220 in T1 shows the highest tiller production throughout the growth period while MR220 in T4 and T5 were the lowest. The same pattern of tiller production also prevailed in NBWR in all density regimes (Fig 5.3).

The first tiller for both MR220 and NBWR appeared at 20 DAT. Both NBWR and MR220 in monocultures with lower density showed an extremely high tiller production at early stages as shown in Fig. 5.3. Both MR220 and NBWR shared almost the same of peak production time at *ca.* 60 DAT. Table 5.4 also showed that when the density was higher, the production of the tillers were less. MR220 and NBWR in 12 and 9 plants per pot have the final tiller number of at most 5 tillers per plant while tiller in monoculture of 1, 3 and 6 plants per pot reached up to 20 tillers per plant.

The tiller number in the replacement and additive series pots was significantly affected by density. The LSD tests indicated significant differences in tiller number in monoculture. However, in mixtures there was no significant difference in tiller numbers for both MR220 and NBWR, indicating that density regimes did not influence, nor affect tiller number production (Table 5.4).

In monoculture, there was a decrease in tiller number in NBWR and MR220 with increasing proportions in the pot, where the highest tiller number occurred in single plant

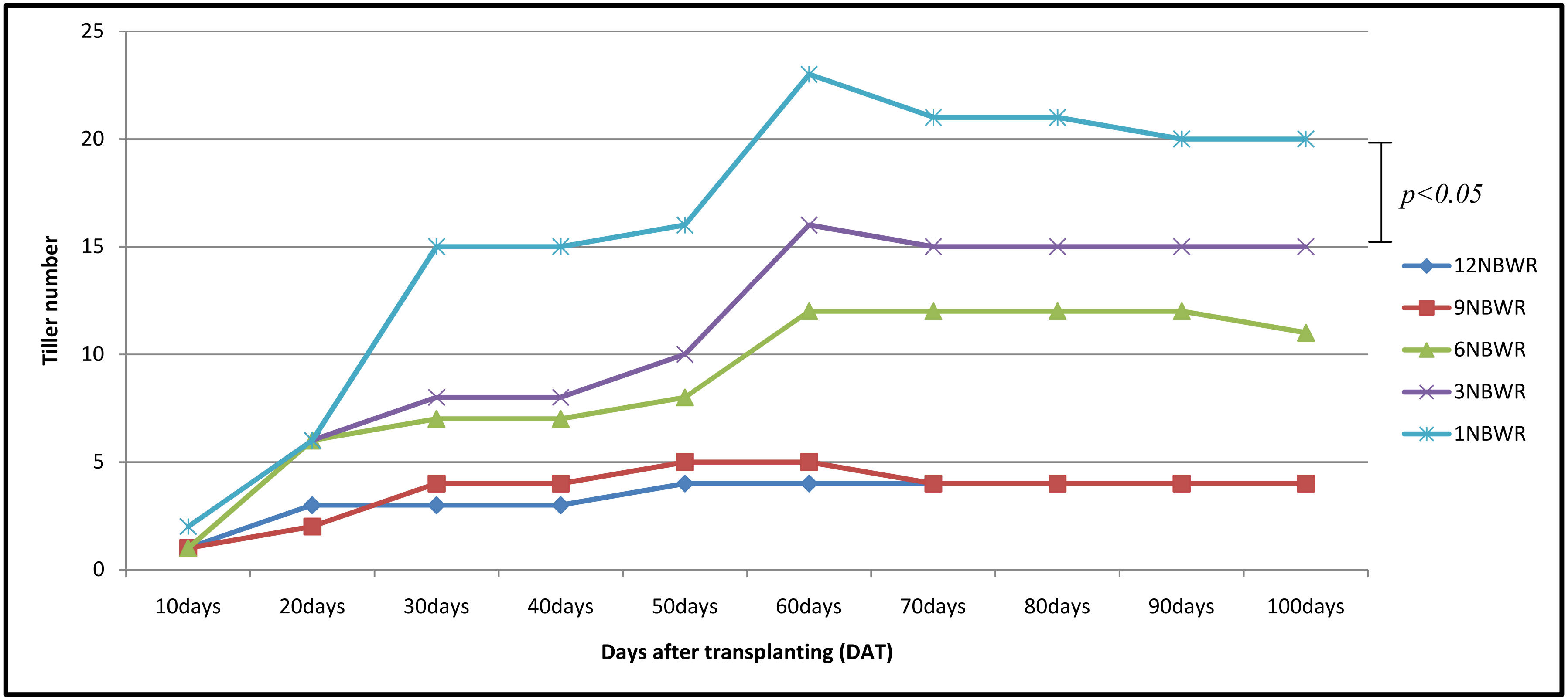

Fig. 5.3. Tiller numbers of new biotype of weedy rice (NBWR) in monoculture as influenced by different densities and days (after transplanting - DAT). Bar represents LSD value at $p<0.05$.

Table 5.4. Tiller numbers of MR220 and NBWR in different density regimes (monoculture and mixture).

MR220				NBWR			
Density regimes	*Average tiller*	LSD	Significance*	*Density regimes*	*Average tiller*	LSD	Significance*
T1	17.75	16.33	a	T6	5.00	3.23	d
T2	12.25	10.83	b	T7	4.50	2.73	d
T3	11.25	9.83	b	T8	4.25	2.48	d
T4	5.75	4.33	c	T9	4.00	2.23	d
T5	3.50	2.08	d	T10	4.50	2.73	d
T6	5.75	4.33	c	T11	10.50	8.73	c
T7	4.50	3.08	c	T12	14.75	12.98	b
T8	4.50	3.08	c	T13	19.25	17.48	a

* Shows the significance value of tiller numbers when grow in different density regimes. Values with the same lowercase letter are not significantly different at $P < 0.05$

per pot for both plants (Table 5.4). Tiller numbers were greatly reduced in the higher density pot for both MR220 and NBWR.

The number of filled grain of rice crop is an important measurement to determine the measurable effect and impact of infestation of weeds in crop field. In this experiment, the number of filled grain per panicle of MR220 did display any significant difference when grown in monoculture. Only in the treatment T1 which has significance difference in the production of filled grain *vis-à-vis* density regimes. In this pot, MR220 has recorded the highest filled grain number among others. The NBWR in monoculture, the production of filled grains per panicle has been affected by different densities of NBWR in the pot. The LSD tests showed that plants subjected to higher density recorded parallel reduction in the production of filled grains/panicle. The highest filled grain/panicle was shown in T13. The number of filled grains/panicle reduced significantly according to the density increment (Table 5.5).

However, MR220 grown in mixture with NBWR had a significant increase number of filled grains. While in NBWR, only in T8 treatment that significant (p <0.05) were observed in the number of filled grains for NBWR. In this pot, the NBWR produced highest filled grain/panicle than those subjected to other mixture regimes.

From these observations, we can assume that the number of filled grain in MR220 was not affected seriously with the increment in density either in monoculture or in mixture. Again in NBWR, the intra-specific competition seems to affect the production of filled grain. The higher density of NBWR in mixture with MR220 reduced the production of filled grain in NBWR (Table 5.5).

Table 5.5. Number of filled grains per panicle of MR220 and NBWR in different density regimes (monoculture and mixture).

MR220				**NBWR**			
Density regimes	*Average*	LSD	Significance*	*Density regimes*	*Average*	LSD	Significance*
T1	95.90	87.73	a	T6	40.70	34.48	d
T2	81.70	73.53	b	T7	40.70	34.48	d
T3	80.40	72.23	b	T8	44.10	37.88	c
T4	79.50	71.33	b	T9	42.50	36.28	d
T5	79.10	70.93	b	T10	48.70	42.48	c
T6	77.40	69.23	b	T11	50.60	44.38	c
T7	82.50	74.33	b	T12	62.70	56.48	b
T8	77.90	69.73	b	T13	75.00	68.78	a

* Shows the significance value of tiller numbers when grow in different density regimes. Values with the same lowercase letter are not significantly different at $P < 0.05$

The 1000 grains weight in both MR220 and NBWR was not been affected by any density regimes either in monoculture or in mixture (Table 5.6). All density regimes showed no significant difference in 1000 grains weight. It can be summed up that grain weight is not affected by any competition either inter-specific or intra-specific.

5.3.2 Relative Yields

Relative yield (RY) is a parameter to measure the yield of one species in comparison with another species. Fig. 5.4 shows the RY values for both MR220 and NBWR in mixture. The NBWR and MR220 when grown in mixtures displayed different results based on relative yields. MR220 in mixture with NBWR (T6) showed the highest value of relative yield of 0.81 while NBWR had low relative yield at 0.43. In T7 treatment, MR220 recorded higher relative value with 0.76 *vis-à-vis* NBWR registering only 0.23.

The Relative Yield Total (RYT) is used to interpret the yield total of two or more species of plant. It also can show the mutualism relationship between two or more species utilizing the same resources. The RYT in T7 treatment mixture has the highest value (0.98) followed by T6 (0.93) and T8 (0.86).

The interactions between of MR220 and NBWR based on the relative yield (RY) can also be illustrated with the reproductive biomass. The response curve has been used as an indicator of the extent of interference between rice and the competing weed species. A concave or convex line indicates that one species gained more resources at the expense of the other, whereas two straight lines indicate the equivalence of interference, with both species being equally competitive (Harper 1977).

Table 5.6. 1000 grains weight of MR220 and NBWR in different density regimes (monoculture and mixture).

MR220				**NBWR**			
Density regimes	*Average weight*	LSD	Significance*	*Density regimes*	*Average weight*	LSD	Significance*
T1	21.82	18.68	a	T6	31.59	30.17	a
T2	21.37	18.22	a	T7	32.91	31.49	a
T3	22.09	18.95	a	T8	31.59	30.17	a
T4	22.45	19.30	a	T9	32.03	30.61	a
T5	21.82	18.68	a	T10	32.67	31.25	a
T6	22.09	18.95	a	T11	31.59	30.17	a
T7	21.82	18.68	a	T12	31.81	30.39	a
T8	22.09	18.95	a	T13	32.03	30.61	a

* Shows the significance value of tiller numbers when grow in different density regimes. Values with the same lowercase letter are not significantly different at P <0.05

The relative yields of the reproductive dry weight versus the proportion mixture of MR220 and NBWR displayed convex curve for MR220 but was in concave shape for NBWR (Fig 5.4). The intersection for equivalent shifted to the right, indicating that MR220 was not affected in capturing the resources for its growth even when ratio of NBWR density was two times greater than MR220. The NBWR was less competitive against MR220, indicating that resource acquisition was more by MR220 compared with NBWR.

Apparently, increasing the density of NBWR in the MR220-NBWR mixture did not seem to have serious effects in the reduction of relative yield for MR220. On the contrary, the increment of MR220 density will reduce the yields of NBWR (Fig 5.4).

5.3.3 Aggresivity Index:

The aggresivity index (A) is a value to determine the aggressiveness of weed in competition with the crop. The aggressivity index values of NBWR in competition with MR220 for all mixtures were negative, indicating that MR220 was more aggressive than NBWR. The aggresivity index values decreased with the parallel reduction in MR220 proportion in the mixtures (Fig 5.5).

5.3.4 Reproductive Effort, Vegetative Effort And Harvest Index

Figure 5.6 shows the reproductive effort (RE), vegetative effort (VE) and harvesting index (HI) of both MR220 and NBWR in monoculture and Fig 5.7 shows the value of RE, VE and HI in mixture. The same values for both MR220 and NBWR in mixtures and in monocultures were shown in RE, VE and HI in mixture (Table 5.7). Basically, the RE, VE and HI values of NBWR and MR220 were almost the same in single-plant pot.

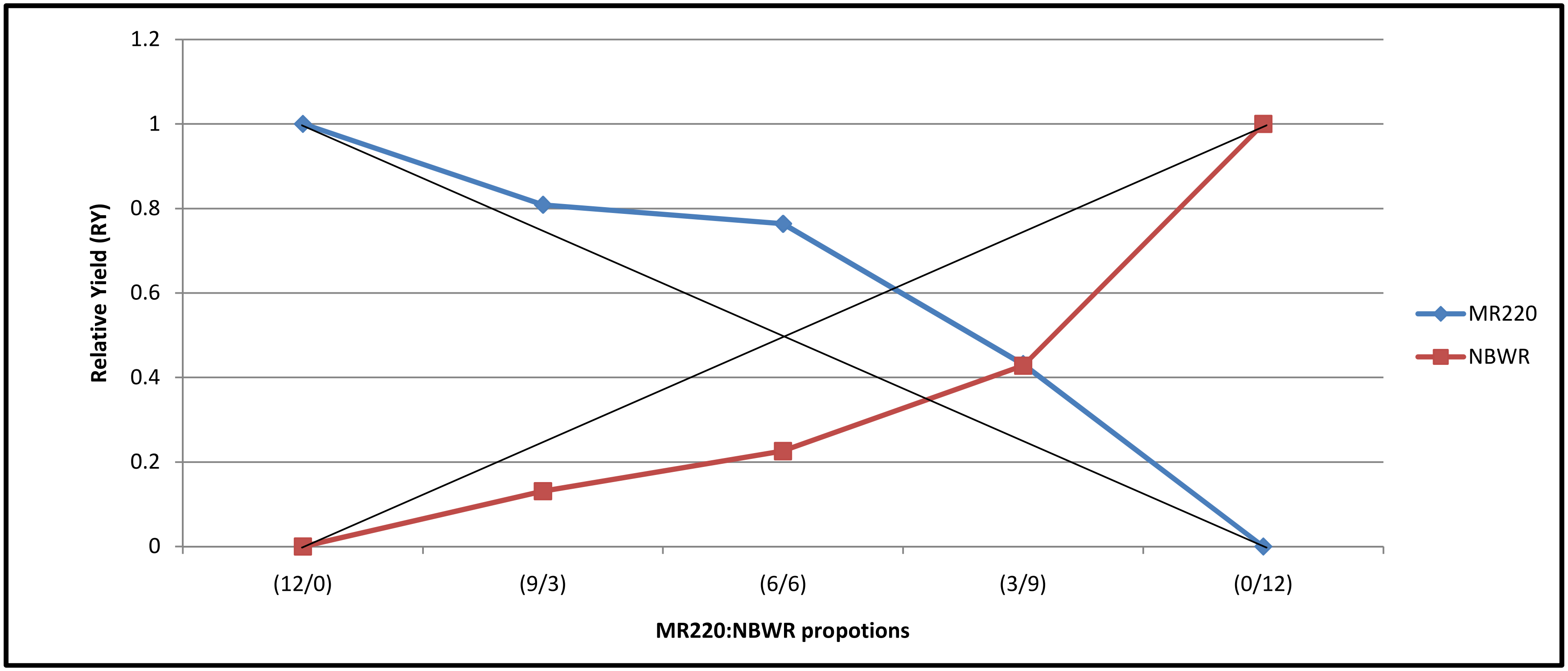

Fig. 5.4. Relative yield (RY) of cultivated rice *var.* MR220 and NBWR as influenced by different density proportions. The two straight lines indicate the theoretically expected responses for two equally competitive species which intersect at the point of equivalency (Harper 1977).

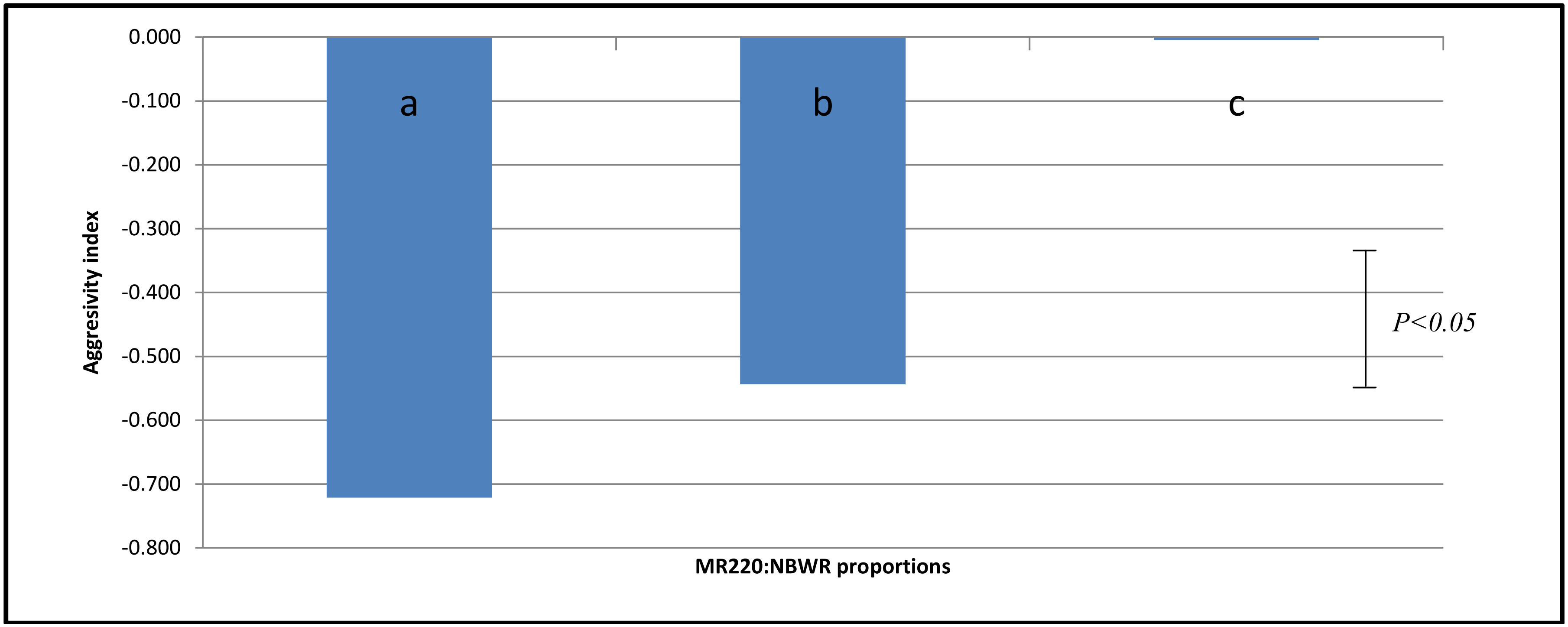

Fig. 5.5. Aggresivity index values of NBWR in three different density proportions. (a) 9MR220:3NBWR mixture; (b) 6MR220:6NBWR mixture; (c) 3MR220:9NBWR mixture. Bar represents LSD value at $p<0.05$.

Table 5.7. Reproductive effort (RE), vegetative effort (VE) and harvest index (HI) for MR220 and NBWR in different density regimes (mixture and monoculture).

MR220:NBWR proportions	MR220			NBWR		
	RE	VE	HI	RE	VE	HI
T6	0.29	0.71	0.29	0.09	0.91	0.09
T7	0.35	0.65	0.35	0.14	0.86	0.14
T8	0.24	0.76	0.24	0.23	0.77	0.23
Monoculture						
T5 and T9	0.34	0.66	0.34	0.40	0.60	0.40
T4 and T10	0.58	0.42	0.58	0.29	0.71	0.29
T3 and T11	0.60	0.38	0.60	0.42	0.58	0.42
T2 and T12	0.48	0.52	0.48	0.25	0.75	0.25
T1 and T13	0.41	0.59	0.41	0.41	0.59	0.41

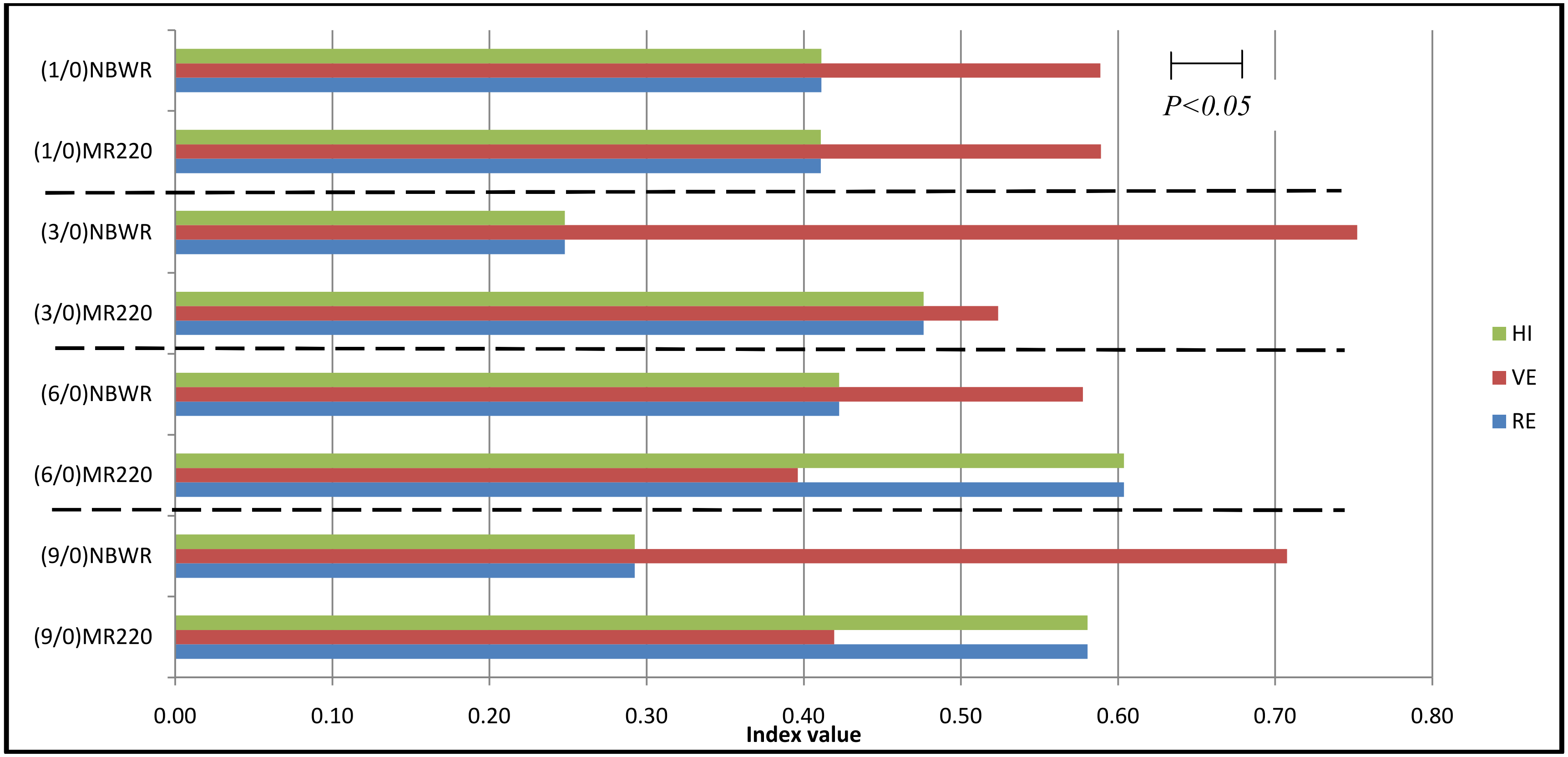

Fig. 5.6. Reproductive effort (RE), vegetative effort (VE) and harvest index (HI) values for MR220 and NBWR in different monoculture densities. Bar represents LSD value at $p<0.05$.

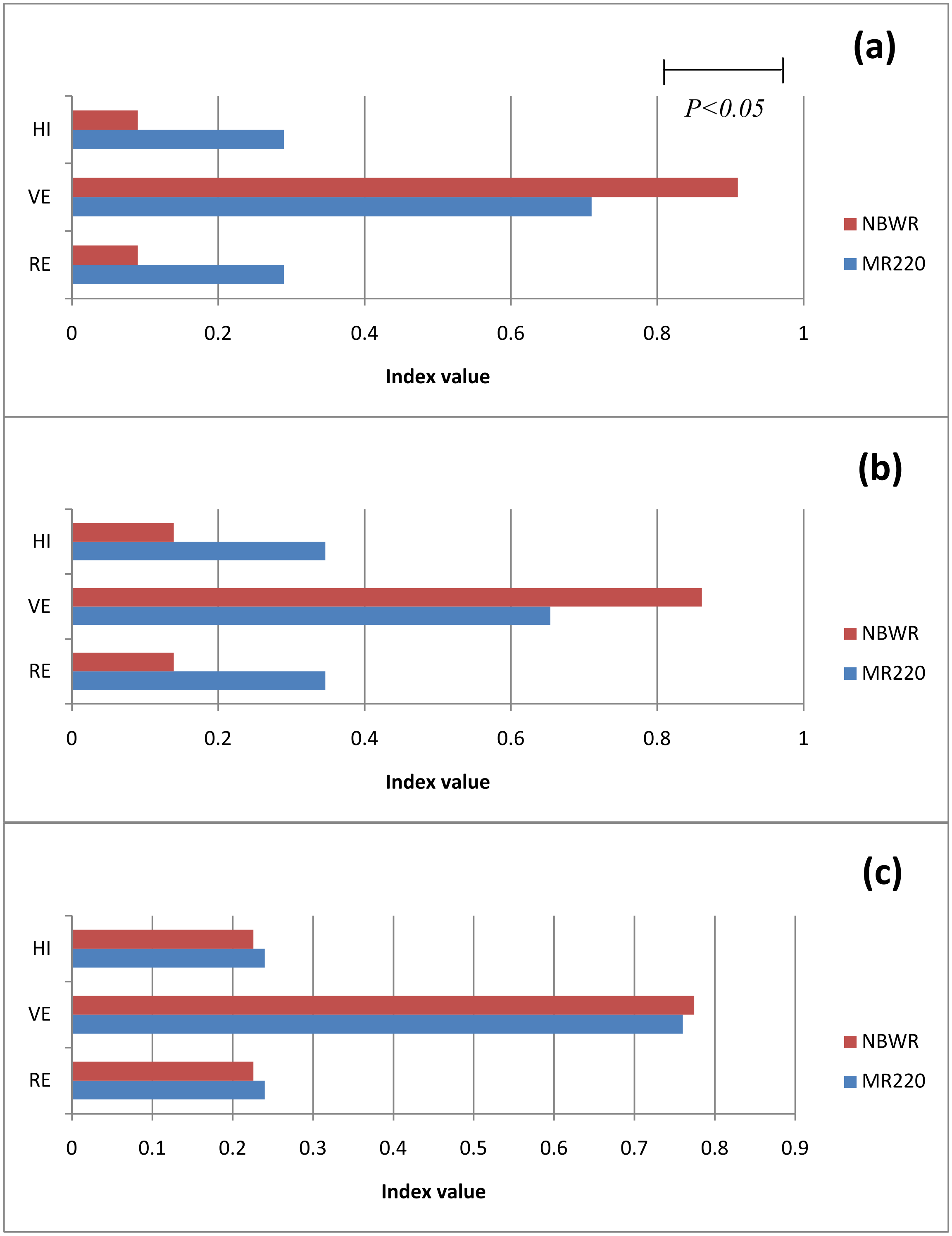

Fig. 5.7. Reproductive effort (RE), vegetative effort (VE) and harvest index (HI) values for MR220 and NBWR in different mixture proportions. (a) mixture of 9 MR220:3 NBWR; (b) mixture of 6 MR220:6 NBWR and (c) mixture of 3 MR220:9 NBWR. Bar represents LSD value at $p<0.05$.

Both of MR220 and NBWR registered high VE values while the RE and HI values were quite similar. This indicates that without any inter- or intra-specific interference, both MR220 and NBWR displayed quite similar growth pattern.

However, when the densities of either MR220 or NBWR in the pot were increased, the values of RE, VE and HI changed likewise. In 3 plants per pot monoculture (T12), the NBWR showed drastic increments in VE (0.75) while the RE (0.25) and HI (0.25) has decreased tremendously. Conversely in MR220 (T2), the VE value (0.52) seems to have a slender decrease but the RE (0.48) and HI (0.48) values increased slightly compared with MR220 in single plant per pot (T1).

The VE value in MR220 decreased in higher monoculture density. With 6 plants per pot (T3), the VE value of MR220 dropped to below 0.4 before it rise a little bit in 9 plants per pot (0.42). However, there were different values for RE and HI. As the density rises, the RE and HI values of MR220 increase from what we get in the single plant pot. The RE and HI values reach 0.6 in 6 plants per pot (T3) monoculture before the RE (0.58) and HI (0.58) start to drop slightly in 9 plants per pot.

As for the NBWR, different patterns occurred with respect to registered VE, RE and HI indices. The NBWR planted in 3 plants per pot (T12) monoculture registered very high VE value (0.75) compared to NBWR in a single plant per pot (0.59). At the same time, the RE and HI values were reduced from T13 to T12. The RE and HI values for T12 were 0.25 while the RE and HI values for T13 were 0.41. The RE and HI values (0.42) of NBWR rise again in 6 plants per pot (T11) monoculture at the same level as in single plants per pot, while the VE value was similar to those observed in single plant per pot (0.58). The HI, VE and RE values in 9 plants per pot were quite similar to those registered in 3 plants per pot.

In mixtures, the value of HI, VE and RE varied according to the respective proportions of MR220 and NBWR mixture. In T7 mixture, NBWR registered a very high VE value of 0.86 as compared with VE value of MR220 (0.65). However, NBWR had a lower value of HI and RE than MR220. The HI value of NBWR in T7 mixture was 0.14 and so was the RE value also 0.14. Conversely, the respective HI and RE values for MR220 were 0.35 and 0.35.

The value of HI, VE and RE for MR220 in T6 were not much different compared with those registered for MR220 in T7 mixture. MR220 in T6 showed a slight decrease in VE value (0.71), but HI (0.29) and RE (0.29) increased slightly while VE, HI and RE in T7 were 0.65, 0.35 and 0.35 respectively. The same pattern also prevailed in NBWR with a small increment in the RE and HI, and a meager decrease in the VE value. VE, RE and HI value for NBWR in T6 were 0.91, 0.09 and 0.09 while in T7 the values were 0.86, 0.14 and 0.14 respectively.

In T8 mixture, VE, HI and RE values of both MR220 and NBWR did not register large margins compared with other mixtures. In T8, the HI (0.23) and RE (0.23) values of NBWR increased a little bit from their values in the T7 mixture while the VE (0.77) value had a slight decrease. The values of HI (0.24) and RE (0.24) in MR220 in T8 displayed no measurable change while the VE value increased up to 0.76 in T8.

From the relative yield and relative yield total values, the proportional contribution to yields of participating species *viz*. rice *var.* MR220 and NBWR had been determined through RE and HI indices. MR220 in monoculture registered more yield than in mixtures with NBWR. Higher MR220 densities in monoculture reduced the vegetative growth but on the other hand had increased the yield. Therefore, rice in monoculture will produce more yields if more plant were planted in the same area. Conversely for NBWR, higher densities in monoculture will reduced the yield.

Rice and NBWR in mixtures in most density regimes produced lesser yield than in monocultures. This scenario implied that the existence of NBWR in rice cultivation have changed yields, and *vice versa*. However, in all mixture regimes, MR220 produced more yields than NBWR. This gives a strong indication that MR220 has a better competitive capability with NBWR.

5.3.5 Path Analysis

The direct effect (Table 5.8; Fig 5.8) of cultivated rice densities *var.* MR220 (RD) and NBWR densities (WD) on all yield components for both rice and weed were always negative. This indicates that increment in RD and WD affects the yield components for both MR220 and NBWR.

The path coefficient values for direct effect of RD and WD on TP of MR220 were higher than the path coefficient values for direct effect of RD and WD on TP of NBWR. The high values of path coefficient of direct effect of RD and WD on TP of MR220 indicated that rice density (RD) affected to rice *var.* MR220 more than NBWR. This factor is important which had resulted in the reduction of tillers per plant (TP) of rice.

The RD also affected PP, GP and FP of both MR220 and NBWR. However, there was no obvious difference in effect between MR220 and NBWR. The path coefficient value of RD on PP for rice was -0.65 while it only has just a slight different in NBWR (-0.68). The same results were registered in path coefficient values of RD on GP for rice (-0.46) and NBWR (-0.49). Both MR220 and NBWR have same path coefficient values of RD on FP (-0.46). It appeared that both MR220 and NBWR were affected by the increasing densities either by MR220 or NBWR when grown in mixtures.

All yield components were influenced by WD in the MR220 and NBWR mixtures. The path coefficient values were different in MR220 and NBWR. The path coefficient

Table 5.8. Comparison of path coefficient values of direct effects between weed and rice densities and yield components; and yield components and fecundity of MR220 and NBWR.

	YIELD COMPONENT			
	TP*	PP*	GP*	FP*
Rice Density (RD)	-0.76[A]	-0.65[A]	-0.46[A]	-0.46[A]
	-0.43[B]	-0.68[B]	-0.49[B]	-0.46[B]
Weed Density (WD)	-0.51[A]	-0.62[A]	-0.36[A]	-0.44[A]
	-0.61[B]	-0.15[B]	-0.38[B]	-0.25[B]
	FECUNDITY OF RICE			
	Yield per Plant (YP)		Number of Grain per Plant (GPP)	
Tiller per plant (TP)	0.11[A]		0.10[A]	
	0.22[B]		-0.10[B]	
Panicle per plant (PP)	-0.25[A]		-0.35[A]	
	0.01[B]		0.26[B]	
Grain per panicle (GP)	0.07[A]		1.52[A]	
	0.39[B]		1.41[B]	
Filled grain per panicle (FP)	0.91[A]		-0.70[A]	
	0.42[B]		-1.05[B]	

*TP= Tiller per plant; PP= Panicle per plant; GP= Grain per panicle; FP= Filled grain per panicle. [A] For MR220 in the MR220:NBWR mixture; [B] For NBWR in the MR220:NBWR mixture.

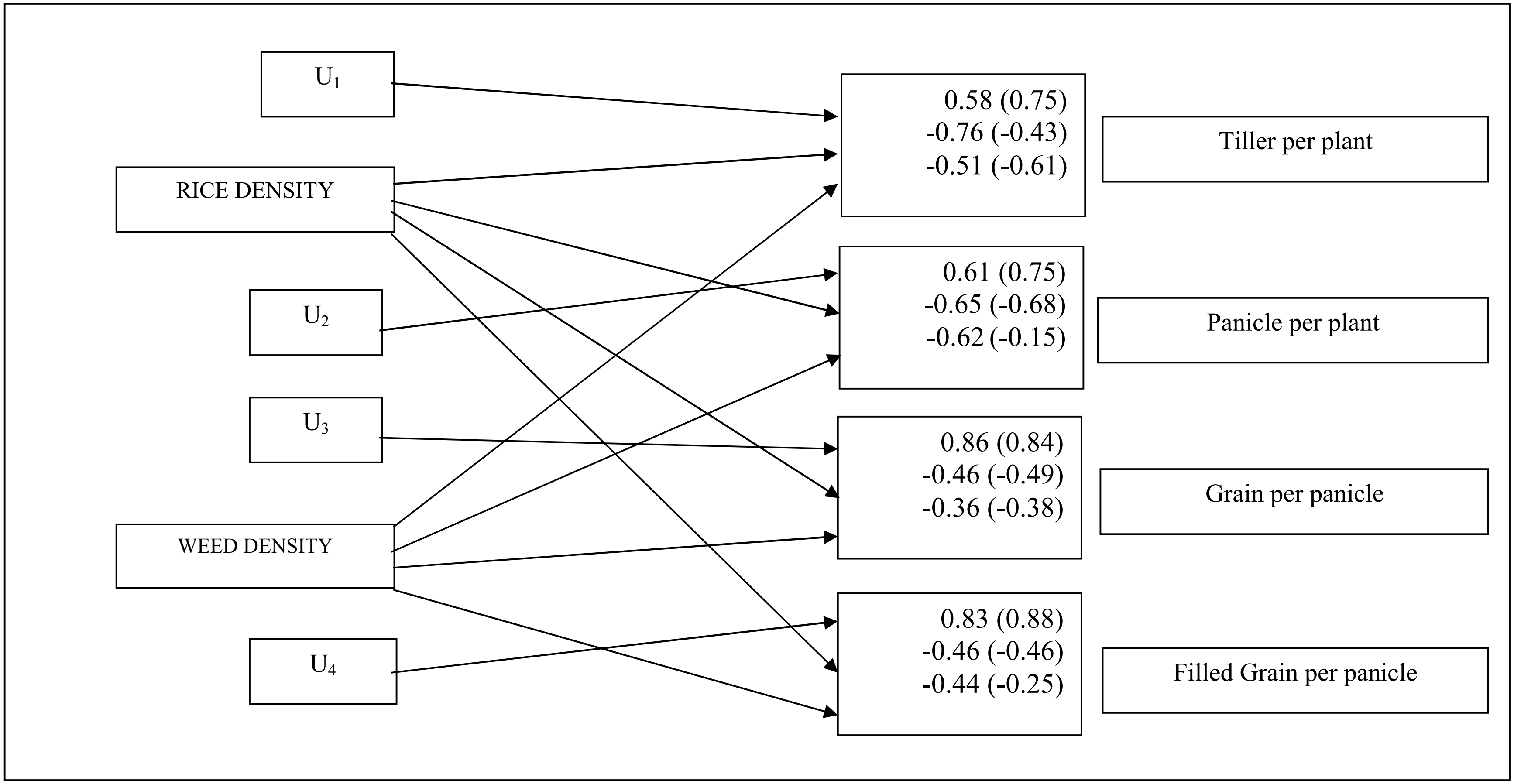

Fig. 5.8. Path analyses diagram for the relationship between planting densities of rice *var.* MR220 (RD) and NBWR (WD) on yield components. (Path coefficient values in parentheses are for NBWR); U_1, U_2, U_3 and U_4 are undetermined residuals).

value of WD on PP for MR220 (-0.62) was lower than that of NBWR (0.15). This indicates that WD gives more effect on NBWR than MR220. The increment in WD will lead to reduction of number of panicle in NBWR more than the MR220.

The same pattern also occurred in the number of filled grain per panicle (FP). The path coefficient value of WD on FP for MR220 (-0.44), also had a lower value than the NBWR (-0.25). Again, the increment of WD in the MR220-NBWR mixture will affect more on the number of filled grains per panicle in NBWR rather than number of filled grains in the panicle of MR220.

Both GP and TP did not show significant difference between MR220 and NBWR. The path coefficient value of WD on GP for MR220 was -0.36, and for NBWR it was -0.38. These results showed that the WD effect on grains per panicle was almost the same for both MR220 and NBWR. The same results were also observed in path coefficient value of WD on TP for rice (-0.51) and NBWR (-0.61). Nevertheless, the path coefficient value of WD on TP for NBWR (-0.61) was a little lower than MR220 (-0.51), indicating that WD on TP will somewhat affect more in MR220 than NBWR.

The residual values (U_1, U_2, U_3, and U_4) for all yield components were in the excess of 0.30, signifying that undetermined factors such as soil humidity, temperature and internal physiology may have strong effects on the yield components of MR220 and NBWR.

The direct effect of RD and WD on yield components can be arranged in ascending orders. Based on these orders, we can determine which components were influenced more on any RD and WD differences. The order of influence of direct effects of MR220 densities (RD) on rice yield components based on path coefficient values was TP (-0.76), PP (-0.65), GP (-0.45) and FP (-0.45). This indicates that tillers of MR220 will be affected more as RD increase than other yield components. On the other hand, the number of filled grain per panicle will be the least affected. Conversely, for NBWR yield components, the order of influence in the path coefficient values was TP (-0.43) > FP (-0.46) > GP (-0.49) > PP (-0.68). This result shows that NBWR's tiller will be the worst affected by RD regimes. This is followed by other yield components, with the panicle production expressing slightest effect.

The order of influenced for direct effect for NBWR densities (WD) on MR220 yield components was different compared to RD on MR220 yield components. The order of influence of direct effects of WD on rice yield components based on path coefficient values was GP>FP>TP>PP, while the order of influence of direct effects of WD on NBWR yield components based on path coefficient values was PP>FP>GP>TP. The MR220's TP was the worst component affected by RD, but in WD, the worst affected yield component was PP. This gives an indication that when either rice or weedy rice densities were changed, the effect on yield components also will change. Similar effects also applied in NBWR. As in RD, the panicle number in NBWR was badly affected, but in WD, the tiller number of NBWR was the most affected by the change in density regimes and their proportions in mixtures. The change on densities and their proportions in mixture will change the pattern of influenced on yield components.

Instead of the direct effect of densities on yield components, there is also the direct effect of yield components (TP, PP, GP and FP) on the rice fecundities (yield per plant and number of grain per plant) (Table 5.9; Fig 5.9). Almost all path coefficient values of the direct effects of yield components on yield per plant (YP) and grains per plant (GPP) for MR220 and NBWR were positive. However, there were some yield components which have negative direct effect YP and GPP, either to MR220 and NBWR.

The path coefficient values of TP on YP for both MR220 and NBWR were positive, giving indication that YP was not directly affected by TP. However, the TP caused a direct effect to GPP for NBWR. The negative value of path coefficient of TP on GPP for NBWR indicated that NBWR was badly influenced by tiller's number on number of grain per plant. On the contrary, the results showed that the path coefficient value of TP had lesser effect to GPP in rice.

Both yield per plant and number of grain per plant of rice have negative path coefficient values of panicle per plant. Conversely, the path coefficient values for PP to YP and GPP in NBWR were always positive (Table 5.9). The PP has a stronger influenced to the YP and GPP of MR220 in comparison with the value of NBWR.

The path coefficient values of GP on YP and GPP for both rice and weed were always positive (Table 5.9). However, the positive value of path coefficient of GP on YP in rice was relatively smaller than NBWR. This indicated that YP in rice was likely to be affected by GP compared to NBWR. Both path coefficient values of GP on GPP in MR220 and NBWR were largely positive. The value shows that GPP in both rice and weed were unlikely to be affected by GP.

The number of filled grain per panicle (FP) will affect the production of number of grain per plant. The large negative values of path coefficient of FP on GPP in MR220 and NBWR (Table 5.9) were the indication of the direct effect of FP to GPP in both rice and NBWR. A high value gave an indication that GPP was strongly influenced by FP. On the contrary, the FP had no direct effects on YP in MR220 and NBWR as the path coefficient values were always positive.

The residual values for rice fecundity (U_5 and U_6) were very high and exceeding 0.30, except the residuals value on yield per plant for rice. It follows that the undetermined factors will strongly affected the YP and GPP for both MR220 and NBWR, but these did not affect the yield per plant for MR220.

Table 5.9. Path coefficient of the yield components of rice *var.* MR220 and NBWR. (Path coefficients in parentheses are for NBWR).

Yield Components	TP*	PP*	GP*	FP*
TP	1	0.83	0.31	0.32
		(0.30)	(0.46)	(0.37)
PP		1	0.26	0.28
			(0.11)	(0.10)
GP			1	0.98
				(0.95)
FP				1

*TP= Tiller per plant; PP= Panicle per plant; GP= Grain per panicle; FP= Filled grain per panicle.

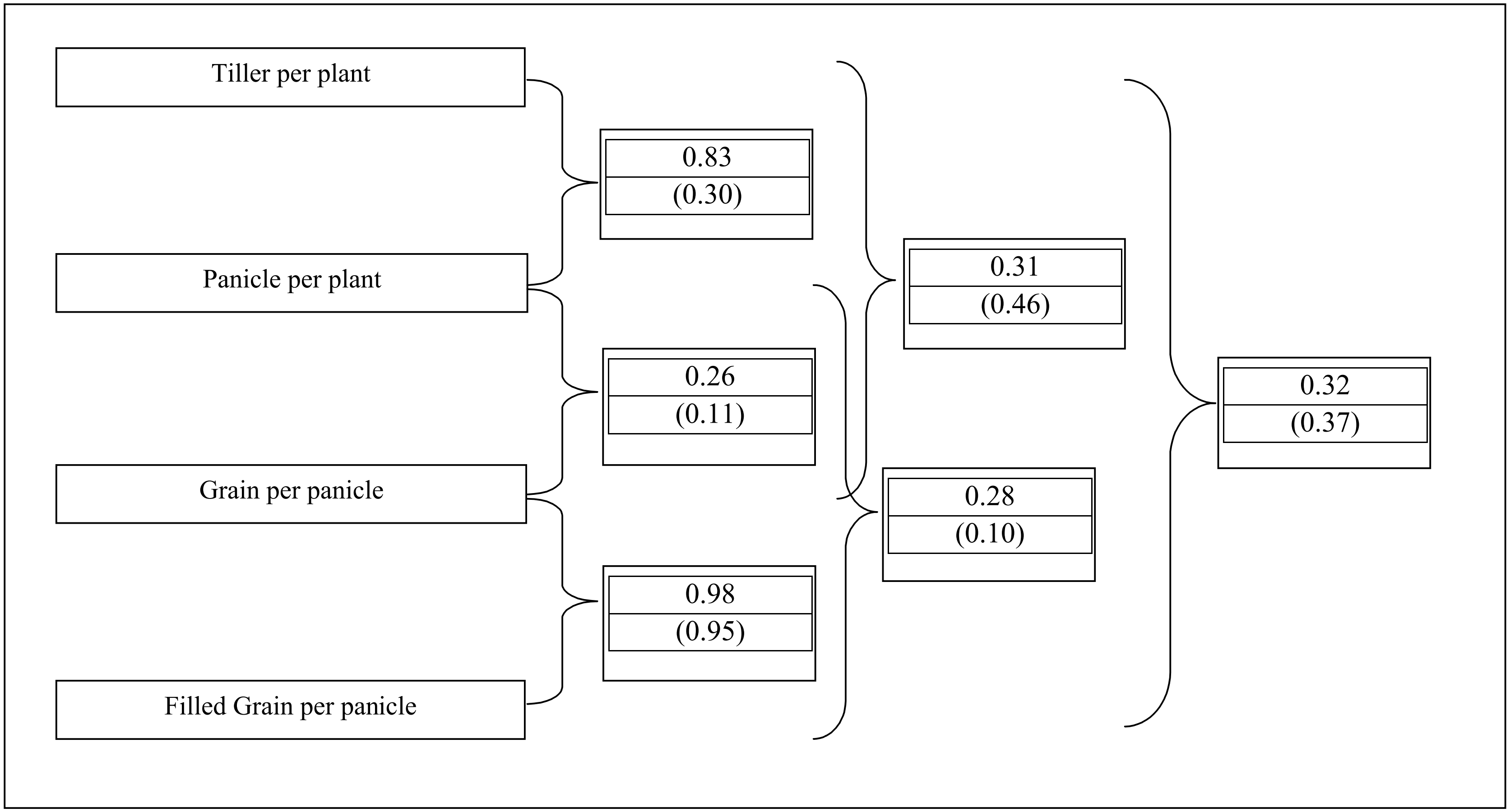

Fig. 5.9. Path analyses diagram for the indirect effect of yield components of rice *var.* MR220 and NBWR. Path coefficient values in parentheses are for NBWR.

The path coefficient values of the indirect effect between yield components for MR220 and NBWR were always positive. This result gives an indication that the yield components had variable influence on each other. The TP of rice had a very strong influence on PP for rice and *vice-versa* but TP of NBWR had only a minor influence to PP. The TP of rice and NBWR did not have strong influence to GP and FP, albeit a slight effect on GP and FP for NBWR.

The path coefficients for PP effect to GP for MR220 and NBWR were 0.26 and 0.11 respectively, while path coefficient for PP effect to FP for MR220 and NBWR were 0.28 and 0.10. This indicated that PP for both MR220 and NBWR only had a minor influence to GP and FP and *vice-versa.* On the other hand, the GP with FP had very strong effects on each other with respect to high path coefficient values of 0.98 for MR220 and 0.92 for NBWR. It follows that increasing GP will bring about a parallel increase in FP and *vice-versa* for both MR220 and NBWR.