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学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

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学位論文題目：
Title of Dissertation　Agriculture Water Use for Rice, Mung Bean and Chili Pepper Cultivations in Dry and Rainy Seasons, South Sulawesi, Indonesia
(インドネシア・南スラウェシの乾季・雨季における水田，リョクトウ畑，トウガラシ畑の農業水利用)

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Dissertation Summary

Introduction. The agriculture sector influences the economic structure in South Sulawesi. The agriculture sector contributes 25.32% to the total South Sulawesi GDP and absorbs 43.12% workforce (BPS Sulawesi Selatan, 2012). At the national level, South Sulawesi Province plays a strategic role in relation to agricultural production. South Sulawesi's rice production occupies the fourth largest position at the national level that contributed 10% of national rice production. In addition, South Sulawesi is the main rice distributor to the eastern part of Indonesia.

One of the dominant factors that influence the agriculture production is water availability. Bulsink et al. (2010) and Fulazzaky (2014) reported that the amount of water resources in Indonesia fluctuates by season and is distributed unfairly from region to region. Suprapto (2002) stated that in general, Indonesia has an annual rainfall of 2700 mm in average and in South Sulawesi has an annual rainfall of 2596 mm in 2013 (BPS Sulawesi Selatan, 2013). Based on the climatic conditions, the planting season, especially in Gowa district, South Sulawesi is divided into three seasons, are the rainy season (Rendeng) on December to April, the first dry season (Gadu I) on May to August, and the second dry season (Gadu II) on August to November. In the rainy season can be defined as a season where the irrigation water depends mainly on rainfall. In the first dry season can be defined as a season for crops cultivation where the irrigation water mainly depends on surface irrigation. Approximately 50% of total rice production in South Sulawesi owes to the irrigation system. In the second dry season can be defined as a season for crops cultivation where the surface irrigation was stopped and rainfall was small (monthly average rainfall was 179 mm) so the irrigation water mainly depends on shallow groundwater uptake. Therefore, due to the water availability, rice is the main crop cultivated in the paddy field in the rainy and the first dry season. Thus, palawija such as mung bean is the main crop cultivated in the second dry season.

However, even the government has been built the irrigation facility to boost the agriculture production such rice in South Sulawesi but not all the irrigation area could get enough irrigation water especially in the downstream area of irrigation system that far from the weir such as Renggang agriculture area in Gowa district, South Sulawesi. Based on the field survey, irrigation water through the canal system has been insufficient even in the first dry season because of uncontrolled water distribution from the primary canal (Limbung primary canal), damages in the secondary canal (Pammase secondary canal), unclean canal, and because of illegal irrigation water intake by farmers. To cope with the insufficient irrigation water, farmer in this area utilize the shallow groundwater through pumping. Data from Statistical office in Gowa Regency shows the amount of pumping use by farmers for cultivation increased from 780 units in 2008 to 2.007 units of the pump in 2012. It is further mentioned that from the total number of pumping used for agriculture in Gowa district, the farmers in the downstream area of Kampili irrigation system is the most pumps for agriculture activity by 980 units of pumps (BPS Gowa, 2012). Furthermore, the utilization of shallow groundwater in this area is manage privately by farmer and its management based on each farmer knowledge and experiences so far.

Objective of this study. This study investigated the irrigation practice and agricultural water use for rice, mung bean and chili pepper including the shallow groundwater irrigation uptake in Renggang WUA agriculture area in the first dry season, the second dry season, and the rainy season. We also evaluated the effect of agricultural water use to the shallow groundwater level during the seasons by applying water balance concept. The water requirement for rice, mung bean, and chili pepper also calculated. As a preliminary study, the observation on irrigation practice and water use could help to understand the water suitability and improvement the agriculture water management in a paddy field during a year.

Irrigation system facility. Indonesia government got ¥ 5.472.000.000 as a loan from JBIC to support the development of Bili-Bili irrigation system (Bili-Bili Irrigation Project, 2004). Bili-Bili dam is located in Gowa regency about 30 km to the east of the city of Makassar, South Sulawesi. The purpose of Bili-Bili multipurpose dam construction is to control floods in Makassar and Gowa regency from 2,200 m^3/s of discharge to 1,200 m^3/s, drinking water supply of 3,300 L/s, and irrigation water supply for 23,685 ha of rice fields. In terms of water supply for irrigation, Bili-Bili multipurpose dam provides surface irrigation water for Bili-Bili Irrigation Systems that divided into three irrigation areas, are Bili-Bili irrigation area (2,360 ha), Kampili irrigation area (10,545 ha), and Bissua irrigation area (10,785 ha). Paddy field in Kampli irrigation area irrigated by Kampili weir through Limbung primary canal (PC). Kampili weir is the oldest weirs in the Bili-Bili Irrigation System, built in 1930's. The length of primary canal and secondary canal in Kampili irrigation area is 13.5 km and 184.3 km, respectively. Besides the irrigation system facility, Indonesian government also develop the water user association (WUA). WUA in Indonesia subsequently known as Perkumpulan Petani Pengguna Air (P3A). The WUA development in Indonesia based on The Indonesian Law Number 7 of 2004 and the Government Regulation Number 20 of 2006. The Indonesian Law Number 7 of 2004 about water resources and the Government Regulation Number 20 of 2006 about irrigation mandates that WUA have a responsibility towards the management of tertiary irrigation network to the farm level.

There are 307 of WUA in Bili-Bili Irrigation System where 20 of WUA in Bili-Bili irrigation area, 126 of WUA in Bissua irrigation area, and 161 of WUA in Kampili irrigation area. One of the WUA in Kampili irrigation area is Renggang WUA. Irrigation area under Renggang WUA coordination is located in the downstream area of Kampili irrigation system. One of the important tasks of the Renggang WUA is the maintenance of irrigation facilities which are described in articles of association of Renggang WUA (articles of association, clause 5 about Function and Responsibility of WUA). The purpose of canal maintenance is to maintain and improve the condition and function of the irrigation network. In this maintenance also involves the participation of members of Renggang WUA through gotong royong (working together without payment) activity. In addition, empowerment program had been done in this WUA to improve the irrigation water management especially in the tertierly and on farm scale. Not only construct the canals, but one of the programs in empower the WUA board due to training and assisting the WUA management to manage the organization professionally, such as making the articles of association (Anggaran Dasar dan Anggaran Rumah Tangga Orgaisasi; AD/ART), and recording of planting area and owner of paddy fields, and also reporting of rice yield in each of farmers (WUA Empowerment

Project, 2007).

Study site. The study was conducted in the paddy field that located in the downstream irrigation area of Kampili irrigation system under Renggang WUA coordination. Administratively, located in Tanabangka and Gentungan villages, Bajeng Barat district, Gowa regency. Geographically, located at 5^{o}19’4.08 – 5^{o}19’52.32 LS and 119^{o}24’27.2” – 119^{o}25’4.8” BT. This research was conducted during the dry season (May to August and September to November) and the rainy season (December to April), in 2012 to 2014. In 2012, In the first dry season 2012, rice (*Oryza sativa* L. subsp. Javanica, cv. Ciliwung) was transplanted on 25th of May and harvested on 25th of August in the experimental field. In the second dry season 2012, mung bean (cv. Kenari) was cultivated in the same field, were seedling on 2nd September 2012 and harvesting started on 16th of November 2012. In the rainy season 2012, rice cv. Santana was transplanted in the experimental field on 26th of December 2012 and harvested on 5th of April 2012. In the first dry season 2013 rice cv. Philipine was transplanted on 23rd – 24th of May and harvested on 20th of August in the experimental field. In the second dry season 2013, we have two experimental fields, were field for rice cultivation and field for chili pepper cultivation. Rice cv. Ampari was transplanting on 28th of August and harvested on 23rd November 2013. Chili pepper cv. Bhaskara was transplanted on 8th of September and harvested on 24th November 2013. In the rainy season 2012-2013 and 2013-2014, rice cv. Santana was transplanted in the experimental field on 27th and 30th of December, and 30 harvested on 5th and 3th of April, respectively. In the second dry season 2014, mung bean cv. Kenari was seedling on 31st of August and harvesting started on 3rd of November 2014 in the same experimental field as rice.

Data. Rainfall data was collected by automatic rain gauge (ECRN-100, Decagon). In addition, micrometeorology instruments were installed in the experimental field where rice, mung bean, and chili pepper crops were cultivated. The station for the micrometeorology observation consisted of CNR-4 (Kipp and Zonen, Netherland) for net radiation at 2.0 m height; psychrometers HMP-45A (Vaisala Inc. Helsinki, Finland) for air temperature and relative humidity observation at 0.6 m and 2.0 m, respectively; anemometers 014A (Met One, USA) for wind speed observation; soil heat plate PHF-03 (PREDE) for soil heat observation; and thermocouple for soil temperature observation at soil surface at 0 cm and 5cm of soil depth. All of the instruments were connected to the CR23X logger (Campbell) and the data were recorded every 10 minutes and averaged in every one hour. Discharges of irrigation from Pammase secondary (Pm6Ka) canal and the reused water irrigation from drainage of Sappaya WUA region, which is adjacent to Renggang WUA region, were estimated by measuring the velocities of water flow in each canal by a current meter (V-20, Kennex). In the second dry season 2012, we observed 29 fields of mung bean and 3 fields of rice that irrigated by shallow groundwater uptake. In the second dry season 2013, we also observed 59 fields of mung bean and 4 fields of rice that irrigated by shallow groundwater uptake.

Plant height was measured by averaging that of ten randomly selected plants every seven days during the rice, mung bean, and chili pepper growing period. The leaf area index (LAI) was estimated by measuring the size of leaves, calculating the average area of a single leaf by applying a relationship between the size and area of the leaf, which had been obtained for each crops cultivar, and multiplying by number of leaves of one crops plant. Rice production data was estimated by using crop cut method in 1m^2 of sampling plot within the experimental field crop cut (Rosenstock et al., 2016). While for the mung bean and chilli pepper productions in the experimental fields was weighted in each harvesting time.

Potential evaporation was computing by the Penman method (1948) (McMahon et al., 2013). Crop evapotranspiration for rice in the first dry season measured by a lysimeter. Daily and daytime evapotranspiration was obtained by the change of the water level in the lysimeter, which was measured by a water level gauge (PH-340, Kennek). In addition, crop evapotranspiration for rice, mung bean, and chili pepper were estimated by Bowen Ratio Energy Budget method (Esmaiel Malek, 1993) (Abtew and Assefa, 2013). Crop coefficient (Kc) in daily basis was calculated as the ratio of actual evapotranspiration to potential evaporation. Soil water content; SWC (%) in the rice, mung bean, and chili pepper field were observed by using the EC-5 and 5TE (Decagon) moisture sensors. Soil moisture at 5 cm and 20 cm of soil depth observed in paddy field. Additional soil moisture sensors at 40 cm of soil depth was installed in mung bean and chili pepper field. We also measured the daily shallow groundwater level manually by scale.

Analysis. To evaluate the agricultural water use and its effect on the shallow groundwater level during the seasons, the water balance concept was applied. Water balance in this study consist of rainfall; P (mm/d), discharge of surface irrigation; Qi (mm/d), re-use drainage; Qr (mm/d), shallow groundwater uptake; Gi (mm/d), evapotranspiration; ET (mm/d), and store of water to the ground; ΔS . The water balance can be written as follows:

$$P + Qi + Qr + Gi = ET + Qd + \Delta S$$

Crop water use efficiency (CWUF) was calculated as the yield (kg/ha) produced per millimeter of evapotranspiration (Tennakoon and Milroy, 2003):

$$CWUE = \frac{yield}{ET}$$

Irrigation water requirements is the depth of water needed to meet the water loss through crop evapotranspiration and could calculated by (Mutsvangwa, 2011):

$$I = ET - Pe$$

Agriculture water use of rice. The gross water supply; rainfall, surface irrigation from the canal, reuse water irrigation, and the shallow groundwater irrigation for rice cultivation in the first dry season 2012 and 2013 were 582.93 mm and 904.29 mm, respectively. While the evapotranspiration in the first dry season 2012 and 2013 were 530.90 mm (112 DAT) and 454.60 mm (107 DAT). The canal irrigation was 151.93 mm in 2012 and 434.06 mm in 2013. Larger gross water supply in 2013 was due to larger rainfall and canal irrigation from Pammase secondary canal. Increased canal irrigation in 2013 expanded the field area that could be irrigated. The area irrigated by the Pammase secondary canal in the first dry season was 38.15 ha in 2012 and increased to 48.98 ha in 2013 Based on the water balance analysis, we found that insufficient water occurred on July in 2012 and 2013. Insufficient water supplies caused the stored water consumption for evapotranspiration, which resulted in the negative ΔS.

In the second dry season, shallow groundwater is the main water source for rice cultivation. The amount of shallow groundwater uptake after land preparation was 716.55 mm in 2012 and greatly increase to 1991.62 mm in 2013. The highest water supply and soil water content caused the increasing of the leaf area index (LAI) where the maximum LAI occurred in the generative stages. Furthermore, even the evapotranspiration in the first dry season is not to difference with the evapotranspiration in the second dry season 2013 (539.12 mm), but the irrigation water use during the second dry season was higher compared with the first dry season. The increasing of water use during the second dry season due to the climatic condition such as temperature and radiation. In addition to weather effects, excessive use of groundwater is also caused by the ease of farmers get a water pumping equipment and farmers have their own well managed privately. So this makes it easier for farmers to exploit shallow groundwater freely.

In the rainy season, rain occurred almost every day during the growing periods, where the total rainfall in the rainy season 2013 and 2014 were 1737.4 mm 928.60 mm, respectively. The climatic conditions during the rainy season caused the variation of potential evaporation and evapotranspiration. The amount of evaporation in the whole growing periods from transplanting to harvesting in the rainy season 2012 and 2013 were 493.55 mm and 476.78 mm, respectively. Thus, the evapotranspiration of rice were 501.73 mm (100 DAT) and 458.94 mm (92 DAT) for both year. The daily average of Kc during vegetative stage was 0.88 and 1.06 in generative stage until harvesting, where the average of Kc during the total growing periods was 1.01. This Kc value was similar to the Kc value that estimate by (Arif et al., 2012).

The component of water balance in this research was different from the second dry season. The components of water balance for the second dry season were precipitation as an input, evapotranspiration and water storage as an outputs. Totally, the quantity of water supplies was larger than evapotranspiration during the rainy season in 2012 and 2014. Moreover, the excess of water during the rainy season as shown in positive values of ∆S was stored to the ground. The negative value of ∆S was occurred in the last plant growth stages for both years due to the small rainfall.

Agriculture water use of mung bean. The cultivated area during the second dry season 2012 was 47.95 ha (64.45%). In this season, mostly mung bean was cultivated or 51.95% from the total cultivated area. The amount of rainfall during the second dry season was lower than the mung bean evapotranspiration. Where the amount of rainfall was 119.2 mm/season and mung bean evapotransporation was 320.74 mm/season. This phenomenon indicated that water deficit could be expected in Renggang WUA agriculture area. Therefore, to cope with the unsufficient water, farmer relay on the shallow groundwater uptake by pumping. Pumping was done two times during the mung bean cultivation, were when the land preparation and when plant have three leaves with the amount of shallow groundwater uptake were 186.06 mm in 2012 and 179.04 mm in 2013. Farmer irrigation practice for mung bean in Renggang WUA is different with another study (Ambachew et al., (2014), Directorate Plant Production (2010), Malik et al., (2006) and Sadeghipour (2009). Where they suggested that the best time for irrigating the mung bean is in the flowering stage and early pod fill. Lack irrigation during the flowering and pod formation stages significantly reduced pod initiation and pod growth rates and thereby reduced harvest index De Costa et al., (1999).

Agriculture water use of chili pepper. Based on estimation, ET of chilli pepper was lower than EP where the daily average of ET and EP were 1.94 mm and 6.71 mm, respectively. The result of ET in this study was simmilar to the study conducted by Qiu et al., (2011). Statistically, crop coefficient (Kc) of chili pepper in each stage was significantly different between stage to stage where the Kc was increase from the vegetative stage (0.25) to the harvesting stage (0.33). This study also founded Kc could be related to soil water content at 5cm depth (SWC5cm) by a logarithmic function. This relationship on every stage of chili pepper growth was expressed by $Kc = a\ ln(SWC5) + b$.

During the second dry season, irrigation event for chili pepper cultivation was done eight times with the total of irrigation was 27.42 mm, while the total rainfall was 180.0 mm. The totally of the amount of water supply including rainfall, was higher than evapotranspiration. However, water balance analysis shows the water supply during the vegetative and generative stages was less than evapotranspiration. In contrast, the abundant water was occurred in the last growing season of chili pepper.

The effect of agriculture water use to the shallow groundwater level. The store of water to the ground affect the shallow groundwater level. The shallow groundwater level rose or kept relatively constant situation in response to the positive ΔS and it dropped in response to the negative ΔS. Further, the shallow groundwater level during the first dry season started to decrease since July especially in 2013 because of the small rainfall, surface irrigation, reuse drainage, and the increasing of crop evapotranspiration. The lowest of shallow ground water during the second dry season season was due to the fields not longer irrigated. The observed shallow groundwater level in the rainy season was close to soil surface (0 – 50 cm). The maximum shallow groundwater level during the second dry season 2012, was around 264.5 cm from the soil surface. That results demonstrated that not only about the quantity, but also the continuity of water supply could clearly affect the shallow groundwater level.

Irrigation water requirement (IWR). The irrigation water requirements are needed for water allocation, risk management and irrigation system planning. Irrigation water requirement for different crops has been estimate in this study. So far the irrigation practice by farmer due to the amount of water supply was not suitable with the irrigation water requirement for rice and mung bean crops during the study. In the first dry season, irrigation water that supplied by farmer was smaller than the irrigation requirement. Whereas, in the rainy season, farmer are advised not to irrigate their fields because of high rainfall.

Similarly, irrigation practice in mung bean field where there is a discrepancy between the amount of water supply by farmer and water requirement. In 2012, farmers provide excess water in September. Where in this month the mung bean crops was still in the vegetative stage. While in October (generative stage), the water given by farmers is still lower compared to the irrigation water requirement.

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