2011
土壌水分ワークショップ
論文集

2011 壌水分ワークショップ論文集
Proceedings of Soil Moisture Workshop 2011

2011 壌水分ワークショップ実行委員会編
Edited by the Executive Committee of Soil Moisture Workshop 2011

2012 年 2 月
February 2012

「2011 壌水分ワークショップ」の開催にあたって

実行委員会　代表
開發一郎
（広島大学大学院総合科学研究科教授）

2011 土壌水分ワークショップを 2011 年 12 月 22 日（木）と 23 日（金）にキャンパスイノベーションセンター東京（国際会議室）に於いて実施した。今回は、招待講演と複数の一般発表セッション（公募発表：下記参照）という構成で行い、発表総数は 18 件、参加者は延べ 55 名であった。尚、今回は「東北巨大地震被災と土壌水分」特別セッションを設けた。

1　招待講演

テーマ名：Development of a mini tensiometer-time domain reflectometry (T-TDR) coil probe for measuring soil-water retention properties

招待講演者：　川本　健（埼玉大学大学院理工学研究科）

2　一般セッション・特別セッション［個人発表（予定発表時間 20 分：発表 15 分、質疑 5 分）］

① 土壌水分観測（衛星・地上モニタリング、土壌水分リモートセンシング、データベース）

② Drought-土壌水分-植生-気候変動

③ 測定技術開発

④ 物理モデルと数値解析

⑤ 凍土と土壌水/土壌水の物理・化学

⑥ 地盤の土壌水分

⑦ 東北巨大地震被災と土壌水分(特別セッション)

⑧ その他

本ワークショップでは以上のトピックスを中心に、土壌水分測定やシミュレーション技術の現状・今後、水循環・気候・植生変動および農作物生産における土壌水分の役割や今後の研究

の展開等の議論を活発に行った。特に、東北巨大地震被災による土壌・水分への影響に関する最新調査の報告はタイムリーで重要なものであった。

本ワークショップは水文・水資源学会、土壌物理学会、GEOSS AWCI Drought Working Groupの後援を受け、JAXAと広島大学東京オフィスの協力の基に実施した。尚、本論文集の刊行にあたってJAXAの支援を受けた。これらの関係団体に本ワークショップを代表して深く感謝する。

目次

Contents

東アジアの試験地での AMSR-E 土壌水分アルゴリズムの検証(Validation of soil moisture measurement algorithm of AMSR-E using the in situ data of soil moisture in East Asia ······ 1
白石一晃 (Kazuaki Shiraishi)、開發一郎 (Ichirow Kaihotsu)、
藤井秀幸 (Hideyuki Fujii)、小池俊雄 (Toshio Koike)

モンゴルにおける SMOS 土壌水分プロダクツの予備的的評価 (Preliminary evaluation of SMOS soil moisture products in Mongolia) ······ 4
開發一郎 (Ichirow KAIHOTSU)、今岡啓次 (Keiji IMAOK)、
藤井秀幸 (Hideyuki FUJII)、武藤太郎(Taroh MUTOH)、
白石一晃 (Kazuaki SHIRAISHI)、小池俊雄 (Toshio KOIKE)

マイクロ波リモートセンシングによる土壌水分と降水の補完的観測 (Complementary observations of soil moisture and precipitation by microwave remote sensing) ······ 7
瀬戸心太(Shinta SETO)、恒川貴弘(Takahiro TSUNEKAWA)、
沖大幹(Taikan OKI)

データ同化を用いた陸面過程モデルにおける土壌パラメータ推定手法 (Estimation of soil parameters for land surface model using data assimilation technique) ······ 13
萬 和明 (Kazuaki YOROZU), キムスンミン(Sunmin KIM),
立川康人(Yasuto TACHIKAWA), 椎葉 充晴(Michiharu SIIBA)
松宮謙治(Kenji MATSUMIYA)

気象研究所陸面モデル HAL(MRI Land Surface Model HAL) ······ 17
保坂征宏(Masahiro HOSAKA)

チベット高原における土壌水分シミュレーション (Simulation of soil moisture over the Tibetan Plateau) ······ 20
広瀬 望 (Nozomu HIROSE)

表計算ソフトを用いた浸透流解析モデルの開発(Numerical Model of Subsurface Flow used Spreadsheet) ······ 25
粟生田忠雄(Tadao AODA), 小澤尚輝(Naoki OZAWA), 安田 裕
(Hiroshi YASUDA), Qudratullah KAKAR

Soil moisture monitoring in Ishikari river basin of Hokkaido ······ 29
Shin MIYAZAKI, Tomohito YAMADA

折返し平行伝送路方式による国産土壌水分計 WD-3 の特性 (Characteristics of a domestically-developed soil water sensor, WD-3, based on a method of folded parallel transmission lines) ······ 33
久保武広(Takehiro KUBO), 登尾浩助(Kosuke NOBORIO)

Development of a mini tensiometer-time domain reflectometry (T-TDR) coil probe for measuring soil-water retention properties (Invited) ········38
Shaphal SUBEDI, Ken KAWAMOTO, Toshiko KOMATSU, Per MOLDRUP and Lis Wollesen de JONGE

岩手県における津波被災農地の塩分濃度モニタリング(Monitoring soil EC of Tsunami-hit farmland in Iwate: Aug. - Oct., 2011) ······················44
武藤由子(Yoshiko MUTO)、河合成直(Shigenao KAWAI)、倉島栄一(Eiichi KURASHIMA)、加藤　幸 (Koh　KATO)、千葉克己(Katsumi Chiba)、溝口勝 (Masaru MIZOGUCHI)

宮城県の津波被災農地における塩類の挙動(Movement of salt on Tsunami-hit farmland in Miyagi) ···49
千葉克己(Katsumi CHIBA)、加藤　徹 (Toru KATO)、冠　秀昭 (Hideaki KANMURI)、加藤　幸(Koh KATO)、武藤由子 (Yoshiko MUTO)、溝口　勝 (Masaru MIZOGUCHI)

青森県の津波被災水田における土壌環境モニタリング (Monitoring of Soil Water and Salt Content in Paddy Fields damaged by Tsunami in Aomori Prefecture) ···55
加藤 幸 (Koh KATO)、高松利恵子 (Rieko TAKAMATSU)、長利洋(Hiroshi OSARI)、武藤由子 (Yoshiko MUTOH)、千葉克己 (Katsumi CHIBA)、溝口勝 (Masaru MIZOGUCHI)

日本国内の地温・凍結深データの収集・整備について (Collection and archiving of historical domestic soil temperature and freezing depth data) ···61
斉藤和之(Kazuyuki SAITO)、末吉哲雄(Tetsuo SUEYOSI)、渡辺晋生(Kunio WATANABE)、武田一夫(Kazuo TAKEDA)

黒ボク土畑表層のバイパス流の定量化 (Quantification of Bypass Flow through Surface Soil in Volcanic Ash Soil) ·····························64
植松慎一郎(Sin' ichiro UEMATSU)、長谷川周一(Syuichi HASEGAWA)、宮崎 毅(Tsuyoshi MIYAZAKI)、西村 拓(Taku NISHIMURA)

Water Management Evaluation of the System of Rice Intensification Paddy Fields by Considering Monitored Soil Moisture·······················72
Chusnul ARIF, Masaru MIZOGUCHI, BudiIndra SETIAWAN, Ryoichi DOI

タイ国における数種の人工林の土壌水分 (Differences of soil moisture contents among plantations in Thailand) ·····························79
酒井正治(Masaharu SAKAI)、Thiti Wisarath

キャピラリバリアによる根群域の保水性向上と地下水からの塩水侵入阻止 (Enhancing soil water holding capacity in root zone and interception of upward saline water flow from ground water using capillary barrier)···82
井上光弘(Mitsuhiro INOUE)、森井俊広(Toshihiro MORII)、斉藤広隆(Hirotaka SAITO)、藤巻晴行(Haruyuki Fujimaki)

Water Management Evaluation of Alternate Wetting and Drying Irrigation in Paddy Fields by Considering Monitored Soil Moisture

Chusnul ARIF [1,2], Masaru MIZOGUCHI[1], Budi Indra SETIAWAN[2], and Ryoichi DOI[1]

[1] Department of Global Agricultural Sciences, The University of Tokyo,
1-1-1 Yayoi, Bunkyo-Ku, Tokyo 113-8657, Japan
[2] Department of Civil and Environmental Engineering, Bogor Agricultural University, Indonesia

Abstract

The current study was conducted to evaluate water management of alternate wetting and drying irrigation in the System of Rice Intensification (SRI) paddy fields by using the data collected from developed field monitoring system. The experimental field was located on SRI paddy field in the Nagrak Organics SRI Center (NOSC), Sukabumi West Java, Indonesia during the first rice season 2010/2011 (October 2010 to February 2011, wet season). Soil moisture was measured and monitored every 30 minutes and the data were sent daily to the server as well as meteorological data. Then, the monitored soil moisture data were used to evaluate four water managements that were classified as Wet (W), Medium (M) and Dry (D) conditions according to four growth stages. Accordingly, we called the water managements as WWWW, MMWW, MMMM and WWDD regimes for first, second, third and fourth plots, respectively. The results showed that maximum yield was produced on the WWWW and WWDD regimes as well as water productivity. Accordingly, during one season experiment of SRI paddy cultivation, the WWDD regime to be the best regime because it could save water up to 26% compare to the WWWW regime. Therefore, the field should be more saturated in the initial and crop development stages, and then drained water to make the field drier in the mid-season and late stages as applied in this regime.

Key Words: *Alternate wetting and drying irrigation, water management, soil moisture, monitoring*

1. Introduction

Recently, the System of Rice Intensification (SRI) is well-known as a set of crop management practices for raising the productivity of irrigated rice by changing the management of plants, soil, water and nutrients. Its benefits have been validated in 42 countries of Asia, Africa and Latin America (Uphoff et al, 2011)[1].

In the SRI paddy cultivation, the water is irrigated absolutely different to the conventional rice cultivation. Commonly, intermittent irrigation with an alternate wetting and drying irrigation system instead of continuous flooding is applied to save water. Previous researches showed it could save up to 28% of water in Japan (Chapagain and Yamaji, 2010)[2], 40% in Eastern Indonesia (Sato et al, 2011)[3] and 38.5% in Iraq (Hameed et al, 2011)[4].

Optimization of water management is to be the main challenges in maintaining sustainability of SRI with the scarcity and competition of water resources. Accordingly, optimization processes could be initiated by giving different water management regimes to the fields. Then, those regimes are evaluated to identify plant response to water and water productivity as well.

Soil moisture represents the water availability in the field, thus different water management regimes will give different soil moisture level during planting period. In addition, it also affects pattern of water balance variables such as evapotranspiration, percolation and runoff in paddy field (Kim et al, 2009[5]; Reshmidevi et al, 2008[6]; Li and Cui, 1996[7]). Therefore, soil moisture could be considered as the main variable to evaluate water management

Field monitoring system is important to collect precise soil moisture data through continuous measurement as well as meteorological data. By precise data, the technology and crop management practice are to be possible to improve in developing sustainable agriculture.

The objective of this study was to develop field monitoring system for SRI paddy field particularly in Indonesia. Then, by monitored soil moisture data as well as meteorological data, different water management regime of alternate wetting and drying irrigation was evaluated particularly in term of water productivity.

2. Methodology

2.1 Field experiments

The current study was conducted at the experimental SRI paddy field in the Nagrak Organics SRI Center (NOSC), Sukabumi West Java, Indonesia during the first rice season 2010/2011 (October 2010 to February 2011, wet season). The field is located at 06°50'43" S and 106°48'20" E, at an altitude 536 m above mean sea level (Fig. 1).

Fig.1 Map showing the study area in Nagrak, Sukabumi, Indonesia.

There were four experimental plots and each plot was a 4 m x 4 m rectangular shape. All plots were planted with the local variety of rice (*Oryza sativa* L), Sintanur, a rice variety usually use for the SRI in West Java, Indonesia. The elements of SRI practices were; single planting of young seedling (5 days after seedling) spaced at 30cm x 30cm, using an organic fertilizer at 1 kg/m^2 on the land preparation and no chemical fertilizer.

2.2 Water Management

Four experimental plots were irrigated under different water management regimes based on the growth stage. During cultivation period, the growth stage was divided into four stages, i.e. initial, crop development, mid-season and late season stages, respectively. The field conditions were classified into three conditions i.e. wet (W), medium (M) and dry (D) according to soil moisture level and its relation to soil suction (pF) as presented on Fig.2.

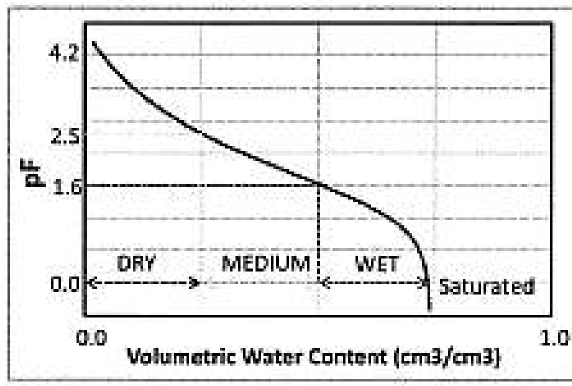


Fig.2 Classification of field condition during cultivation period.

Table 1. Water management regime in each plot

Growth stage	Water management regimes			
	WWWW	MMWW	MMMM	WWDD
I	Wet	Medium	Medium	Wet
II	Wet	Medium	Medium	Wet
III	Wet	Wet	Medium	Dry
IV	Wet	Wet	Medium	Dry

I: Initial; II: Crop development; III: Mid-season; IV: Late season

As a control, the WWWW regime was irrigated to maintain wet condition in all growth stages as a control. For the MMWW regime, during initial and crop development stages, the field was conditioned at medium level and then wet condition until late stage. In the MMMM regime, medium condition was applied during cultivation period, while for the WWDD regime;

wet condition was applied in the initial and mid-crop development stages and then let it dry until late stage (Table 1).

The wet condition was reached if soil is saturated with the soil suction between 0 and 1.6. Medium condition was achieved if soil suction value between the air entry and field capacity conditions (1.6<pF<2.54), while dry condition was reached if the soil is drier than medium level. Each plot has different soil retention and its curve was defined by the van Genuchten model (van Genuchten, 1980)[8]. The model showed the relationship between soil water content and pressure head in simple equation as follow:

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{[1 + (\alpha h)^n]^m} \quad (1)$$

$$m = 1 - 1/n \quad (2)$$

where, θ is soil water content (cm^3/cm^3), h is pressure head (cm H_2O), θ_s, θ_r, α, n, and m are Genuchten independent parameters for saturated water content (cm^3/cm^3), residual water content (cm^3/cm^3) and shape factors, respectively. These parameters were estimated from observed soil-water retention data and presented in Table 2.

Table 2. Genuchten parameters of each regime

	Water management regimes			
Parameter	A	B	C	D
Saturated water content (cm^3/cm^3)	0.578	0.597	0.600	0.595
Residual water content (cm^3/cm^3)	0.250	0.250	0.300	0.260
Shape factor:				
A	63	63	63	50
N	1.316	1.330	1.410	1.340
M	0.240	0.248	0.291	0.254

A: WWWW; B: MMWW; C: MMMM; D: WWDD

2.3 Field Measurements

Soil moisture was monitored by the developed field monitoring system as well as meteorological parameters (Fig. 3).

The soil moisture sensor, developed by Decagon Devices, Inc., USA, was installed at the 10-cm depths from the top of soil to measure soil moisture and soil temperature every 30 minutes. The meteorological data including precipitation were recorded by using Davis Vantage Pro2 Weather Station every 30 minutes. Daily average values of air temperature, wind speed and relative humidity as well as total solar radiation were used to calculate reference evapotranspiration (ETo) based on the FAO Penman-Monteith (Allen et al, 1998)[9]. All of data were sent daily to the web server on the particular time (12.00 – 12.30 p.m.), thus we called this information system as a quasi real time monitoring system.

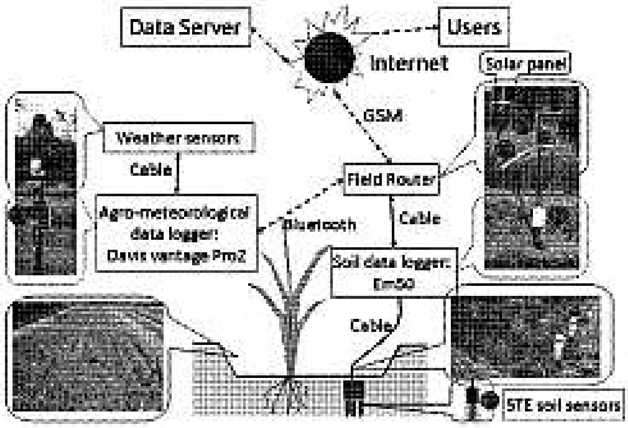


Fig.3 Field monitoring system for SRI paddy field in Indonesia.

2.4 Water Balances Analysis

Water balance analysis was performed based on the measurement data. Here, water inflow to the field consists of precipitation and irrigation water, while water leave from the field through runoff, percolation and crop evapotranspiration. We defined runoff as lateral water movement either artificially through drainage or naturally when water level exceeds the height of the drainage outlet and as seepage through bunds in paddy fields.

Accordingly, water balance equation can be expressed as:

$$\Delta S(t) = P(t) + I(t) - Qr(t) - DP(t) - ETc(t) \quad (3)$$

where, ΔS is the change of soil moisture (mm), P is precipitation (mm), I is irrigation water (mm), Qr is runoff (mm), DP is percolation (mm) and ETc is crop evapotranspiration (mm).

Furthermore, we calculated water productivity (WP) to look up another water-rice production relationship. In paddy fields, WP is calculated using the following equation:

$$WP = \frac{Y}{\sum ETc} \quad (4)$$

where, Y is the yield (ton/ha) and ETc is total water consumption by crop evapotranspiration (mm) derived from water balance analysis.

3. Results and Discussions

3.1 Weather conditions during cultivation period

Fig.4 shows daily minimum, average and maximum air temperature during cultivation period as well as relative humidity. Fig.5 shows the daily changes of solar radiation and reference evapotranspiration (ETo).

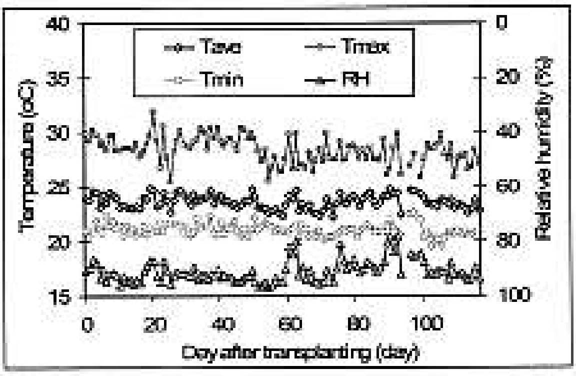


Fig.4 Changes in air temperature and relative humidity.

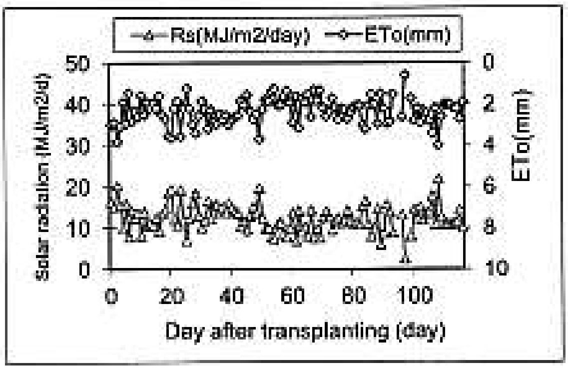


Fig.5 Daily solar radiation and measured evapotranspiration during cultivation period.

The meteorological data were measured continuously and daily sent to the server. However, the data on 94 and 95 DAT were lost due to battery of the Davis console was depleted. The data trend of air temperature was found to be contrasting to those of relative humidity (Fig.4). The maximum, average and minimum air temperatures were 31.9°C, 23.6°C, and 19.5°C, respectively. Meanwhile, the maximum, average and minimum values of relative humidity were 97%, 91% and 78%, respectively.

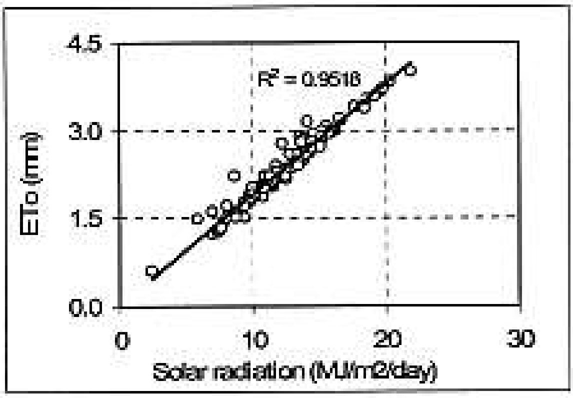


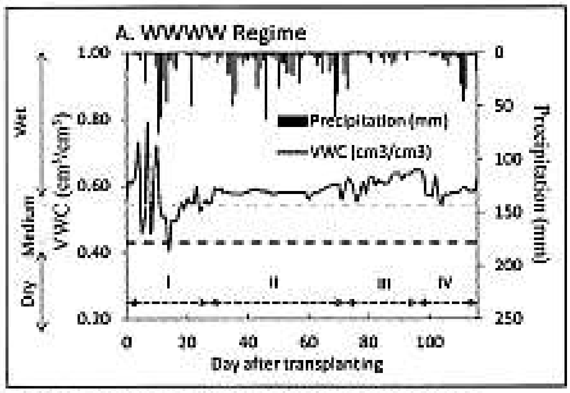
Fig.6 Regression slope between measured daily evapotranspiration and solar radiation.

On the other hand, the solar radiation data had a positive correlation to the reference evapotranspiration (Fig.6) with the coefficient determination (R^2) of 0.9518. The maximum value of solar radiation was 22.0 MJ/m^2/day on the 30 January 2011 when the age of plant was 109 DAT. Also, the maximum reference evapotranspiration was reached to 4.0 mm/day on this day. On the other hand, the minimum solar radiation was 2.4 MJ/m^2/day and the minimum reference evapotranspiration was 0.6 mm/day on the 19 January 2011. During cultivation period, the averages of solar radiation and reference evapotranspiration were 12.3 MJ/m^2/day and 2.3 mm/day, respectively.

3.2 Dynamics change in monitored soil parameters

Fig.7 shows monitored soil moisture and rain precipitation for the WWWW regime in the first plot. Based on water retention curve, the wet condition was reached when soil moisture is equal or higher than 0.540 cm^3/cm^3. During cultivation period, the soil moisture was almost wet except particular day in the initial stage. It was occurred when heavy rain with high intensity came which caused great changed in soil moisture level. Total rain precipitation during cultivation period was 1331.8 mm and the highest daily precipitation was 75.2 mm/day (24 October 2010).

In the MMWW regime, the border between wet and medium condition was 0.550 cm^3/cm^3 and the changes of soil moisture was presented in Fig.8. In this regime, the heavy rain in the initial stage was drained to keep the soil at medium level. The averages of soil moisture for initial and crop development stages were 0.537 cm^3/cm^3 and 0.545 cm^3/cm^3, respectively. Then, soil moisture increased by irrigation water in the mid-season stage since rain intensity was low. We recorded the averages between 0.561 cm^3/cm^3 and 0.578 cm^3/cm^3 for mid-season and late stages, respectively.



I: Initial; II: Crop development; III: Mid-season; IV: Late season

Fig. 7 Dynamics changed of soil moisture during cultivation period for the WWWW regime.

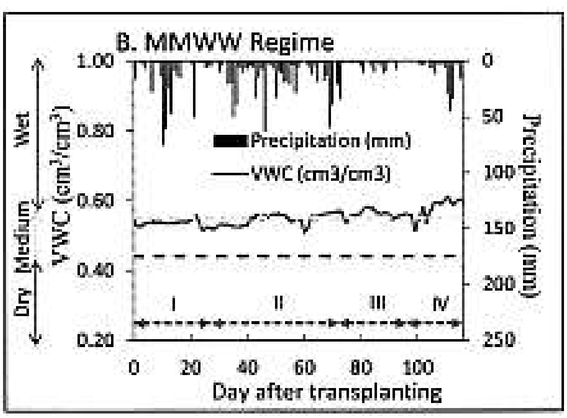


Fig.8 Dynamics changed of soil moisture during cultivation period for the MMWW regime.

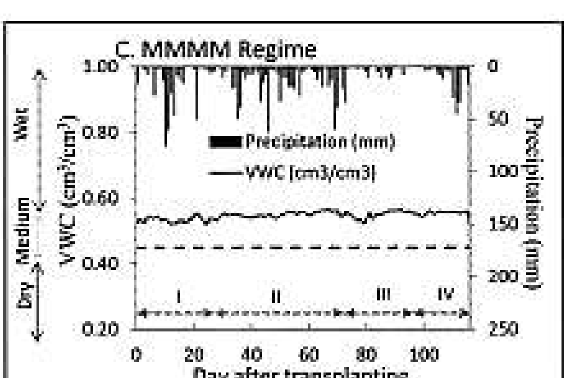


Fig.9 Dynamics changed of soil moisture during cultivation period for the MMMM regime.

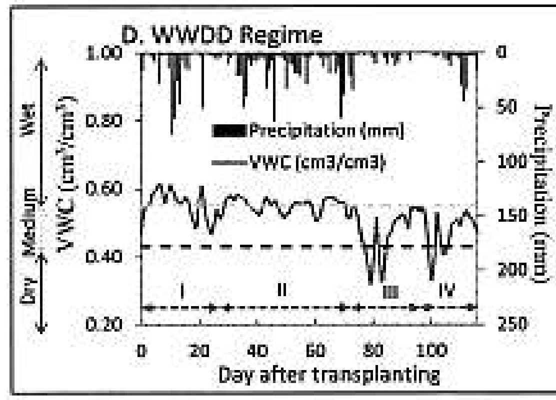


Fig.10 Dynamics changed of soil moisture during cultivation period for the WWDD regime.

The field was kept in medium condition in all growth stages for the MMMM regime in the third plot (Fig.9). Here, the threshold between wet and medium condition was 0.560 cm^3/cm^3 based on soil retention curve. We observed the averages soil moisture for initial, crop development, mid-season and late stages were 0.533 cm^3/cm^3, 0.550 cm^3/cm^3, 0.550 cm^3/cm^3, and 0.553 cm^3/cm^3, respectively.

The WWDD regime has widespread interval of soil moisture condition from wet to dry condition as shown in Fig.10. The medium condition was reached when the soil moisture was in between 0.430 cm^3/cm^3 and 0.550 cm^3/cm^3, while its value was higher or lower than the interval, the field will be wet or dry, respectively. The highest soil moisture was reached at level of 0.611 cm^3/cm^3 in the initial stage when high rain intensity was occurred. On the other hand, its lowest value was 0.320 cm^3/cm^3 in the mid-season stage when rain intensity was the lowest for several days.

Soil temperature trends were comparable among all plots as shown in Fig.11. The soil temperatures' trends were high until the plant age reached to 45 DAT (October-November 2010) and then decreased during December 2010 to February 2011. This phenomenon was affected by the plant cover. Here, in the initial stage when plants only approximately 10% cover soil surface, the soil temperature trends was high because solar radiation and air temperature that directly reached the soil. On the other hand, from 45 DAT to the last stage, when the plants covered all soil surfaces, the soil temperature trends decreased, because plants became a barrier from solar radiation. The highest soil temperature of 35.7°C was observed on 13 November 2010 in the second regime. On the other hand, the lowest value was 22.0°C in the MMWW and WWDD regimes.

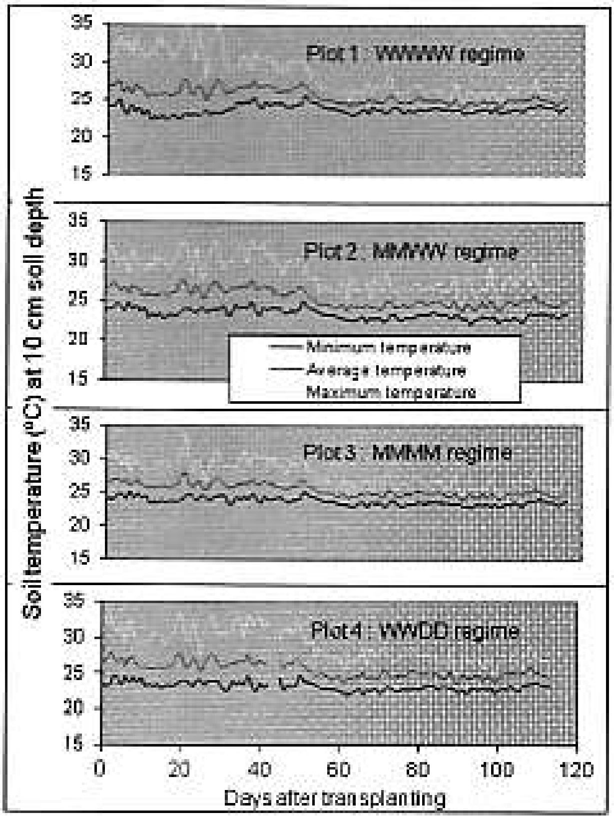


Fig.11 Soil temperatures fluctuations for all regimes.

3.3 Effects of different soil moisture on plant growth

The maximum and average plant heights were affected by different water management as shown in Fig. 12.

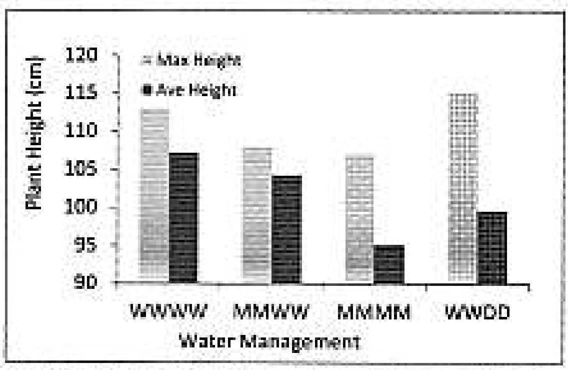


Fig.12 The maximum and average plant height for each water management.

The highest plant height was resulted by the WWDD regime, however, the WWWW regime resulted in the average plant height at the highest level. Accordingly, the WWWW regime was the best regime in producing plant with more uniform in height compared to other regimes.

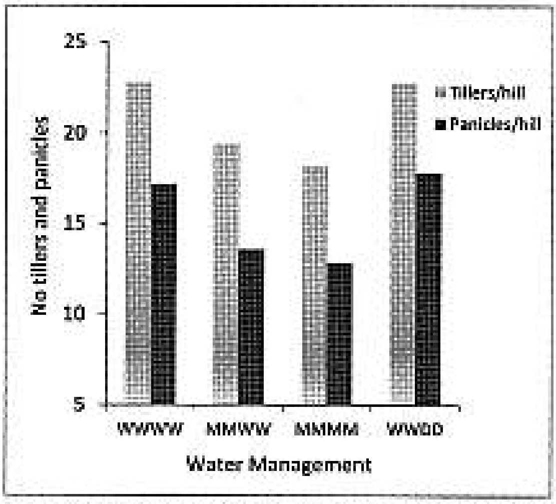


Fig. 13 Number tillers and panicles/hill for each water management.

The number of tillers/hill and panicles/hill between the WWWW and WWDD regimes were comparable and their values were higher than the MMWW and MMMM regimes. We observed the maximum numbers of tillers/hill and panicles/hill of 23 and 18, respectively. Number tillers/hill represents total biomass produced; therefore, the WWWW and WWDD regimes can be selected for producing more biomass in the SRI paddy cultivation.

3.4 Water management evaluation

Table 3 presents water management evaluation for each regime. From the water balance analysis, total irrigation water for the WWWW regime was highest among all regimes to keep the field wet in all growth stages. Although the field was drier than the MMWW and MMMM regimes in the two later stages, the WWDD regime needs more irrigation water to keep the field wet in the initial and crop development stages. We observed that during cultivation period in wet season, the total irrigation water were relatively low since high rain precipitation intensity occurred.

Water consumption through crop evapotranspiration for all water management regimes were comparable. Even though the WWDD regime has the highest crop evapotranspiration, its value was not significantly different compare to the others regimes.

Table 3. Water management evaluation for each regime

Parameters	A	B	C	D
Water Balance				
Inflow (mm)				
Precipitation	1332	1332	1332	1332
Irrigation	280	129	123	207
Outflow (mm)				
Evapotranspiration	339	331	331	340
Runoff	1136	997	1003	1085
Percolation	119	116	117	113
Production				
Yield (ton/ha)	5.31	4.7	3.75	5.31
Water Productivity (kg/m^3)	1.57	1.42	1.13	1.56
Water saving (%)*	-	54%	56%	26%

A: WWWW regime; B: MMWW regime; C: MMMM regime; D: WWDD regime as control

For the yield, the WWWW and WWDD regimes produced 5.31 ton/ha, the highest among the four regimes. Yield has a positive correlation to water productivity and its values for the WWWW and WWDD regimes were comparable. Accordingly, the WWDD regime looked to be the best water management for SRI paddy cultivation that can produced the maximum yield, saving water up to 26% compared to the WWWW regime. Therefore, the field should be more saturated in the initial and crop development stages and could be drier in the mid-season and late season stages.

4. Conclusions

The current study was conducted to evaluate four different water management regimes by considering in-situ monitored soil moisture. We found, from one season experiment in wet season, the WWDD regime in which the field was more saturated in the initial and crop development stages and then driest in the next stages as the best water management regime. By this regime, the maximum yield of 5.31 ton/ha was produced and 1.56 kg/m^3 of water productivity was achieved with water saving of 26% compare to WWWW regime as the control. More field experiments will be meaningful to take the advantages of this finding.

Acknowledgements

We are grateful to the Directorate Higher Education, Ministry of National Education, Republic of Indonesia for generous financial support through grant of International Research Collaboration and Scientific Publication during data acquisition in Indonesia.

References

1) Uphoff N, Kassam A, Harwood R (2011): SRI as a methodology for raising crop and water productivity: productive adaptations in rice agronomy and irrigation water management. *Paddy Water Environ*, 9, 3-11.

2) Chapagain T, Yamaji E (2010): The effects of irrigation method, age of seedling and spacing on crop performance, productivity and water-wise rice production in Japan. *Paddy Water Environ*, 8 (1), 81-90.

3) Sato S, Yamaji E, Kuroda T (2011): Strategies and engineering adaptions to disseminate SRI methods in large-scale irrigation systems in Eastern Indonesia. *Paddy Water Environ*, 9 (1), 79-88.

4) Hameed KA, Mosa AKJ, Jaber FA (2011) Irrigation water reduction using System of Rice Intensification compared with conventional cultivation methods in Iraq. *Paddy Water Environ*, 9 (1), 121-127

5) Kim HK, Jang TI, Im SJ, W PS (2009): Estimation of irrigation return flow from paddy fields considering the soil moisture. *Agr Water Manage*, 96, 875–882.

6) Reshmidevi TV, Jana R, Eldho TI (2008): Geospatial estimation of soil moisture in rain-fed paddy fields using SCS-CN-based model. *Agr Water Manage*, 95 (4), 447-457.

7) Li YH, Cui YL (1996): Real-time forecasting of irrigation water requirements of paddy fields. *Agr Water Manage* 31 (3), 185-193

8) van Genuchten, MT., (1980): A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci.Soc.Am.J 44, 892-898.

9) Allen RG, Pareira LS,Raes D, Smith M (1998): Crop Evapotranspiration Guidelines for computing crop water requirements. FAO - Food and Agriculture Organization of the United Nations, Rome

(Accepted December 29, 2011)