Sustainability **2014**, *6*, 5785-5800; doi:10.3390/su6095785

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Rice Ratoon Crop: A Sustainable Rice Production System for Tropical Hill Agriculture

Golam Faruq *, Rosna Mat Taha and Zakaria H. Prodhan

Institute of Biological Sciences, Faculty of Science, University of Malaya, Kuala Lumpur 50603, Malaysia; E-Mails: rosna@um.edu.my (R.M.T.); rajugenetics2003@gmail.com (Z.H.P.)

* Author to whom correspondence should be addressed; E-Mail: faruq@um.edu.my or faruqwrc@gmail.com; Tel.: +6-03-7967-5805; Fax: +6-03-7967-5908.

Received: 11 March 2014; in revised form: 15 July 2014 / Accepted: 24 July 2014 / Published: 29 August 2014

Abstract: Increasing and sustainable production of rice in tropical hill area is facing various problems where rice ratooning can overcome the limitations. In this study; 22 rice entries were transplanted into experimental tank placed in the hill slope following Completely Randomized Design with five replications to asses' agronomic performance of main crop and ratoon crop where Entry 13 demonstrated highest grain yield per plant (42.06 ± 1.2 gm) as main crop, as well as ratoon crop (3.37 ± 0.28 gm); Entry 19 produced lowest grain yield per plant (5.01 ± 0.31 gm) as main crop and Entry 31 as ratoon crop (0.47 ± 0.03 gm). The grain yield per plant of both the main and ratoon crop demonstrated significant (** at 5% level and *** at 1% level) positive correlation with number of tiller per plant (0.64 ** and 0.52); number of fertile tiller per plant (0.66 ** and 0.63 **); grain per panicle (0.72 ** and 0.53); fertile grain per panicle (0.80 *** and 0.63) and thousand-grain weight (0.66 ** and 0.54). The Duncan Multiple Range test and Analysis of Variance also confirmed the different grouping and significant differences of productivity and agronomic performances of the entries. The information of this investigation will helps the rice breeder as well as marginal rice farmers to consider rice ratooning as an important practice for sustainable rice production in tropical agriculture system for maximum gains.

Keywords: agronomic performance; ratoon crop; rice

1. Introduction

Rice is a main staple food for human consumption all over the world. The people who live in the tropical hill area, such as Malaysian people, also consume rice based dishes but the production of rice in this area is insufficient (currently 72% [1]). Thus, Malaysia imports rice from different counties, such as Thailand, Vietnam, Pakistan, and India, every year [2]. The Malaysian Government has taken several initiatives in the 3rd to 7th Malaysian Plans (3 MP–7 MP) to increase rice production [2], hence, the productivity increased from 2.1 ton/ha to 3.6 ton/ha from 1961 to 2008 [1]. However, the land area for rice cultivation remained constant at 0.7 million hectares since 1980 [1]. Due to some agro-ecological constraints it is difficult to increase rice cultivation area in Malaysia, so increasing production per unit area is the only way to achieve sustainable rice production [3]. The American Society of Agronomy [4] and United States Congress [5] have defined sustainable agriculture and mentioned five important parts, such as emphasizing productivity, improving environmental quality, efficient use of non-renewable resources, enhancing economic viability, and upgrading the quality of life. In these circumstances, ratooning of rice can be a good solution for intensifying and sustainable rice production [6] in hill regions. Rice ratooning is not a new cultivation practice for rice breeding because many countries (USA, Brazil, Japan, India, Philippines, Thailand, and Taiwan) of the world have already adopted this system [7]. Moreover, the Dominican Republic and USA are using rice ratooning on a commercial scale. Malaysian tropical hill areas, where heavy rainfall and high temperature are sustained all year are suitable for ratoon rice cultivation under rain-fed conditions [7]. Ratoon rice grows 65% earlier than main crops and requires 50% to 60% less labor. The production cost is also lower than main crops due to the minimized cost for land preparation, transplantation, and crop maintenance. Ratooning requires a short duration, and yield is up to 50% of main crops, which increase the opportunity for cropping intensity per unit of cultivated area [8,9].

During previous research (from 2009 to 2011), while screening the best parental lines for aroma and kernel elongation among 53 aromatic rice lines, stubbles from different lines demonstrated good ratoon performance (Visual estimation) [10], which inspired a detailed study of their potentiality as sustainable ratoon rice crop production. Based on this preliminary information, in the present investigation, performance of agronomic characters, such as number of tillers per hill, number of fertile tillers per hill, number of days to flowering, grain filling periods, number of days to maturity, plant height, panicle length, grains per panicle, fertile grains per panicle, thousand-grain weight, and grain yield per plant, of 22 rice entries, and their ratoon were evaluated to assess the possibility of using rice ratoon crops for the rising production of rice in Malaysian tropical hill areas.

2. Materials and Methods

A total of 22 rice entries (*Oryza sativa* subsp. *indica*) were collected from International Centre for Tropical Agriculture (CIAT, Cali, Colombia), International Rice Research Institute (IRRI, Los Baños, Laguna, Philippines), West African Rice Development Association (WARDA, Cotonou, Benin), International Institute of Tropical Agriculture (IITA, Ibadan, Oyo State, Nigeria), and Senegal, Mayanmar and Argentina (Table 1), for conducting experiment at the experimental field (hill slope) of the Institute of Biological Sciences, University of Malaya, Malaysia, from June 2013 to December

2013. The experiment was laid out in a Completely Randomized Design (CRD) with five replications for main and ratoon crops. Before planting, seeds of the selected genotypes were sown in small pots containing 500 gm black soil. After 3 weeks, seedlings were transplanted into experimental tank (75 × 100 × 75 cm) filled with loam soil and 100 gm NPKS (15:15:15:2) as recommended by Chatterjee and Maiti [11], at the rate of two seedlings per hill with row to row distance of 25 cm and plant to plant distance of 20 cm. Intercultural operations, *i.e.*, weeding, water management, and plant protection measures were followed for normal growth of main crop [12].

Table 1. Descriptions of the selected 22 rice entries.

Entry	Designation	Cross	Origin
E1	(88023-RE)	Unknown	CIAT
E2	(CT9882-16-4-2-3-2P-M)	Unknown	CIAT
E3	(H013-5-3-B4)	Unknown	ARGENTINA
E4	(H014-1-1-B2)	Unknown	ARGENTINA
E8	(IR 77736-54-3-1-2)	NSIC RC 148/PSB RC 64//NSIC RC 148	IRRI
E9	(IR 78006-55-2-3-3)	IR 67406-6-3-2-3/IR 72860-80-3-3-3	IRRI
E11	(IR 78554-145-1-3-2)	IR 72861-13-2-1-2/IR 68450-36-3-2-2-3	IRRI
E12	(IR 77298-14-1-2)	IR 64 (WH)/ADAY SEL//3*IR64	IRRI
E13	(IR 77512-2-1-2-2)	IR 68726-3-3-1-2/IR 71730-51-2	IRRI
E14	(IR 77629-72-2-1-3)	IR 71730-51-2/IR 71742-267-3-2	IRRI
E15	(M1-10-29 UL)	Unknown	MYANMAR
E16	(TOX 3226-5-2-2-2-2)	ITA 235/IR 9828-91-2-3//CT 19	IITA
E18	(WAB 272-B-B-5-H5)	3290/WASC165	WARDA
E19	(WAB 99-84)	ITA257/WABUKA	WARDA
E20	(WAB 337-B-B-15-H1)	ITA 135/WABC 165	WARDA
E21	(WAB 515-B-10 A 1-4)	Unknown	WARDA
E22	(WAS 169-B-B-4-2-7)	Jaya/Basmati 370	SENEGAL
E25	(WAS 197-B-4-1-25)	IR 31851-96-2-3-2-1/IR 66231-37-1-2	SENEGAL
E31	(WAS 197-B-6-3-4)	IR 31851-96-2-3-2-1/IR 66231-37-1-2	SENEGAL
E32	(WITA 7 = TOX 3440-171-1-1-1-1)	TOX891-212-1-201-1-105/TOX3056-5-1	WARDA
E35	(IR 64)	IR 5657-33-2-1/IR 2061-465-1-5-5	IRRI
E37	(PSB RC2= IR 32809-26-3-3)	IR 4215-301-2-2-6/BG90-2//IR 19661-131-1-2	IRRI

The hills (5 hills excluding the border hills) were randomly selected from each unit block for pre- and post-harvest data, such as number of tiller per hill, number of fertile tiller per hill, number of days to flowering, grain filling periods, number of days to maturity, plant height (cm), panicle length (cm), grains per panicle, fertile grains per panicle, thousand-grain weight (gm), and grain yield per plant (gm) [13]. The main crop was harvested, leaving a stubble height of 20 cm above ground level [14] and allowed for ratooning. No intercultural operations (weeding, insecticide, and fertilizer) were done for ratoon crops, and after maturity, five hills were selected for pre- and post-harvest data collection. Collected data were analyzed with SAS Version 9.2 [15] for descriptive statistical analysis (Mean and Stander Error of Mean), where the mean differences were adjudged with Duncan's Multiple Range Test (DMRT), Analysis of Variance (ANOVA), and trait correlation analysis.

3. Results

The performances (Mean value with Standard error of mean) of agronomic traits (Number of tillers per hill, number of fertile tillers per hill, days to flowering, grain filling periods, days to maturity, plant height, panicle length, grains per panicle, fertile grains per panicle, thousand-grain weight, and grain yield per plant) of the selected 22 entries were different for main crop and in ratoon crop. The maximum and minimum mean values of the traits were demonstrated by different entries which observed in different significance level (Tables 2 and 3) by Analysis of Variance (ANOVA), different groups (Tables 4 and 5) by Duncan Multiple Range Test (DMRT), and different type of correlation (Tables 6 and 7).

3.1. Number of Tillers per Hill

In the present investigation, the total number of tillers in the main crop was different for the entries, where Entry 13 and Entry 15 demonstrated maximum tiller number per hill (26.6 ± 0.68, 26.6 ± 0.75) and Entry 19 produced minimum tiller number per hill (7.8 ± 0.58). For the number of tillers per hill, Entry 13 and Entry 15 fall in the same group (Group a) while Entry 19 fall in the different group (Group l) by DMRT. There were significant differences between the replication (6.91 ***) and between the Entry (76.83 ***) in the main crop. The number of tillers per hill demonstrated significant positive correlation with number of fertile tillers per hill (0.97 ***) and grain yield per plant (0.64 **) while there was a negative correlation with plant height (−0.54). Previously many researchers [16–18] mentioned that number of tillers per hill has positive effects on yield.

For the ratoon crop, the maximum number of tiller per hill was observed in Entry 35 (17.2 ± 0.73) and minimum number of tiller per hill in Entry 19 (4.4 ± 0.40). DMRT also confirmed the position in different group of Entry 19 (Group l) and Entry 35 (Group a). The replications were significantly different (6.86 ***) with the different entries (47.83 ***) for number of ratoon tiller per hill in ratoon crop. The number of ratoon tiller per hill represented significant positive correlation with number of fertile ratoon tiller per hill (0.93 ***) but did not show negative correlation with any of the traits.

3.2. Number of Fertile Tillers per Hill

The maximum number of fertile tillers per hill for main crop was observed in Entry 13 (24.2 ± 0.80), which was positioned in Group a (DMRT), and minimum number of fertile tillers per hill was in Entry 19 (5.4 ± 0.51) and was placed in Group j (DMRT). The replications (7.85 ***) and the Entry (52.18 ***) was significantly different and the number of fertile tillers per hill demonstrated significant positive correlation with grain yield per plant (0.66 **) while negative correlation with plant height (−0.57).

In case of the ratoon crop, the maximum number of fertile tillers per hill was observed in Entry 13 (15.2 ± 0.37) and minimum number of tiller per hill in Entry 19 (3.0 ± 0.32). DMRT also confirmed the position in different group of Entry 13 (Group a) and Entry 19 (Group i). The replications were significantly different (5.91 ***) with the different entries (35.34 ***) for number of fertile ratoon tillers per hill. The number of fertile ratoon tillers per hill is the most important trait for higher grain yield in ratoon crop, which represented positive correlation with all the traits.

Table 2. Analysis of Variance (ANOVA) of agronomic traits of main crop.

Source	No. of Tiller/Hill	No. of Fertile Tiller/Hill	Days to Flowering	Grain Filling Periods	Days to Maturity	Plant Height (cm)	Panicle Length	Grain/ Panicle	Fertile Grain/ Panicle	Thousand Grain Weight (gm)	Grain Yield/Plant (gm)
Replication	6.91 ***	7.85 ***	1.97 ^{NS}	3.29 **	0.41 ^{NS}	0.74 ^{NS}	2.37 ^{NS}	2.10 ^{NS}	1.58 ^{NS}	3.48 **	5.32 ***
Variety	76.83 ***	52.18 ***	141.67 ***	9.38 ***	160.95 ***	189.45 ***	20.37 ***	67.15 ***	76.97 ***	76.63 ***	82.69 ***

Note: The F values represented by ^{NS} = Non-significant, ** = Significant at 5% level and *** = Significant at 1% level.

Table 3. Analysis of Variance (ANOVA) of agronomic traits of ratoon crop.

Source	No. of Tiller/Hill	No. of Fertile Tiller/Hill	Days to Flowering	Grain Filling Periods	Days to Maturity	Plant Height (cm)	Panicle Length	Grain/ Panicle	Fertile Grain/ Panicle	Thousand Grain Weight (gm)	Grain Yield/Plant (gm)
Replication	6.86 ***	5.91 ***	3.11 **	0.37 ^{NS}	2.31 ^{NS}	0.78 ^{NS}	1.42 ^{NS}	0.27 ^{NS}	1.17 ^{NS}	2.64 **	1.10 ^{NS}
Variety	47.83 ***	35.34 ***	425.32 ***	22.25 ***	470.20 ***	108.38 ***	39.68 ***	15.10 ***	27.18 ***	73.35 ***	30.14 ***

Note: The F values represented by ^{NS} = Non-significant, ** = Significant at 5% level and *** = Significant at 1% level.

Table 4. Duncan Multiple Range Test (DMRT) of agronomic traits of main crop.

Genotypes	No. of Tiller/Hill	No. of Fertile Tiller/Hill	Days to Flowering	Grain Filling Periods	Days to Maturity	Plant Height (cm)	Panicle Length	Grain/ Panicle	Fertile Grain/Panicle	Thousand Grain Weight (gm)	Grain Yield/Plant (gm)
E1	16.2 gf	15.4 cde	82.4 h	6.8 cdefgh	103.6 efg	68.0 j	15.8 hi	64.2 ghi	54.6 f	17.5 h	14.1 ij
E2	18.0 ef	16.2 bcd	91.2 ef	7.8 bc	115.8 a	73.4 h	20.4 cde	142.6 a	98.2 a	19.3 fg	29.4 d
E3	15.2 gh	13.8 efg	92.4 de	7.6 bcd	114.2 bc	83.8 cd	21.2 bcd	113.0 b	91.8 b	30.0 a	34.0 c
E4	11.8 jk	10.4 hi	86.0 g	6.4 defgh	113.6 bc	77.6 ef	16.2 ghi	108.4 b	83.8 c	29.3 a	24.7 e
E8	16.2 gf	12.8 fg	79.4 i	7.8 bc	97.6 h	87.8 b	15.4 i	62.8 hij	50.6 fg	21.5 de	14.8 hij
E9	12.0 jk	9.8 i	87.2 g	11.0 a	115.2 ab	72.6 h	22.8 b	55.6 ijkl	46.2 ghi	14.0 i	6.9 l
E11	24.8 b	22.4 a	85.8 g	5.8 gh	104.4 def	64.2 k	16.6 ghi	66.6 fgh	48.4 fg	15.2 i	17.6 ghi
E12	20.2 d	16.8 bcd	85.8 g	5.6 h	104.6 def	73.2 h	20.2 cde	92.2 c	83.8 c	26.4 bc	38.0 b
E13	26.6 a	24.2 a	95.4 c	6.8 cdefgh	113.0 c	79.2 e	21.2 bcd	77.8 de	64.6 e	27.2 b	42.1 a
E14	22.0 c	17.8 b	86.8 g	8.0 bc	104.8 de	70.6 i	22.0 bc	63.8 ghi	47.8 fgh	21.0 de	17.8 gh
E15	26.6 a	23.4 a	81.0 hi	6.2 efgh	93.8 i	72.8 h	17.6 fgh	60.4 hijk	48.6 fg	19.3 fg	21.5 ef
E16	13.8 hi	12.0 gh	103.2 a	8.2 b	116.2 a	85.0 c	25.4 a	72.6 efg	60.8 e	17.3 h	12.9 jk
E18	13.0 ij	10.6 hi	81.0 hi	7.4 bcde	103.2 efg	76.0 fg	19.0 ef	52.8 kl	44.6 ghij	21.1 de	10.5 k
E19	7.8 l	5.4 j	90.4 f	6.0 fgh	105.4 d	84.8 c	20.3 cde	46.4 l	35.6 k	20.5 ef	5.0 l
E20	11.0 k	7.2 j	80.6 i	7.2 bcdef	103.0 fg	96.0 a	21.8 bc	50.2 l	40.4 ijk	18.7 gh	5.6 l
E21	8.6 l	6.8 j	86.0 g	7.0 bcdefg	102.4 g	96.0 a	17.8 fg	53.8 jkl	38.6 jk	21.4 de	5.4 l
E22	11.4 jk	9.4 i	85.8 g	7.0 bcdefg	104.0 defg	88.0 b	15.8 hi	47.8 l	37.2 k	21.8 de	6.7 l
E25	17.2 ef	15.4 cde	93.4 d	7.4 bcde	112.6 c	68.6 j	17.0 ghi	53.0 kl	41.4 hijk	22.4 d	15.7 ghij
E31	14.0 hi	12.4 gh	95.6 c	7.0 bcdefg	113.8 bc	73.4 h	19.1 ef	49.4 l	35.8 k	15.1 i	6.8 l
E32	16.4 gf	14.8 def	101.4 b	6.2 efgh	113.6 bc	82.2 d	17.8 fg	85.8 cd	72.4 d	22.4 d	23.2 e
E35	19.0 de	17.6 bc	85.8 g	7.2 bcdef	114.0 bc	75.6 g	20.7 cde	61.6 hijk	49.4 fg	20.9 de	18.5 fg
E37	17.6 ef	15.2 de	93.2 d	8.2 b	115.0 ab	62.6 k	19.4 def	75.4 ef	61.2 e	25.0 c	23.3 e

Note: Means with the same letter are not significantly different at 5% level.

Table 5. Duncan Multiple Range Test (DMRT) of agronomic traits of ratoon crop.

Genotypes	No. of Tiller/Hill	No. of Fertile Tiller/Hill	Days to Flowering	Grain Filling Periods	Days to Maturity	Plant Height (cm)	Panicle Length	Grain/ Panicle	Fertile Grain/Panicle	Thousand Grain Weight (gm)	Grain Yield/Plant (gm)
E1	9.8 def	7.0 de	35.8 b	3.0 gh	46.0 b	20.8 cd	11.7 abc	9.2 hi	5.6 cdefg	7.5 l	0.6 cd
E2	0.0 m	0.0 j	0.0 k	0.0 i	0.0 k	0.0 i	0.0 g	0.0 j	0.0 h	0.0 m	0.0 e
E3	9.0 efg	6.0 efg	37.6 a	3.6 fgh	47.6 a	24.2 b	12.3 ab	11.2 fghi	7.0 c	14.9 bc	0.6 cd
E4	8.0 fgh	6.0 efg	25.6 d	5.0 cd	35.6 de	21.2 cd	11.5 abc	9.2 hi	6.0 cdef	19.3 a	1.2 b
E8	11.2 cd	6.6 ef	25.4 de	4.4 cdef	34.6 efgh	19.4 d	10.6 cd	20.8 a	14.8 a	11.9 efgh	1.4 b
E9	7.6 ghi	5.2 efgh	24.2 fg	3.6 fgh	34.8 defg	17.0 e	11.1 bcd	11.4 efghi	4.6 defg	7.2 l	0.6 cd
E11	13.0 c	8.6 cd	28.2 c	6.0 b	40.0 c	13.6 f	9.1 e	12.6 cdefgh	6.2 cde	10.6 hi	0.6 cd
E12	13.0 c	9.4 c	24.2 fg	2.6 h	34.6 efgh	23.8 b	10.8 bcd	12.4 cdefgh	5.4 cdefg	8.6 kl	0.7 cd
E13	16.4 ab	15.2 a	24.8 def	3.4 fgh	33.0 i	23.6 b	12.7 a	18.2 ab	11.4 b	16.1 b	3.4 a
E14	10.6 de	6.6 ef	22.2 h	4.0 efg	34.6 efgh	19.4 d	11.5 abc	12.0 defgh	6.4 cd	9.1 jk	0.7 cd
E15	9.2 efg	6.4 ef	25.4 de	5.0 cd	36.0 d	20.6 cd	11.4 abc	15.0 cd	6.2 cde	12.1 efgh	0.8 cd
E16	5.4 kl	3.8 hi	28.2 c	7.2 a	41.0 c	10.6 g	7.1 f	8.6 i	4.0 g	7.5 l	0.6 cd
E18	5.6 jkl	3.6 hi	21.2 hi	5.2 bc	34.6 efgh	33.4 a	11.9 abc	14.8 cde	6.8 c	13.7 cd	0.6 cd
E19	4.4 l	3.0 i	24.6 def	4.8 cde	34.2 fghi	23.6 b	12.8 a	10.2 ghi	4.6 defg	10.1 ij	0.5 cd
E20	5.4 kl	3.6 hi	23.4 g	3.6 fgh	33.4 hi	21.4 cd	11.6 abc	14.0 cdef	6.4 cd	12.7 def	0.7 cd
E21	7.4 ghij	5.0 fgh	25.4 de	3.6 fgh	34.2 fghi	22.2 bc	11.6 abc	12.2 cdefgh	4.8 defg	11.2 ghi	0.6 cd
E22	10.0 de	6.2 efg	20.8 i	3.4 fgh	33.6 ghi	13.6 f	6.9 f	12.0 defgh	4.2 fg	8.1 kl	0.6 cd
E25	12.4 c	9.2 c	24.4 efg	4.2 def	35.4 def	21.0 cd	9.9 de	15.6 bc	6.0 cdef	12.2 efg	0.8 cd
E31	6.8 hijk	4.4 ghi	24.8 def	3.6 fgh	35.0 def	16.2 e	11.4 abc	12.8 cdefg	4.6 defg	9.1 jk	0.5 d
E32	6.0 ijkl	4.0 hi	24.4 efg	3.4 fgh	34.4 efgh	12.8 f	9.1 e	11.6 defghi	4.2 fg	8.5 kl	0.9 c
E35	17.2 a	12.2 b	21.6 hi	6.0 b	34.4 efgh	13.4 f	9.1 e	12.2 cdefgh	4.4 efg	11.4 fghi	0.8 cd
E37	15.2 b	13.4 b	16.0 j	4.8 cde	31.6 j	8.0 h	6.7 f	15.0 cd	4.6 defg	13.0 de	1.3 b

Note: Means with the same letter are not significantly different at 5% level and Entry 2 did not produce ratoon tiller.

Table 6. Correlations of agronomic traits of main crop.

Traits	No. of Tiller/Hill	No. of Fertile Tiller/Hill	Days to Flowering	Grain Filling Periods	Days to Maturity	Plant Height (cm)	Panicle Length	Grain/ Panicle	Fertile Grain/Panicle	Thousand Grain Weight (gm)
No. of Fertile Tiller/Hill	0.97 ***									
Days to Flowering	0.02	0.08								
Grain Filling Periods	0.18	0.20	0.06							
Days to Maturity	0.11	0.03	0.74 ***	0.30						
Plant Height (cm)	0.54	0.57	0.05	0.04	0.21					
Panicle Length	0.01	0.03	0.39	0.36	0.40	0.10				
Grain/Panicle	0.21	0.25	0.25	0.02	0.42	0.15	0.12			
Fertile Grain/Panicle	0.23	0.27	0.27	0.06	0.41	0.15	0.15	0.95 ***		
Thousand Grain Weight (gm)	0.07	0.08	0.09	0.23	0.14	0.12	0.06	0.47	0.56	
Grain Yield/Plant (gm)	0.64 **	0.66 **	0.23	0.20	0.25	0.29	0.11	0.72 **	0.80 ***	0.66 **

Note: ** = Significant at 5% level and *** = Significant at 1% level.

Table 7. Correlations of agronomic traits of ratoon crop.

Traits	No. of Tiller/Hill	No. of Fertile Tiller/Hill	Days to Flowering	Grain Filling Periods	Days to Maturity	Plant Height (cm)	Panicle Length	Grain/ Panicle	Fertile Grain/Panicle	Thousand Grain Weight (gm)
No. of Fertile Tiller/Hill	0.93 ***									
Days to Flowering	0.26	0.17								
Grain Filling Periods	0.28	0.22	0.38							
Days to Maturity	0.37	0.27	0.95 ***	0.53						
Plant Height (cm)	0.11	0.07	0.56	0.17	0.54					
Panicle Length	0.25	0.21	0.71 **	0.25	0.70 **	0.81 ***				
Grain/Panicle	0.52	0.50	0.33	0.30	0.41	0.43	0.52			
Fertile Grain/Panicle	0.41	0.36	0.39	0.18	0.36	0.48	0.49	0.72 **		
Thousand Grain Weight (gm)	0.43	0.44	0.45	0.42	0.49	0.58	0.59	0.53	0.56	
Grain Yield/Plant (gm)	0.52	0.63 **	0.13	0.08	0.13	0.21	0.29	0.53	0.63 **	0.54

Note: ** = Significant at 5% level and *** = Significant at 1% level.

3.3. Days to Flowering

The range of days to flowering was 79.4 ± 1.36 (Entry 8) to 103.2 ± 0.37 (Entry 16) for the main crop, while, for the ratoon crop, it was 16.0 ± 0.45 (Entry 37) to 37.6 ± 0.25 (Entry 3). The DMRT represented the similar group (Group a) for main crop (Entry 16) and ratoon crop (Entry 3) while different groups for the main crop (Entry 8, Group i) and ratoon crop (Entry 37, Group j). The differences of replications of the main crop were non-significant (1.97 ^{NS}) while for the ratoon crop, it was significantly different (3.11 **) but in both cases (main crop, 141.67 *** and ratoon crop, 425.32 ***) the entries was significantly different. For both crops (main and ratoon crop) the flowering days was positively correlated with all the studied traits but the flowering days of main crops demonstrated significant positive correlation with days to maturity (0.74 ***) while the flowering days of ratoon crop exhibited significant positive correlation with days to maturity (0.95 ***) and panicle length (0.71 **).

3.4. Grain Filling Periods

The grain filling periods for the main crop was 5.6 ± 0.25 (Entry 12) to 11.0 ± 0.45 (Entry 9), while, for the ratoon crop, it was 2.6 ± 0.25 (Entry 12) to 7.2 ± 0.37 (Entry 16). The Entry 9 of main crop and Entry 16 of ratoon crop was placed in the same group (Group a) while Entry 12 for both crop was in lowest group (Group h) for the lowest grain filling periods by DMRT. The replications for grain-filling periods were significantly different for main crop (3.29 **) but non-significantly differ (0.37 ^{NS}) for ratoon crop while the entries was significantly different in both (main crop, 9.38 *** and ratoon crop, 22.25 ***) crops. The grain filling periods of main crop was positively correlated with days to maturity (0.30) and panicle length (0.36) but negatively correlated with all other traits, while, for the ratoon crop, it was positively correlated with all studied.

3.5. Days to Maturity

The range of days to maturity was 93.8 ± 0.58 (Entry 15) to 116.2 ± 0.80 (Entry 16) for the main crop while for ratoon crop it was 31.6 ± 0.51 (Entry 37) to 47.6 ± 0.51 (Entry 3). The DMRT represented the similar group (Group a) for the main crop (Entry 16) and the ratoon crop (Entry 3) while different for groups from the main crop (Entry 15, Group i) and ratoon crop (Entry 37, Group j). The differences of replications of the main crop (0.41) and ratoon crop (2.31) were non-significant but, in both cases (main crop, 160.95 *** and ratoon crop, 470.20 ***), the entries was significantly different.

The days to maturity of main crop was negatively correlated with plant height (−0.21) and ratoon crop was positively correlated with plant height (0.54) and panicle length (0.70) while other traits was positively correlated with the days to maturity of main and ratoon crop.

3.6. Plant Height

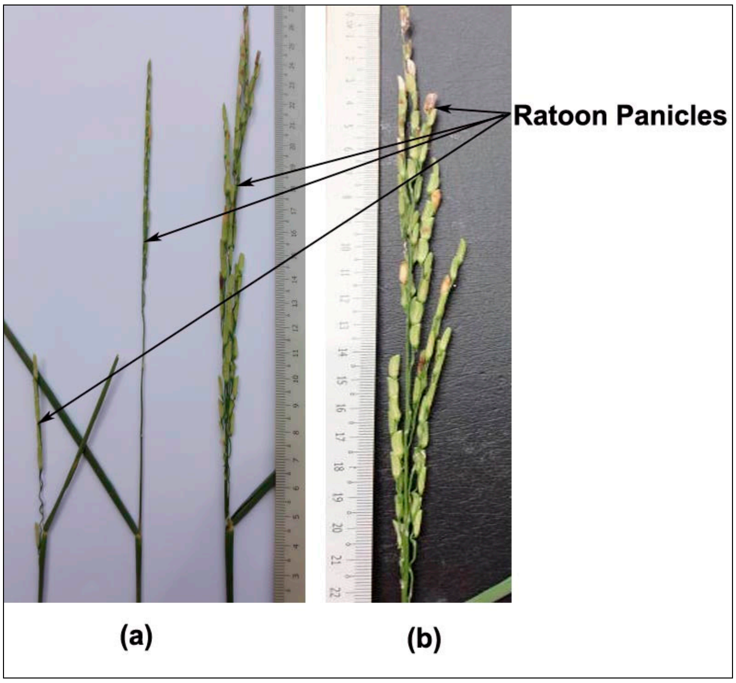
The plant height of the main crop was maximum 96 cm for Entry 20 (96.0 ± 0.71) and Entry 21 (96.0 ± 0.45) while for ratoon crop it was 33.4 cm in Entry 18 (33.4 ± 0.51). The minimum plant height was observed 62.6 cm (62.6 ± 0.68) for main crop and 8 cm (8.0 ± 0.32) for ratoon crop in Entry 37. The DMRT represented same group (Group a) for Entry 20 and Entry 21 as main crop and

Entry 18 as ratoon crop, while Entry 37 falls in a different group than the main crop (Group k) and ratoon crop (Group h). For main crop and ratoon crop, the replication difference was non-significant (0.74 ^{NS} and 0.78 ^{NS}) but the entries differences were significant (189.45 *** and 108.38 ***). Plant height was positively correlated with panicle length (0.10) and thousand-grain weight (0.12) but negatively correlated with other traits in main crop while it demonstrated positive correlation with all the studied traits in the ratoon crop.

3.7. Panicle Length

The panicle length of the main crop was 15.4 ± 0.68 (Entry 8) to 25.4 ± 0.51 cm (Entry 16) while, for ratoon crop, it was 6.7 ± 0.24 (Entry 37) to 12.8 ± 0.47 cm (Entry 19). The lowest panicle length (6.7 ± 0.24 cm) was observed in Entry 37 (Figure 1a) and the higher panicle length (12.7 ± 0.49 cm) were observed in Entry 13 (Figure 1b) while most of the entries demonstrated medium panicle length (10 to 11 cm) (Figure 1a).

Figure 1. Different types of panicle length of ratoon crop: (**a**) shows ratoon rice panicles with different length and (**b**) demonstrate best panicle with grain and length.



The Entry 16 of main crop and Entry 19 of ratoon crop was placed in the same group (Group a) while Entry 8 of main crop fall in different group (Group i) and Entry 37 of ratoon crop in another group (Group f) by DMRT. The replications for panicle length were non-significantly different for main crop (2.37) and ratoon crop (1.42) while the entries was significantly different in both (main crop, 20.37 *** and ratoon crop, 39.68 ***) crops. The panicle length of main crop was negatively correlated with number of tillers per hill (−0.01), number of fertile tillers per hill (−0.03), and thousand-grain weight (−0.06), but positively correlated with all other traits, while for ratoon crop it was positively correlated with all studied traits and significantly positive correlation was observed days to flowering (0.71 **), days to maturity (0.70 **), and plant height (0.81 ***).

3.8. Grain per Panicle

The maximum number of grain per panicle for main crop was observed in Entry 2 (142.6 ± 6.76), which was positioned in Group a (DMRT), and minimum number of grain per panicle was in Entry 19 (46.4 ± 3.25) was placed in Group l (DMRT). The differences between replications (2.10) was non-significant but the entries (67.15 ***) was significantly different and the number of grain per panicle demonstrated significant positive correlation with fertile grain per panicle (0.95 ***) and grain yield per plant (0.72 **), while negative correlation with grain filling periods (−0.02) and plant height (−0.15).

For ratoon crop, the maximum number of grain per panicle was observed in Entry 8 (20.8 ± 1.07) and minimum number of grain per panicle in Entry 16 (8.6 ± 0.51). DMRT also confirmed the position in the different groups of Entry 8 (Group a) and Entry 16 (Group i). The replication differences were non-significant (0.27 ^{NS}), while significant differences were observed among the entries (15.10 ***). The number of grain per panicle represented significant positive correlation with fertile grain per panicle (0.72 **) and positive correlation with all other traits.

3.9. Fertile Grain per Panicle

The number of fertile grain per panicle was 35.6 ± 2.06 (Entry 19) to 98.2 ± 3.17 (Entry 2) for the main crop while for ratoon crop it was 4.0 ± 0.32 (Entry 16) to 14.8 ± 0.86 (Entry 8). The Entry 2 of main crop and Entry 8 of ratoon crop was placed in the same group (Group a) while Entry 19 of the main crop falls in different group (Group k) and Entry 16 of ratoon crop fall in another group (Group g) by DMRT. The replications for number of fertile grain per panicle was non-significantly differ for both the main (1.58 ^{NS}) and ratoon (1.17 ^{NS}) crop while the entries was significantly different in both (main crop, 76.97 *** and ratoon crop, 27.18 ***) crops. The number of fertile grain per panicle of main crop demonstrated significant positive correlation with grain per panicle (0.72 **) and grain yield per plant (0.80 ***), but negative correlation with number of tillers per plant (−0.23), grain filling periods (−0.06) and plant height (−0.15), while for ratoon crop it was positively correlated with all studied traits and significantly positive correlated with grain per panicle (0.72 **) and grain yield per plant (0.63 **).

3.10. Thousand Grain Weight

The thousand-grain weight of the main crop was 13.9 ± 0.49 (Entry 9) to 30.0 ± 1.02 gm (Entry 2) while for ratoon crop it was 7.2 ± 0.54 (Entry 9) to 19.3 ± 1.47 gm (Entry 4). The Entry 3 of main crop and Entry 4 of ratoon crop were placed in the same group (Group a) while Entry 9 falls in a different group than the main crop (Group i) and ratoon crop (Group l). The replications and entries for thousand-grain weight were significantly different for main crop (3.48 ** and 76.63 ***) and ratoon crop (2.64 ** and 73.35 ***). The thousand-grain weight was negatively correlated with grain filling periods (−0.23) and panicle length (−0.06) but positively correlated with all other traits for the main crop, while for ratoon crop it was positively correlated with all studied traits.

3.11. Grain Yield per Plant

The maximum grain yield per plant for main crop was observed in Entry 13 (42.1 ± 1.20 gm), which was positioned in Group a (DMRT) and minimum grain yield per plant was in Entry 19 (5.0 ± 0.31 gm) was placed in Group l (DMRT). The replications (5.32 ***) and the entries (82.69 ***) were significantly different. The grain yield per plant demonstrated significant positive correlation with number of tillers per hill (0.64 **), number of fertile tillers per hill (0.66 **), grain per panicle (0.72 **), fertile grain per panicle (0.80 ***) and thousand-grain weight (0.66 **) while negative correlation with grain filling periods (−0.20) and plant height (−0.29).

In case of the ratoon crop, the maximum grain yield per plant was observed in Entry 13 (3.4 ± 0.28 gm) and minimum grain yield per plant in Entry 31 (0.5 ± 0.03 gm). DMRT also confirmed the position in different group of Entry 13 (Group a) and Entry 31 (Group d). There were no significant differences among the replications (1.10 ^{NS}) but the entries were significantly different (30.14 ***) for grain yield per plant of ratoon crop. The grain yield per plant represented significant positive correlation with number of fertile tillers per hill (0.63 **) and fertile grain per panicle (0.63 **) while no negative correlation was observed with any of the trait.

4. Discussion

The average number of tillers per hill for main crop (16.34 ± 5.38) was reduced for the ratoon crop (9.70 ± 3.93) for all the studied entries which is similar to the observation of Maqsood *et al.* [19] while the average number of fertile tiller per hill for main crop (14.08 ± 5.29) also reduced in ratoon crop (6.92 ± 3.56) as the observation of Bollich and Turner [8], who mentioned that the ratoon crop produce less tiller than the main crop. The average days to flowering, grain filling periods and days to maturity for main crop (88.63 ± 6.50, 7.21 ± 1.36 and 108.35 ± 6.54) also shortened for ratoon crop (25.15 ± 4.62, 4.30 ± 1.28 and 36.12 ± 4.12), which is the same observation of Santos *et al*. [20] and Haque and Coffman [21], while Jones and Snyder [22] also mentioned that the ratoon rice needs very short growth duration usually 35% to 60% less than the main crop. The average plant height of the main crop (77.79 ± 9.17 cm) was greater than the average plant height of ratoon crop (19.04 ± 5.81 cm) which was previously mentioned by Zandstra and Samson [23], afterward Mengel and Wilson [24], while Jones [25] identified the less ability of using resources of ratoon plant. The average panicle length, grain per panicle and fertile grain per panicle of ratoon crop (10.52 ± 2.03 cm, 12.90 ± 3.56 and 6.10 ± 2.75) was less than the main crop (19.27 ± 2.84 cm, 70.74 ± 24.86 and 56.17 ± 18.95) as the statement of Evatt and Beachell [26], Akhgari *et al*. [27], and Birhane [28]. The average thousand-grain weight and grain yield per plant was higher in main crop (21.23 ± 4.37 gm and 17.92 ± 10.92 gm) than the ratoon crop (11.19 ± 3.20 gm and 0.87 ± 0.66 gm), while Kasturi and Purushothaman [29], Fageria *et al*. [30], Choi and Kwon [31], Hsieh and Young [32], and Szokolay [33] also observed the reduction of yield and yield related traits in ratoon crop.

Sadeghi [34] and Ranawake *et al*. [35] observed that the number of fertile tillers and number of grain per panicle had direct effect on grain yield per plant which also observed in the present investigation. The grain yield per plant was significantly and positively correlated with number of tiller per hill, number of fertile tiller per hill, grain per panicle, fertile grain per panicle and thousand-grain weight of both the main and ratoon crop. Ranawake *et al*. [35] observed negative correlation of plant height with thousand-grain weight but in the present study, both the main and ratoon crop demonstrated positive correlation of plant height with thousand-grain weight. Previously, Beser and Genctan [36], and later on Aide and Beighly [37] mentioned that plant height might be affected by plantation method, plant density and fertilizer application. Surek [38] and Ghosh *et al*. [39] mentioned that fertile tiller number and grain number per panicle affected by the environmental and cultivation factors which have great effect on grain yield while in this study, significant positive correlation of grain yield per plant was observed with most of the yield related traits in main and ratoon crop. Oad *et al*. [40] observed fewer effective tillers in ratoon crop compared to main crop, while Reddy and Pawar [41] observed lower performance of most of the traits in ratoon crop compared to the main crop which also observed in the present study. However, considering the cost, duration and management practice of rice ratoon crop, the production might be satisfactory for the marginal farmers of the hill region for using the same field within the short duration which will provide extra gain for sustainable rice production in tropical hill area.

5. Conclusions

Rice ratooning is not a new concept for the rice breeder, but evaluating high yielding main crop and ratoon crop variety has a great prospect for tropical hill agriculture. The marginal farmer of Malaysian hill area leave the field abandoned after harvesting the main crop and if they collect ratoon crop without any cultural practice, they can collect at least 8% grain Yield/Plant from Entry 13. In this experiment, for ratoon crop any intercultural operation such as weeding, pesticide and fertilizer did not follow to observe the real scenario of ratoon crop productivity at zero cost level. However, it is expected higher yield in good management practice, specially the vegetative and reproductive performance of Entry 13 ratoon's can ensure higher yield. The Entry 13 can be a suitable rice variety as both main and ratoon crop for sustainable rice production in tropical agro-ecological environment.

Acknowledgments

The authors are deeply thankful to the International Rice Research Institute (IRRI, Los Baños, Laguna, Philippines), Malaysian Agricultural Research Development Institute (MARDI), International Centre for Tropical Agriculture (CIAT, Cali, Colombia), West African Rice Development Association (WARDA, Cotonou, Benin), International Institute of Tropical Agriculture (IITA, Ibadan, Oyo State, Nigeria), Senegal, Mayanmar and Argentina for providing research materials. They are also grateful to the Ministry of Higher Education Malaysia (MOHE) and University of Malaya, Kuala Lumpur for providing research facilities and grant (IPPP PV044-2011A) during these investigation.

Author Contributions

Golam Faruq has planed, analyzed results and helps to write this article as a supervisor. Rosna Mat Taha has advised, corrected and contributed to complete the experiment. Zakaria Hossain Prodhan participated in the research, collected data and did data analysis.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Sung, C.T.B. Will Malaysia achieve 100% self-sufficiency in rice by 2015? Available online: http://christopherteh.com/blog/2010/07/will-malaysia-achieve-100-self-sufficiency-in-rice-by-2015/(accessed on 20 December 2013).
2. Daño, E.C.; Samonte, E.D. Public sector intervention in the rice industry in Malaysia. In *State Intervention in the Rice Sector in Selected Countries: Implications for the Philippines*; Southeast Asia Regional Initiatives for Community Empowerment (SEARICE) and Rice Watch and Action Network (R1): Quezon City, Philippines, 2005; pp. 187–216.
3. Department of Statistics, Malaysia. *Year Book of Statistics*; Department of Statistics: Kuala Lumpur, Malaysia, 2009; pp. 1–351.
4. American Society of Agronomy. Decision reached on sustainable agriculture. *Agronomy News*, January 1989, p. 15.
5. Congress of U.S. *Food*, *Agriculture*, *Conservation*, *and Trade Act of 1990*; Department of Justice: Washington, DC, USA, 1990; pp. 101–624.
6. Mahadevappa, M. Rice ratooning practices in India. In *Rice Ratoon*; International Rice Research Institute: Manila, Philipine, 1988; pp. 69–78.
7. Rehman, H.; Farooq, M.; Basra, S.M.A. Rice Ratooning: A Technology to Increase Production; Available online: http://www.pakissan.com/english/advisory/rice.ratooning.technology.to.increase.production.shtml (accessed on 23 December 2013).
8. Bollich, C.; Turner, F. Commercial ratoon rice production in Texas, USA. In *Rice Ratoon*; International Rice Research Institute: Manila, Philippines, 1988; pp. 257–264.
9. Sarian, Z. Ratooning rice is advantageous. Avaiable online: http://www.agripinoy.net/ratooning-rice-is-advantageous.html (accessed on 26 December 2013).
10. How, T.J. Cross compatibility in Aromatic Rice. Bachelor's Thesis, University of Malaya, Kuala Lumpur, Malaysia, 2011.
11. Chatterjee, B.N.; Maiti, S. Principles & practices of rice growing. In *Principles and Practices of Rice Growing*, 2nd ed.; Kolkata Oxford and India Book House: Calcutta, India, 1981; p. 314.
12. Datta, D. *Principles and Practices of Rice Production*; International Rice Research Institute: Manila, Philipine, 1981; p. 618.
13. Bardenas, E.A.; Chang, T.-T. *Morphology and Varietal Characteristics of the Rice Plant*; International Rice Research Institute: Manila, Philipine, 1965; p. 40.
14. Harrell, D.L.; Bond, J.A.; Blanche, S. Evaluation of main-crop stubble height on ratoon rice growth and development. *Field Crops Res*. **2009**, *114*, 396–403.
15. SAS Institute. *SAS Software*, version 9.2; SAS Institute: Cary, NC, USA, 2008.
16. Seyoum, M.; Alamerew, S.; Bantte, K. Genetic variability, heritability, correlation coefficient and path analysis for yield and yield related traits in upland Rice (*Oryza sativa* L.). *J. Plant Sci*. **2012**, *7*, 13–22.

17. Hasan, M.; Kulsum, M.; Akter, A.; Masuduzzaman, A.; Ramesha, M. Genetic variability and character association for agronomic traits in hybrid rice (*Oryza sativa* L.). *Bangladesh J. Plant Breed. Genet.* **2013**, *24*, 45–51.
18. Mirhoseini, S.M.; Daliri, M.S.; Moghaddam, M.N.; Mohaddesi, A.; Abbasian, A. Study of agronomic traits in a number of promising rice lines by multivariate statistical methods. *Int. J. Biosci.* **2013**, *3*, 119–125.
19. Maqsood, M.; Irshad, M.; Hussain, M.I.; Rafiq, K. Effect of nitrogen on the growth, yield and quality of fine rice. *Pak. J. Biol. Sci.* **2000**, *3*, 1831–1832.
20. Santos, A.; Fageria, N.; Prabhu, A. Rice ratooning management practices for higher yields. *Commun. Soil Sci. Plant Anal.* **2003**, *34*, 881–918.
21. Mahiul Haque, M.; Coffman, W. Varietal variation and evaluation procedures for ratooning ability in rice. *Sabrao J. Breed. Genet.* **1980**, *12*, 113–120.
22. Jones, D.; Snyder, G. Seeding rate and row spacing effects on yield and yield components of ratoon rice. *Agron. J.* **1987**, *79*, 627–629.
23. Zandstra, H.; Samson, B. Rice Ratoon Management. In Proceedings of the International Rice Research Conference, Manila, Philippine, 16–20 April 1979; pp. 17–21.
24. Mengel, D.; Wilson, F. Water management and nitrogen fertilization of ratoon crop rice. *Agron. J.* **1981**, *73*, 1008–1010.
25. Jones, D.B. Rice ratoon response to main crop harvest cutting height. *Agron. J.* **1993**, *85*, 1139–1142.
26. Evatt, N.S.; Beachell, H. Ratoon cropping of short-season rice varieties in Texas. *Int. Rice Comm. Newsl.* **1960**, *9*, 1–4.
27. Akhgari, H.; Noorhosseini-Niyaki, S.A.; Sadeghi, S.M. Effects of planting methods on yield and yield components of ratoon and main plant of Rice (*Oryza sativa* L.) in Rashy, Iran. *Indian J. Fundam. Appl. Life Sci.* **2013**, *3*, 150–157.
28. Birhane, A. Effect of planting methods on yield and yield components of Rice (*Oryza sativa* L.) varieties in Tahtay Koraro Wereda, Northern Ethiopia. *Int. J. Technol. Enhance. Emerg. Eng. Res.* **2013**, *1*, 1–5.
29. Kasturi, K.; Purushothaman, S. *Varietal and Fertilizer Responses of Ratoon Rice* (*Oryza sativa*); Indian Society of Agronomy, Indian Agricultural Research Institute, Division of Agronomy: New Delhi, India, 1992; Volume 37, pp. 565–566.
30. Fageria, N.K.; Santos, A.B.D.; Baligar, V.C. Phosphorus soil test calibration for lowland rice on an Inceptisol. *Agron. J.* **1997**, *89*, 737–742.
31. Choi, H.; Kwon, Y.; Kwon, Y. Evaluation of varietal difference and environmental variation for some characters related to source and sink in the rice plants. *Korean J. Crop Sci.* **1985**, *30*, 460–470.
32. Hsieh, C.; Young, F. Studies on the cultivation of ratoon. *J. Taiwan Agric. Res.* **1959**, *8*, 31–32.
33. Szokolay, G. Ratooning of rice on the Swaziland irrigation scheme. *World Crops* **1956**, *8*, 71–73.
34. Sadeghi, S.M. Heritability, phenotypic correlation and path coefficient studies for some agronomic characters in land race rice varieties. *World Appl. Sci. J.* **2011**, *13*, 1229–1233.
35. Ranawake, A.; Amarasingha, U.; Dahanayake, N. Agronomic characters of some traditional rice (*Oryza sativa* L.) cultivars in Sri Lanka. *J. Univ. Ruhuna* **2013**, *1*, 3–9.
36. Beser, N.; Genctan, T. Effects of different plantation methods on some agricultural features and productivity in the rice (*Oryza sativa* L.). In Proceedings of the Turkey Third Field Crop Congress, Adana, Turkey, 15–18 November 1999; pp. 462–467.

37. Aide, M.; Beighley, D. Hyperspectral reflectance monitoring of rice varieties grown under different nitrogen regimes. *Trans. Missouri Acad. Sci.* **2006**, *40*, 6–11.
38. Surek, H. *Rice Agriculture*; Harvest Publications Ltd. Co.: Istanbul, Turkey, 2002.
39. Ghosh, M.; Mandal, B.; Mandal, B.; Lodh, S.; Dash, A. The effect of planting date and nitrogen management on yield and quality of aromatic rice (*Oryza sativa*). *J. Agric*. *Sci*. **2004**, *142*, 183–191.
40. Oad, F.; Samo, M.A.; Oad, N.; Chandio, G.; Cruz, P.S. Relationship of Physiological, Growth and Yiedl Contributing Parameters of Locklodged Rice Ratoon Crop. *J. Appl*. *Sci*. **2002**, *2*, 429–432.
41. Reddy, V.; Pawar, M. Studies on ratooning in paddy. *Andhra Agric*. *J*. **1959**, *6*, 70–72.