Effects of Position of Rainfed Rice Field in a Toposequence on Water Availability and Rice Yield in Central Java, Indonesia

Pengaruh Posisi Sawah Tadah Hujan pada Toposekuen Terhadap Ketersediaan Air dan Hasil Padi di Jawa Tengah, Indonesia

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ABSTRACT

The productivity of rainfed rice needs to be increased in order to support the Indonesian Food Security programs, especially rice. Rainfall is one of the main sources of the water availability on the rainfed rice field. This research was conducted from October 2000 to February 2001 at four sites in Central Java Province. The objectives of this research were to study the variability of water availability that influenced by toposequen's position and to analyze the rice yields due to treatments on toposequence. This experiment was carried out in the farmers' field using "Group Balanced Block in Split-Split Plot Design" and Inceptisols soil order. Mainplots were the four positions in toposequence (top, upper middle, lower middle, and bottom), and the four villages were used as replication. The sub-plot was treatments group and sub-sub-plot consists of group-1: farmer's practice and without weeding; group-2: farmer's practice without fertilizer and added recommended fertilizer. The research showed that rainfall affected the fluctuation of ground water table and standing water periods. The straw and unhulled rice/grain yields at the bottom position was the highest, and was significantly different from the top position of the toposequence, namely 7.1 and 5.6 t ha^{-1} for straw yield while 5.2 and 4.0 t ha^{-1} for grain yield. Without weeding, the straw and grain yields decreased by 1.0 t ha^{-1} (6.1 to 5.1 t ha^{-1}) and 0.8 t ha^{-1} (4.6 to 3.8 t ha^{-1}). While, without fertilization, the straw and grain yields were produced only 4.4 and 3.8 t ha^{-1}. Straw and grain yields increased up to 7.0 and 5.1 t ha^{-1}, respectively, when recommended fertilizers were applied.

Key Words : Rainfed rice field, Toposequence, Water availability

ABSTRAK

Dalam rangka mendukung program ketahanan pangan khususnya beras, lahan sawah tadah hujan perlu ditingkatkan produktivitasnya. Curah hujan merupakan salah satu sumber penyediaan air pada lahan ini. Penelitian pengaruh posisi sawah tadah hujan dalam toposekuen terhadap ketersediaan air dan hasil padi telah dilaksanakan dari Oktober 2000 sampai dengan Februari 2001 pada empat lokasi di Jawa Tengah. Penelitian bertujuan mempelajari keragaman ketersediaan air sawah yang dipengaruhi posisi dalam toposekuen dan menganalisis hasil padi pada berbagai perlakuan. Percobaan ini dilakukan di lahan petani pada tanah Inceptisol dan menggunakan rancangan "Group Balanced Block dalam Split-Split Plot Design". Sebagai petak utama adalah empat posisi dalam toposequen (atas, tengah-atas, tengah-bawah, dan bawah) dan sebagai ulangan adalah empat desa yang digunakan. Anak petak adalah dua kelompok perlakuan sedangkan anak-anak petak terdiri atas Kelompok-1: cara petani dan tanpa penyiangan; Kelompok-2: cara petani tanpa pemupukan dan ditambah pemupukan dosis rekomendasi. Hasil penelitian menunjukkan bahwa curah hujan berpengaruh pada perubahan muka air tanah dan lama genangan. Jumlah hari tanpa genangan pada posisi bawah toposekuen paling rendah dibanding posisi lainnya. Hasil jerami dan gabah kering giling pada posisi bawah lebih tinggi dan berbeda nyata daripada posisi atas, yaitu 7,1 dan 5,6 t ha^{-1} untuk hasil jerami dan 5,2 dan 4,0 t ha^{-1} untuk hasil gabah. Tanpa penyiangan, hasil jerami dan gabah turun, masing-masing sampai 1,0 t ha^{-1} (6,1 menjadi 5,1 t ha^{-1}) untuk jerami dan 0,8 t ha^{-1} (4,6 menjadi 3,8 t ha^{-1}). Sedangkan jika tanpa pemupukan, jerami dan gabah yang dihasilkan masing-masing hanya 4,4 dan 3,8 t ha^{-1}. Penggunaan dosis pupuk anjuran dapat menghasilkan jerami dan gabah masing-masing 7,0 dan 5,1 t ha^{-1}.

Kata Kunci : Sawah tadah hujan, Toposekuen, Ketersediaan air

INTRODUCTION

Background

In Indonesia, about 2.1 million ha of rice field is considered as rainfed lowland, and about 35% of that area is located in Java (Amien and Las, 2000). The largest area of rainfed lowland is found in Central Java Province with 293,600 ha or 29.4% of total areas, followed by East Java (252,400 ha or 22,0%) and West Java (240,800 ha or 20.9%). Due to its large area, even with low yield 3.1- 5.0 t ha^{-1} for wet season rice and 1.9-2.8 t ha^{-1} for dry season (Fagi,1995), the rainfed areas in Indonesia still play an important role in the staple food production and employment opportunity for the population. Therefore, increasing the productivity of this land will contribute significantly to the security of food supply, especially rice, in Indonesia.

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According to Zeigler and Puckridge (1995) and Wade *et al.* (1999), rainfed lowlands are defined as having level to slightly sloping bunded fields with non-continous flooding of variable depth duration. IRRI (1984) and Garitty et al. (1986) divided the rainfed lowland rice into five broad categories from the point of view of varietal improvement and crop management. Those are: 1) rainfed shallow; 2) rainfed shallow, drought-prone; 3) rainfed shallow, submergence-prone; 4) rainfed shallow, drought-and submergence-prone; and 5) rainfed medium-deep, waterlogged.

Many factors affect water availability in the soil, such as intensity and distribution of rainfall, soil properties and land position on toposequence or topography. The water availability in the top position of a toposequence may be different from that in the bottom position. The bottom position of the toposequence is expected to have more available nutrients and water compared to the top position because of erosion and water movement from the top to the bottom positions.

Rainfed lowland rice ecosystem in Java such as in Jakenan sub district can be found not only in the plain areas but also in the sloping areas, with slope ranged between 3 and 8%. The rainfed rice ecosystem is distributed from the coastal area to the undulating area with varying rainfall and water availability (Suganda et al., 2001). Jakenan lies on the north side of Java Island. It is one of the areas in Central Java, Indonesia where farmers plant rainfed rice. The following questions were our interest to find out in order to better understand the effects of position of rainfed rice field in a toposequence. Is there any differences in water availability and rice field due to position?

The hypotheses tested in this study were (a) The water availability will be affected by position in a toposequence; (b) Rice yields are strongly affected by water availability and therefore vary with toposequence.

The specific objectives of the study were: to investigate variability of water availability as influenced by position in a toposequence; and to compose the rice yield in some treatments on a toposequence.

MATERIALS AND METHODS

Time and location

The research was conducted at four villages surrounding the Jakenan Experimental Station, Central Java, Indonesia, from October 2000 to February 2001. The villages are Megulung, Jadi (Rembang district), Sidomukti, and Pelemgede (Pati district). Schematic diagram of the experimental field in each sites are presented in Figure 1.

Experimental design

This experiment was carried out in farmer's field using group balanced block in split-split plot design (Gomez and Gomez, 1985). The four sites or villages (Megulung, Jadi, Sidomukti, and Pelemgede) were used as replication. Each replicate was divided into four field positions (top, upper middle, lower middle and bottom) on the toposequence and assigned as main plots (Figure 1). Each main plot was further divided into two sub plots. Group-1 consisted of two treatments: T_1 = Farmers' practice (FP) and T_2 = FP without weeding (FP-W), and Group-2 consisted of two treatments : T_3 = FP without fertilizer (FP-F) and T_4 = FP with recommended fertilizer (FP + IF).

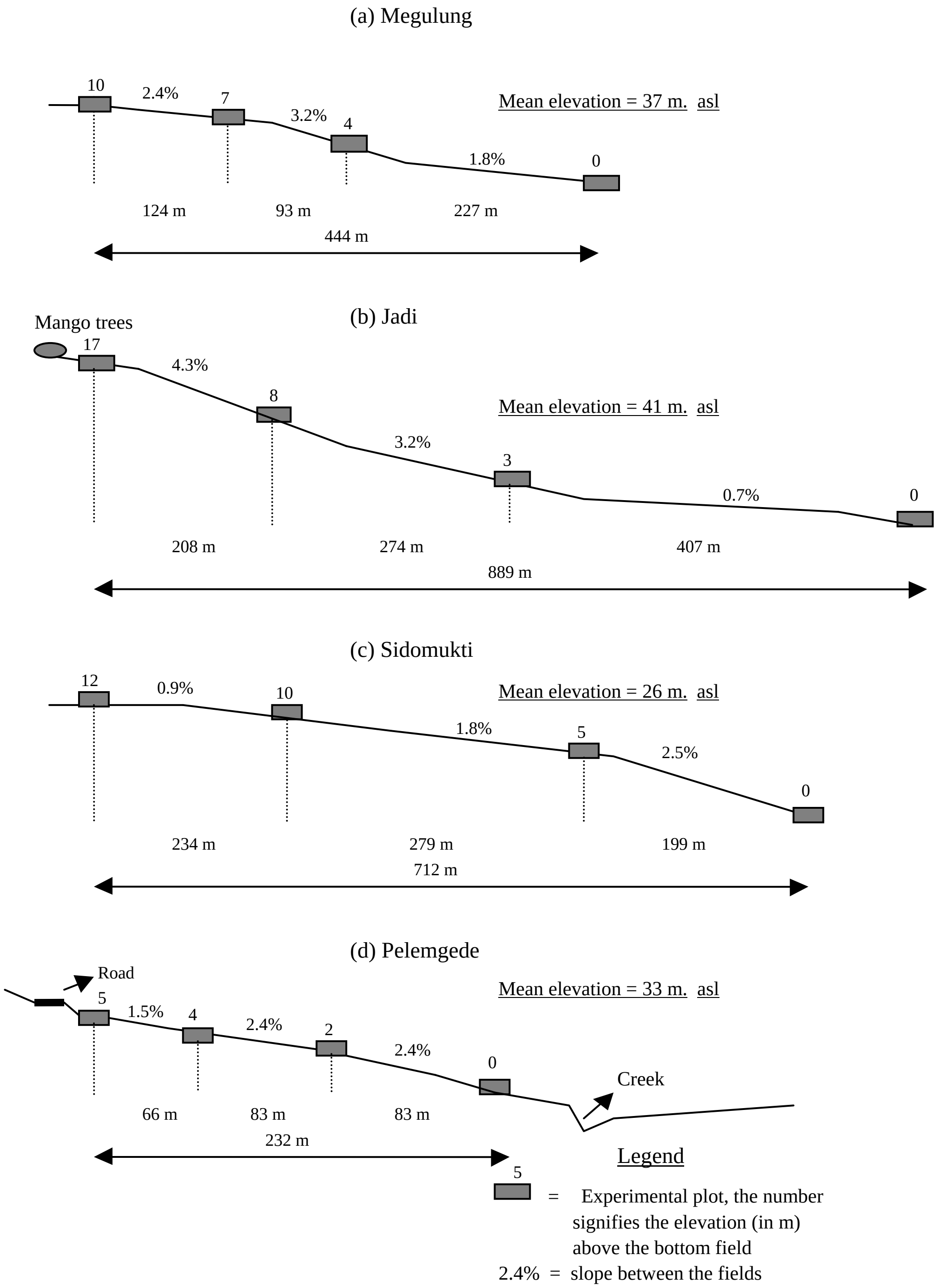


Figure 1. Schematic diagram showing vertical and horizontal distances between the experimental plots across the toposequence at each site

In T_1 all prevailing practices were the same with those were commonly done by the farmer in a farming system, such as in land preparation (implementation, timing), crop establishment, weeding (method, timing) and input use (fertilizer). In T_2 was the same with T_1 treatment, but without weeding only.

In T_3 was the same with T_1 treatment, but without fertilizer application only. In T_4 the following recommended fertilizer rates were applied: Nitrogen (N), 120 kg; Phosphorus (P), 22.5 kg; Potassium (K), 90 kg; and Sulfur (S), 20 kg.

Sources of fertilizer were Urea (45% N), Single Superphosphate (16.5% P_2O_5 = 7.2% P), and Muriate of Potash (60% K_2O = 49.8% K). Fertilizers were applied in three splits. Basal application of ¼ N, all P, ½ K; second application of ½ N and ½ K at maximum tillering; and third application with ¼ N at panicle initiation.

Climate data

Daily temperature data were obtained from climate stations (at the Jakenan Experimental Station) located about 1 to 10 km from the research area. Historic temperature and rainfall data (5 – 10 years) were obtained from the Statistic Office of Pati District (for Sidomukti and Pelemgede) and Sumber subdistrict Office, Rembang District (for Megulung and Jadi).

Standing water layer

Standing water fluctuation or water surface in the rice fields were measured using perched water tubes. The tubes were made from PVC, 20-cm in diameter and 35-cm in length, perforated for easy water movement in the soil. The tubes were installed at a depth of 20 cm below the soil surface and 15 cm above the soil surface.

Perched water

Perched water tubes measured the fluctuation of water surface between 20-cm below the soil surface or up to plow pan layer and 15-cm above the soil surface. The equipment was installed in each experimental field (top, upper middle, lower middle and bottom). Standing water in the field was measured every Monday, Wednesday, and Friday at 7:00 to 8:00 a.m. until rice harvest.

Ground water table

Ground water tube or piezometer measured the fluctuation of ground water table depth. The piezometers were made from PVC pipe, 5 cm in diameter and 150-cm in length, perforated for easy movement of water in the soil. They were installed at a depth of 150 cm below the soil surface and 50 cm above the soil surface

The equipment was installed in each experimental field (top, upper middle, lower middle and bottom). Ground water table was measured every on Monday, Wednesday, and Friday at 7:00 to 8:00 a.m. until rice harvest.

Percolation

The percolation rate in each position (top, middle upper, middle lower, and bottom) on the toposequence was determined with a percolation ring equipment. This was made of a metal ring 20-cm in diameter and 40 cm in height, the top portion of the ring was always covered to avoid evaporation.

The equipment was installed in each experimental field (top, upper middle, lower middle and bottom. Percolation rate was measured every on Monday, Wednesday, and Friday at 7:00 to 8:00 a.m. until rice harvest.

Data analysis

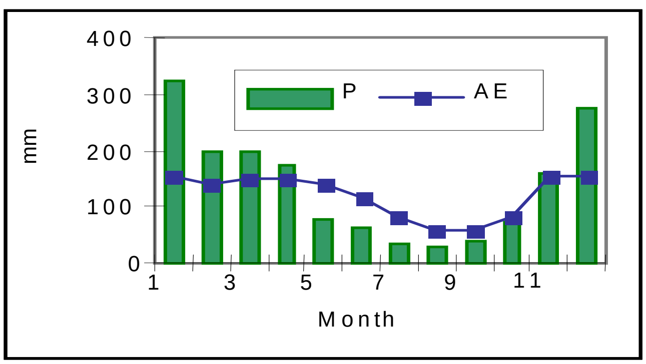
The study utilized group balanced block in split-split plot design, which consists of four replications (assumed Megulung, Jadi, Sidomukti and Pelemgede), four main plots (assumed top, upper middle, lower middle and bottom position on toposequence) two subplots (group 1 and 2) and two sub-sub plots (T_1 and T_2 in group 1; and T_3 and T_4 in group 2). Statistical test used analysis of variance (ANOVA). If the treatments were significantly different, the differences were then analyzed using least significant difference (LSD) test. All statistical analyses were done using SAS for Windows version 6.12 (SAS Institute, 1988).

RESULTS AND DISCUSSION

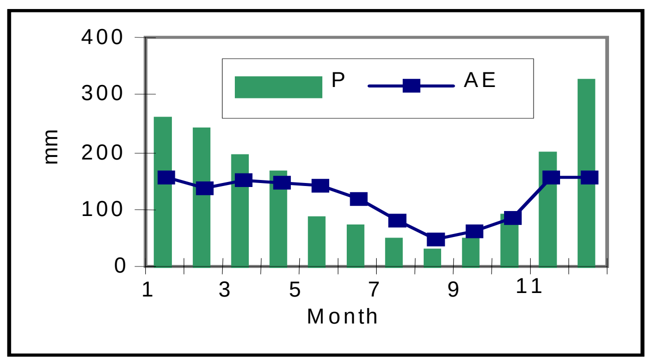
Climate and cropping pattern

According to Oldeman (1975) this area is classified as C4 (It can be planted once with rice and a secondary crop after harvesting rice, but for the second crop must be careful with the time of dry month).

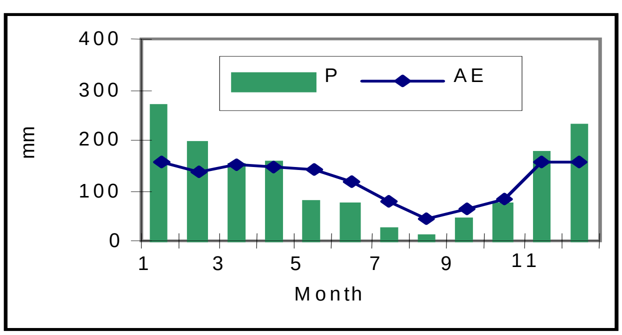
Monthly distribution of rainfall and evapotranspiration in the study sites was presented in Figure 2. Actual evapotranspiration were calculated from Thornthwaite and Mather equation (1957). The average annual rainfall was about 1500-1700 mm. From Figure 2, it can be seen that rainy season (rain > AE) occurred from November to March-April and dry season (rain < AE) from May to October.



a. Megulung and Jadi site



c. Pelemgede site



b. Sidomukti site

Figure 2. Monthly rainfall (P) and actual evapotranspiration (AE) at four sites

Source : Sumber subdistrict office (1985-1990), Statistic office of Pati district (1990-2000)

Table 1. Daily rainfall, day interval without rainfall and daily evaporation in different sites during the experiment (October 2000 to February 2001)

Climate factor		Megulung	Jadi	Sidomukti	Pelemgede
Observation period					
27 Oct'00-13 Feb'01	(day)	110	110	110	110
Rainfall					
Total	(mm)	661.2	633.0	662.3	639.0
Maximum/day	(mm)	52.0	55.0	60.5	48.0
Minimum/day	(mm)	0.5	1.0	1.0	0.5
Mean/day	(mm)	13.3	13.2	14.1	13.8
Stdev	(mm)	13.0	13.5	14.1	13.2
Rainy day	(day)	68	65	65	65
Interval day w/o rain					
Maximum	(day)	9	9	9	9
Minimum	(day)	1	1	1	1
Mean	(day)	1.9	1.6	1.7	1.8
Stdev		1.9	1.6	1.7	1.9
Evaporation (Class A Pan)					
Maximum	(mm day^{-1})	9.8	8.2	8.0	9.5
Minimum	(mm day^{-1})	1.5	1.4	1.4	1.2
Mean	(mm day^{-1})	4.8	4.7	4.8	5.1
Stdev		1.7	1.7	1.6	2.0

Farmers begin land preparation in the rice field in October, when the soil is relatively dry and planting usually starts in November. They expected that the planted rice would grow well because there is an adequate rainfall during the plant growth period (from November to February). However, some farmers start land preparation earlier (August or September) then plant rice in the second or third week of October. They expected to harvest the first rice cropping earlier to give more chance for the secondary cropping to survive from frought. Generally, the cropping pattern in this area is rice-rice; rice-secondary cropping (peanut, mungbean, corn).

Rainfall and evaporation

Rainfall, interval days without rainfall, and evaporation for each site during the experiment are presented in Table 1. The total and maximum daily rainfall values in all sites were almost the same.

During the study, there was a period of 9 days without rainfall. This occurred on 335-344 DOY (day of year) or around December 1 to 10. This condition adversely affected plant growth, because of the shortage of moisture available in the soil. Visually, in the field, especially in the top and upper middle positions in the toposequence at Jadi and the bottom at Pelemgede, the soil was cracked 2-5 cm wide because of excessive drying. Evaporation varied with time from 1.2 to 9.8 mm day^{-1}. The mean did not differ significantly among sites.

Seepage and percolation rate

Seepage and percolation rates in the different sites and toposequence positions are presented in Table 2. In general, seepage and percolation in these areas was < 7 mm day^{-1}. The extreme rate was at the bottom position of Pelemgede, with 22.4 mm day^{-1}. The high seepage and percolation rates caused difficulty in keeping water in the equipment (percolarimeter). Water in the percolarimeter infiltrated almost instantaneously into the soil. This could be explained by the soil physical properties (coarse texture), steeper slope, or the soil being very close to the creek.

The seepage and percolation rates among the site were almost the same, although Jadi had the highest value. There was a tendency for the rates at the bottom position to be lower than those at the top or the upper middle position.

Ground water table and field water depths

Data for ground water table depth at each position along the toposequence at the four sites is presented in Figures 3 and 4. At the four sites (Megulung, Jadi, Sidomukti and Pelemgede), the level of the ground water table was around 20 cm to 40 cm below soil surface. The ground water table was lower than 80 cm from the soil surface when there was no rainfall for 9 days (338-357 DOY), particularly at the upper middle and top positions of the toposequence.

At the bottom position of almost all sites, the ground water table was always close to the soil surface, sometimes even above the soil surface when there was a heavy rainfall or flooding. Except at the bottom position of Pelemgede, probably because the experimental site was close to the creek and the soil was coarse, so the water can easily move to the creek.

At the lower middle position in the toposequence, during most of the growing period, the three sites showed shallower water tables, i.e. the level of ground water was closer to the soil surface than in the upper positions (Figure 3-4). At Jadi, in many days, the water table was even above the soil surface. At the two other sites, the number of days when the water table was above the soil surface was fewer. Interestingly, it was only at Sidomukti where the water table went down to almost 100 cm below the surface of the soil, and this happened at 320 and 345 DOY.

In the lower position in the toposequence, in all three sites, there were many more days when the water table was above the soil surface than below (Figure 3-4). This means flooding. However, there were several days when the water table at Sidomukti went down to as low as 100 cm at about 320 DOY and to 60 cm below the soil surface at about 345 DOY.

Overall, the water table at Megulung was nearer the soil surface in all positions in the toposequence than at the other two sites. The most number of days of flooding occurred at Jadi, followed by Sidomukti, at both the lower middle and bottom positions. On the average, the water tables at Megulung and Sidomukti were farther from the soil surface at the two upper positions than those at Jadi. All these differences can be attributed to the differences in the types of soils that exist in three study sites.

Table 2. Seepage and percolation rates during experiment in four different sites and positions

Toposequence	Megulung		Jadi		Sidomukti		Pelemgede	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
	……… mm day^{-1} ………							
Top	4.2	3.3	4.4	2.9	3.6	2.3	4.3	3.2
Upper middle	1.9	1.9	3.6	3.1	4.6	3.3	4.6	2.9
Lower middle	1.4	1.2	2.0	1.6	3.1	2.3	6.6	10.9
Bottom	1.6	1.0	1.6	2.1	1.8	2.0	22.4	5.7

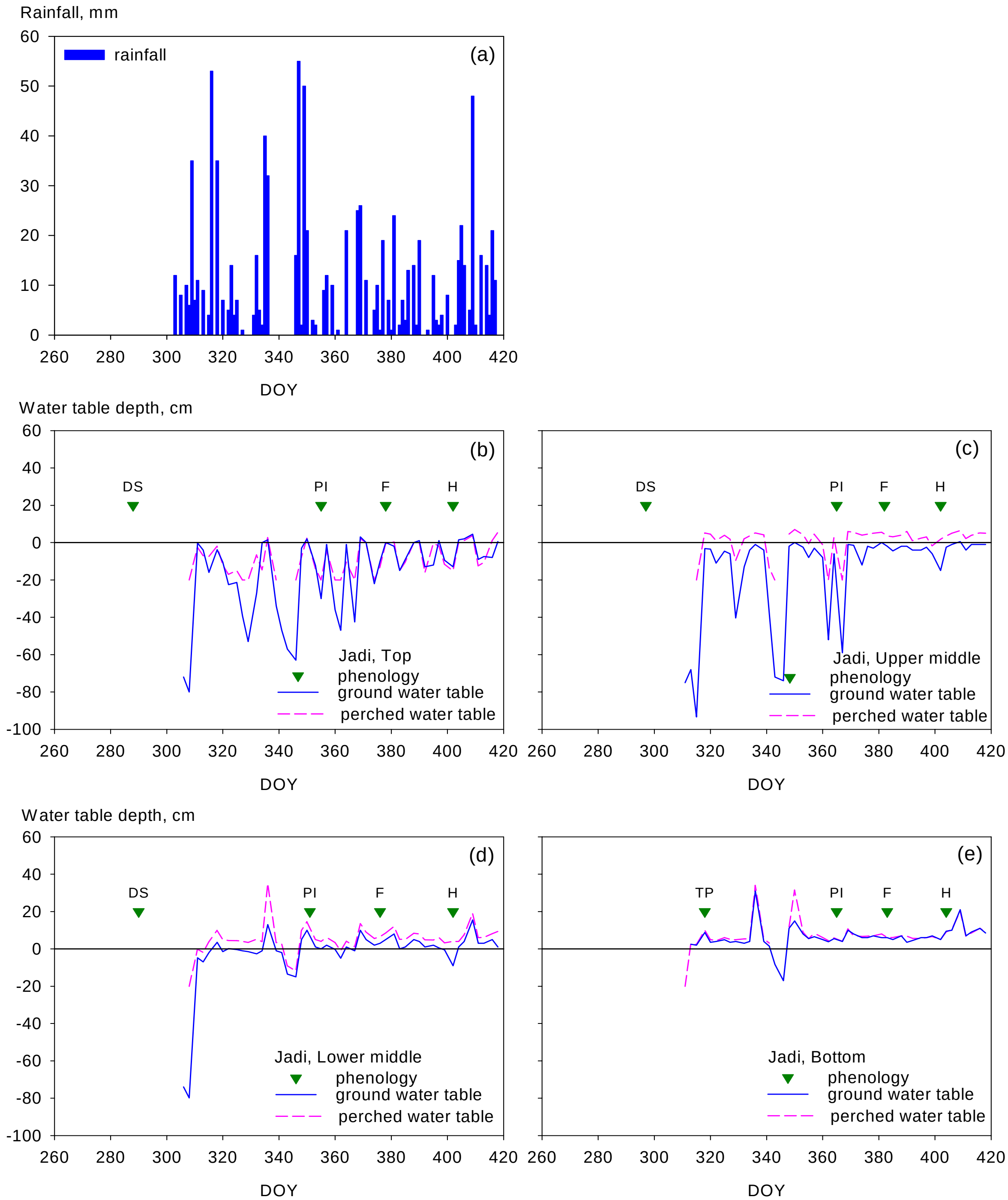


Figure 3. Daily rainfall and ground and perched water table depths in the toposequence at Jadi

Note : DS = Dry seeding, TP = Transplanting, PI = Panicle initiation, F = Flowering, and H = Harvest

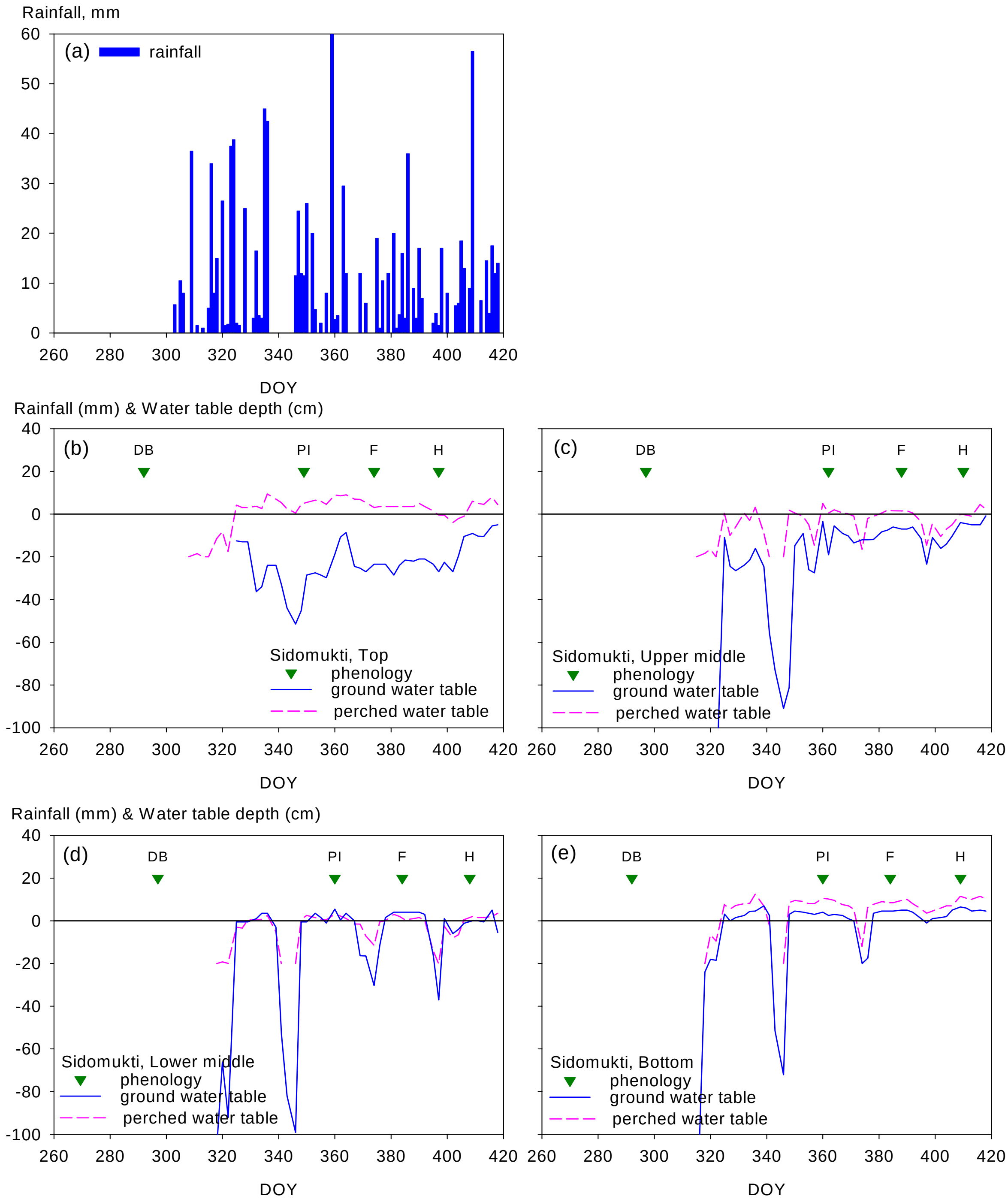


Figure 4. Daily rainfall and ground and perched water table depths in the toposequence at Sidomukti

Note : DB = Dibbling, PI = Panicle initiation, F= Flowering, and H = Harvest

Straw and grain yield

Straw and grain yields based on site, position in the toposequence and treatment were given in Table 3. Straw yield (in 3% mc.) range from 4.4 t ha^{-1} to 7.1 t ha^{-1}. The average grain yield varied from 3.8 to 5.2 t ha^{-1} (in 14% mc.).

Weeding and fertilizer affected straw and grain yields. Without weeding, the straw and grain yields decreased from 6.1 to 5.1 t ha^{-1} and from 4.6 to 3.8 t ha^{-1}, respectively. Applying recommended fertilizer produced straw (7.0 t ha^{-1}) and grain (5.1 t ha^{-1}) yields, which are higher as compared to without fertilizer, 4.6 and 3.8 t ha^{-1}, respectively.

Straw and grain yields varied significantly depending on toposequence positions. The straw and unhulled rice/grain yields at the bottom position were the highest, and were significantly different from top position of the toposequence, namely 7.1 and 5.6 t ha^{-1} for straw yield while 5.2 and 4.0 t ha^{-1} for grain yield.

The yield differences between top and bottom positions can reach more than 1.2 t ha^{-1} in grain yield and 1.4 t ha^{-1} in straw yield. These are probably due to the differences in water availability and soil properties.

Soil bulk density (BD) was significantly higher in the top than in lower positions (the range was 1.36 to 1.50 g cm^{-3}). The total soil pores spaces increased from the top towards bottom position with a range from 43.5-48.4% vol. mc. In all toposequences, the concentration of selected soil chemical properties (exchangeable Ca, Mg, Na, available S and CEC) increased from the top to the bottom positions (Table 4).

Wihardjaka *et al.* (1996) studied the rainfed lowland rice yields at different positions in the

Table 3. Straw, grain yield in different sites, toposequence and treatment (Site Pelemgede was excluded from analysis)

Item	Yield	
	Straw (in 3%mc)	Rice grain (in 14% mc)
	……… kg ha^{-1} ………	
Sites:		
. Megulung	6079 a	4847 a
. Jadi	6526 a	4798 a
. Sidomukti	5306 a	4132 a
$LSD_{0.05}$		
Position:		
. Top	5662 b	4022 b
. Upper middle	4664 c	4102 b
. Lower middle	6433 a	4999 a
. Bottom	7123 a	5246 a
$LSD_{0.05}$	759	575
Treatment:		
Group 1		
. FP	6094 a	4643 a
. FP - W	5100 b	3849 b
Group 2		
. FP - F	4370 b	3791 b
. FP + IF	7024 a	5115 a
LSD (w/n a group)$_{0.05}$	627	548
LSD (across groups)$_{0.05}$	1188	871

For each column under each factor, number followed by the same letter are not significantly different at 5 by LSD test toposequence, in Central Java, Indonesia, and reported that the lowland rice soils at bottom position of the toposequence have the highest soil organic matter and cation exchange capacity, and also produce highest yield. The soil at the bottom position was found to be more fertile than at the top position. Similarly, water availability was higher than at the top position due to water inflows from the top to bottom positions in the toposequence. So that, the harvest yields, at the bottom was higher than the top position.

Statistical analyses showed that the difference of the grain yields between top and bottom positions at all sites was not significant. However, it was significantly different when the Pelemgede site was excluded in the statistical analyses. The existance of a highway near the top of the slope and a creek near the bottom of the slope at the Pelemgede site (Figure 1 d) dominantly affected the measures as compared to the position treatments in the toposequence. Therefore, excluding the Pelemgede site in the statistical analyses improved the results.

CONCLUSION

1. The distribution of rainfall affected the fluctuation of ground water table depth and standing water. During the experiment there was a period of nine days without rainfall. The ground water table depth at the bottom position was always closer to the soil surface compared to other positions.
2. The straw and unhulled grain yields at the bottom position were the highest and were significantly different from top position of the toposequence, namely 7.1 and 5.6 t ha^{-1} for straw yields, while 5.2 and 4.0 t ha^{-1} for grain yields.
3. Without weeding, the straw and grain yields decreased by 1.0 t ha^{-1} (from 6.1 to 5.1 t ha^{-1}) and by 0.8 t ha^{-1} (4.6 to 3.8 t ha^{-1}). Without fertilizer addition, the straw and grain yields were only 4.4 and 3.8 t ha^{-1}. Applying recommended fertilization, the land produced straw and grain yields up to 7.0 and 5.1 t ha^{-1}, respectively.

Table 4. Mean of some of soil properties on 0-20 cm soil depth in different toposequence

Soil properties	Unit	Toposequence							
		Top		Upper middle		Lower middle		Bottom	
Soil Physical *)									
BD	g cm^{-3}	1.50		1.46		1.37		1.36	
TPS	(% vol.mc)	43.5		44.8		48.2		48.4	
Soil Chemical **)									
Tot-N	(%)	0.07	a	0.07	a	0.06	a	0.08	a
Avl-P	ppm	5.92	a	5.77	a	4.72	a	6.92	a
Exch-K	$cmol_c\ kg^{-1}$	0.25	ab	0.24	b	0.26	ab	0.28	a
Exch-Ca	$cmol_c\ kg^{-1}$	2.75	b	3.03	ab	5.64	ab	5.90	a
Exch-Mg	$cmol_c\ kg^{-1}$	1.03	b	1.05	b	1.73	a	1.89	a
Exch-Na	$cmol_c\ kg^{-1}$	0.16	c	0.31	bc	1.59	a	0.51	ab
Avl-S	ppm	47.57	b	61.07	ab	71.39	ab	79.87	a
Avl-Zn	ppm	6.47	a	6.97	ab	7.23	a	9.39	a
CEC	$cmol_c\ kg^{-1}$	8.17	b	9.03	b	13.68	ab	15.73	a

*) Mean from three sites : Megulung, Jadi and Sidomukti
**) Mean from four sites : Megulung, Jadi, Sidomukti and Pelemgede
For each row under each toposequence position, number followed by the same letter are not significantly different by LSD test.

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