CarakaTani
Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)

Caraka Tani: Journal of Sustainable Agriculture, 38(1), 1-13, 2023
URL: https://jurnal.uns.ac.id/carakatani/article/view/58029
DOI: http://dx.doi.org/10.20961/carakatani.v38i1.58029

Increase of Cropping Index in Dryland Supported by Groundwater Irrigation

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Abstract

Dryland has the potential to increase agricultural production, by increasing the cropping index. The main problem of dryland is the availability of water which depends on rainfall. Groundwater can be an alternative option to meet the availability of water in the dryland. This study aimed to determine the cropping pattern and increase of cropping index supported by groundwater irrigation in the dryland. The research was conducted in the dryland of Playen, Gunungkidul, Special Region of Yogyakarta, supported by groundwater irrigation. This research used a combination of survey, interview and plot demonstration methods. Surveys and interviews were conducted to determine the condition of cultivation and profit in the first and third growing seasons. The plot demonstration, to increase the rice cropping index from 1 to 2, was applied in the second growing season. The results showed that rice productivity in the first growing season was 5.215 ton ha^{-1}, with a profit of 12,288,000 IDR ha^{-1} and B/C of 1.28. In the second growing season, Sidenuk productivity was 8.025 ton ha^{-1}, with the dry straw of 8.049 ton ha^{-1}, grain carbon of 3.471 ton ha^{-1} and straw carbon of 3.723 ton ha^{-1}, higher than those of Situbagendit, but comparable those of Inpari-42, with a profit of 20,700,000 IDR ha^{-1} and B/C of 1.54. Rice contributed to higher biomass, carbon and profit than groundnut. In the third growing season, groundnut productivity was 2.026 ton ha^{-1}, with a profit of 15,572,000 IDR ha^{-1} and B/C of 1.78. Groundwater irrigation can support the increase in the cropping index on dryland and intensify agricultural production as well.

Keywords: aquifer; cropping pattern; water requirement

Cite this as: Anshori, A., Srihartanto, E., Fibrianty, Suswatiningsih, T. E., Budiarti, S. W., Riyanto, D., Cahyaningrum, H., & Suradal. (2023). Increase of Cropping Index in Dryland Supported by Groundwater Irrigation. *Caraka Tani: Journal of Sustainable Agriculture*, *38*(1), 1-13. doi: http://dx.doi.org/10.20961/carakatani.v38i1.58029

INTRODUCTION

Humans, economy and environmental sustainability are influenced by food, energy and water, especially in conditions of diminishing resources and climate change (Bekchanov et al., 2015). Food security is the main agenda of a country (Suryana, 2014). The increase in food consumption is in line with the increase in population (Wahdah et al., 2015). Technically irrigated rice fields have decreased by land conversion (Nurcholis and Supangkat, 2011),

[*] *Received for publication December 31, 2021*
Accepted after corrections August 14, 2022

and the opportunities for opening new rice fields are getting smaller and this becomes an obstacle in meeting food needs.

Enhancing the potency of dryland is an option to increase agricultural production (Adunya and Benti, 2020; Indrawan et al., 2020; Arifin et al., 2021), with water availability as the main problem (Nurasa and Supriadi, 2012). The lack of water is the main problem in dryland (Viandari and Anshori, 2021). Dryland usually can only be planted twice a year, planting rice once during the rainy season. An increase in agricultural production from dryland can be done by increasing cropping index. The increase in cropping index in dryland requires additional water for irrigation, one of which can be obtained from groundwater (Anshori et al., 2021b).

The increase of cropping index is one of solutions in overcoming bigger food needs. About 37% of the food self-sufficiency in 1984 came from an increase in the cropping index (Las et al., 1999). Increase of cropping index is related to the management of soil, water, climate and nutrient resources (Singh et al., 2014; Sutrisno et al., 2016). These conditions are related to climate, soil, water availability, crops and costs (Terán-Chaves and Polo-Murcia, 2021). The application of cropping patterns can reduce food disparities and improve welfare (El-Gafy, 2013). The cropping patterns can save water and energy, as well as multiple agricultural yields (El-Gafy et al., 2017). Optimization of cropping pattern rises gross net profit by 6.44%, compared to existing cropping patterns (Osama et al., 2017).

The groundwater utilization does not exceed the safe yield of aquifer, so sustainable (Basso et al., 2013). There is a balance between pumping and recharging the aquifer, as a sustainable water management (Butler Jr et al., 2018), related to aquifer thickness, specific yield of aquifer and groundwater quality (Ravindran et al., 2015). Utilization of groundwater for irrigation takes into account rainfall, land cover, river debit and evaporation (Mao et al., 2005). Actual evapotranspiration is the actual use of water, in which a certain amount of water is used to produce a certain amount of crop yields (Mainuddin et al., 2020). Irrigation facilities and irrigation water delivery techniques determine the efficiency of irrigation water use (Chen et al., 2018) and groundwater recharge (Bouimouass et al., 2020). On the other side, soil management improves soil to make it suitable for crops (Viandari and Anshori, 2021). Plant management prioritizes the adaptation of rice varieties to environmental conditions (Anshori, 2020). The sustainability of the groundwater irrigation system is attributed to climatic conditions, soil parameters, hydrogeological parameters, information on channels and rivers, cropping patterns and other related factors (Liu and Chen, 2020). Thus, there is a match between the availability of water from groundwater, soil as a growth medium and plants in accordance with environmental conditions. The use of water to increase the cropping index does not exceed the aquifers' safe yield.

The use of groundwater for irrigation has been developed in several countries. Groundwater irrigation in Bangladesh requires 1,402 l of water per kg of rice, with an evapotranspiration rate of 661 l. The government supports it through water saving policies (Mainuddin et al., 2020). China has developed groundwater irrigation as the main irrigation supplemented by surface water irrigation and used water as additional irrigation (Liu and Chen, 2020). Groundwater development is an option in management, supported by modeling (Mao et al., 2005).

The dryland area in Indonesia is estimated of 144.5 million ha (Mulyani, 2015), with water as a limiting factor (Suwarno, 2010), which has great potential to support food production. Groundwater irrigation increases water availability, productivity and crop index (Anshori et al., 2020). It can be technically implemented in dryland. Irrigation increases percolation, which in turn increases groundwater recharge (Pakparvar et al., 2017), which will support the sustainability of groundwater irrigation systems. Grounsdwater irrigation has the capacity to increase carbon sequestration through the formation of plant biomass. Groundwater irrigation is also potential to support the dryland development and increase the national food production.

The area of Gunungkidul Regency is dominated by dryland, which mostly relies on rainfall, has the main cropping pattern of rice-groundnut-fallow and is representative area for dryland agricultural research. The research location is dryland supported by groundwater irrigation. Groundwater irrigation has the potential to increase the cropping index from rice-groundnut-fallow to rice-rice-groundnut, which in turn increases rice production. The increase in agricultural production, especially rice, can be achieved by increasing the cropping index by changing the cropping pattern to rice-rice-groundnut. In terms of environmental sustainability, responsible use of groundwater will encourage groundwater conservation and carbon sequestration. This study was conducted determine the cropping pattern and increase of cropping index in dryland supported by groundwater irrigation. The goals of the study include: (1) to determine the farmers' existing rice cultivation in the first growing season, (2) to increase rice cropping index from 1 to 2 in the second growing season supported by groundwater irrigation and (3) to increase the cropping index 2 to 3 by planting groundnut, which is supported by groundwater irrigation. Research results can be applied to areas that have similar agroecosystems, with commodities and management adapted to the nature and conditions of groundwater or aquifers.

MATERIALS AND METHOD

The research was conducted on dryland in Playen, Gunungkidul, Special Region of Yogyakarta, Indonesia, starting from January to November 2020, at three growing seasons. The field research is located in 7.93192°N, 110.54454°E and lies on 207 m above sea level. The research location is dryland, with groundwater irrigation. Installation of groundwater irrigation was built about one year before this research. The existing cropping pattern when the study conducted was rice-groundnut-fallow, without irrigation. This research changed the cropping pattern to rice-rice-groundnut, with groundwater irrigation. The first growing season was during December 2019 and March 2020 with rice plants, the second growing season was during April and July 2020 with rice plants, while the third growing season was during July and September 2020 with groundnut plants. The annual rainfall average was 1,852 mm, with consecutive 5 months of rainy season and 6 months of dry season. The soil has neutral pH, low organic carbon, low total nitrogen and high cation exchange capacity. The climate and soil properties can be seen in Table 1. Water availability comes from rainfall and groundwater pump irrigation. This research uses a combination of survey methods, interviews and demonstration plots.

In the first growing season survey and interview was conducted. The survey was conducted in three farmers' fields with the Situbagendit rice variety and the farmers were interviewed. The water availability was maintained from rainfall and the technology of rice cultivation based on the existing technique. The data collected were regarding the rice cultivation for the existing techniques, the productivity of harvested dry rice and dry straw, carbon absorption in grain and straw, and socio-economic conditions of farmers. The productivity of harvested dry rice and dry straw was measured from tiles based on Makarim et al. (2017) and carbon absorption in grain and straw by dry ashing method based on Eviati and Sulaeman (2009) and then, the mean and standard deviation were calculated. Farmer profits are calculated based on the farming analysis (Hendayana, 2016).

The rice demonstration plot and interviews were applied in the second growing season. The demonstration plot was used to increase the rice cropping index 1 to 2 by utilizing water availability from rainfall and groundwater irrigation. The rice varieties in the demonstration plot were Situbagendit, Inpari-42 and Sidenuk, with three times of replications. The specific location technology component was explored with the farmers, and then used a basis for the plot demonstration. The observation parameters include the productivity of harvested dry rice and dry straw from tile (Makarim et al., 2017) and carbon absorption in grain and straw by dry ashing (Eviati and Sulaeman, 2009). Data were analysed using SPSS to determine the variance of various parameters. Significant treatment was determined by F-test and Duncan multiple range test (DMRT) to find the interaction effect of treatments to estimate by least significant difference (LSD) at significance level of < 0.05 (Steel and Torie, 1978). The groundnut was used as a comparison for the increase in rice cropping index. The pod productivity and groundnut biomass were determined from tile based on Suparman and Abdurahman (2003) and carbon absorption in pod and biomass by dry ashing based on Eviati and Sulaeman (2009). Farmers' profit from rice and groundnut cultivation are determined by economic analysis based on (Hendayana, 2016).

The survey and interview were applied in the third growing season. Groundnut was planted in this season with water irrigation from groundwater. The technology component of groundnut followed the habits of farmers. The three farmers were interviewed and continued with the survey in each farmers' land. The data collected were groundnut productivity as harvested pod, dry biomass, carbon absorption in pod and biomass, and socio-economic conditions of farmer. The pod productivity and groundnut biomass were determined by tile according to Suparman and Abdurahman (2003), carbon absorption was decided by dry ashing method proposed by Eviati and Sulaeman (2009) and the mean and standard deviation were then figured. Farmer profit was calculated based on economic analysis according to Hendayana (2016).

RESULTS AND DISCUSSION

Rainfall, groundwater and cropping pattern

Water utilization refers to the Law of the Republic of Indonesia No. 17 of 2019 concerning water resources. At the regional level, the implementation of the use of water resources, including groundwater, is in accordance with regional regulations issued by each regional government. The Ministry of Agriculture through the Indonesian Agency for Agricultural Research and Development issued technical guidelines for increasing the rice cropping index (Center for Agricultural Technology Studies and Development, 2017), which is supported by the implementation of water harvesting infrastructure (Kartiwa et al., 2017). Rules are made to achieve sustainable water resources.

Utilization of groundwater requires initial capital for the construction of groundwater wells and irrigation canals and this becomes particular costs for farmers. Anticipating these conditions, the local government facilitates the construction of groundwater wells and irrigation canals. The initial capital for building groundwater wells and water canals is managed by the government. In some places, farmers build groundwater irrigation at their own expense. The Department of Agriculture and Food of Gunungkidul built 7 units of shallow groundwater irrigation and 10 units of medium groundwater irrigation (Department of Agriculture and Food of Gunungkidul, 2022). It was reported that there are 229 units of groundwater irrigation in Lombok Island, 152 units in Sumbawa and 264 units in Bima-Dompu (Rengganis, 2016). Beside from quantity, the quality aspect of irrigation water becomes a major concern, as in Jembrana Regency (Inayah et al., 2022). The utilization of groundwater irrigation has the potential to increase crop production in a dryland.

Dryland farmers of Playen, Gunungkidul planted rice during the first growing season, relying on water from rainfall. In the second growing season, farmers grew corn/groundnut/soybean, according to Riyanto et al. (2021) with monoculture or intercropping system. In the third growing season, farmers planted feed corn/groundnut/fallow, but mostly fallow, adjusting the rainfall. The original cropping pattern was an adaptation of farmers to rainfall. Increasing agricultural production could be done through crop intensification in the first growing season and increasing the cropping index in the second and third growing seasons, supported by supplementary irrigation, such as groundwater.

The increase in the cropping index was reinforced by groundwater irrigation. The increase in rice cropping index 1 to 2 was maintained in the second growing season. Commodities changed from corn/groundnut/soybean to rice. Groundwater irrigation allows planting in the dry season, when there is no rain. Groundwater is a source of supplementary irrigation, when rainfall is unavailable or insufficient for crops. Supplementary irrigation is a form of weather/climate factor substitution. The dryland cropping pattern supported by supplementary irrigation can be seen in Figure 1.

About 361 mm of rainfall occurred in April (10 daily of I, II and III) and May (10 daily of I, II and III). The water obtained from rainfall was not sufficient for the growth and development of rice plants in the second growing season. The water irrigation was done according to the physical conditions of plants and land. Sufficient water was from the irrigation of groundwater pump. The effort to increase the rice cropping index in the second growing season could be carried out with the support of groundwater irrigation. The groundnuts were planted in the third growing season. During the third growing season, the water requirement of groundnut plants was fulfilled by groundwater irrigation.

Table 1. Soil and climate properties at dryland of Playen, Gunungkidul

Type of land	pH	TOC (%)	TN (%)	CEC (cmol(+) kg^{-1})	pF 2.54 (%)	pF 4.20 (%)	Permeability (cm h^{-1})	P (mm)
Dryland	6.64	1.36	0.14	29.47	39.41	17.73	1.74	1,852

Note: TOC = total organic carbon; TN = total nitrogen; CEC = cation exchange capacity; pF = percent of moisture content at soil moisture potential; P = annual precipitation

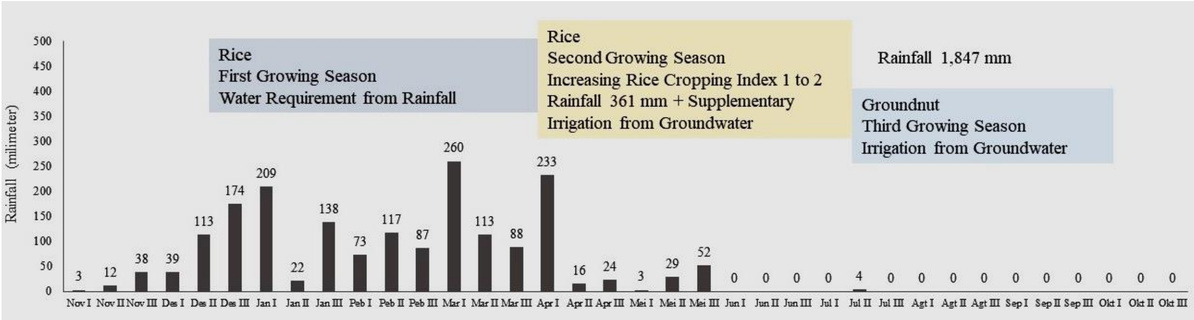

Figure 1. Rainfall and cropping pattern supported by groundwater irrigation at dryland of Playen, Gunungkidul, Special Region of Yogyakarta in 2019 to 2020

Rice cultivation in the first growing season

Rice was planted in the first growing season depending on the availability of water from rainfall. Rainfall is the main source of water. The first growing season was in the rainy season, with the peaks of rain in January and February. The irrigation was applied only under special conditions when rice plants needed additional water. The technology components applied were the rice superior varieties of Situbagendit, quality seeds, 20 cm x 20 cm planting method, N fertilizer 100 kg ha^{-1} and NPK 250 kg ha^{-1}, integrated control of plant pests and timely harvesting and threshing with pedals thresher. Rice harvest yield and economic analysis of the first growing season are presented in Table 2.

The rice productivity was 5.215 ton ha^{-1} of harvested dry grain, in conditions without supplementary irrigation. The farmers' profit was 12,288,000 IDR ha^{-1} with a B/C value of 1.28. Rice productivity in dryland during the rainy season can be increased by the application of recommended technology components (Erythrina et al., 2021). Technological components are new high-yielding varieties (Shoidah and Adnan, 2021), the *jajar legowo* system (Witjaksono, 2018), the application of organic fertilizers, soil nutrients and supplementary irrigation (Anshori et al., 2021a) The increase in productivity will be largely determined by the performance and interaction of the recommended technology components and the growing environment.

The dry straw of 5.190 ton ha^{-1} has the potential to be a source of organic matter through recycling processes to support productivity and soil health. The carbon absorption in grain and straw of 4.614 ton ha^{-1} reduces the amount of carbon dioxide from the air, lowering the concentration of greenhouse gases in the air. The straw returning to the field improves soil fertility and health (Supriyadi et al., 2020; 2021), as well as the sustainability of the agricultural system (Viandari et al., 2022). Rice farming in the first growing season and the rainy season has been carried out by farmers across generation and is feasible to develop.

Table 2. Rice harvest yield and economic analysis at first growing season

Yield	ton ha^{-1}
Harvested dry grain	5.215±0.426
Dry straw	5.190±0.623
Carbon absorption in grain	2.221±0.181
Carbon absorption in straw	2.393±0.287
Economic analysis	**IDR ha^{-1}**
Material	1,815,000
Labor	7,800,000
Water for irrigation	-
Total cost	9,615,000
Receipt	21,903,000
Profit	12,288,000
B/C	1.28

Rice cultivation on the second growing season

Application of technology

The rainfall was insufficient for rice cultivation in the second growing season on the dryland of Gunungkidul. Supplementary irrigation is needed to support the increase of the rice cropping index. Groundwater irrigation is an additional source of water with a special management. Irrigation facilities are met from pump to distribution. Butler Jr et al. (2018) states that management must lead to sustainable conditions.

The increased rice cropping index in second growing season was supported by a special technology component package, especially related to supplementary irrigation. Irrigation was provided according to plant and land physical conditions. Supplementary irrigation was given every four days on average, or as needed, in conditions without rain. Situbagendit, Inpari-42 and Sidenuk were planted in a 2:1 row. The dose of N fertilizer was 100 kg ha^{-1} and 250 kg ha^{-1} of NPK. Harvest was conducted on time, with a pedal threshers and the yields were immediately dried. This method would determine the quality of yields. Technically, technology should be effective and easy to implement.

Rice yields

The variety of Sidenuk gave the highest yields, harvested dry grains, dry straws, carbon in grains and carbon in straws, which were significantly different from Situbagendit, but not significantly different from Inpari-42 (Table 3). The Sidenuk productivity of 8.025 ton ha^{-1} and Inpari-42 of 7.873 ton ha^{-1} of harvested dry grains were high for dryland conditions. Both varieties could adapt well and thus have the potential to be developed to the increase of the rice cropping index in dryland. Sasmita et al. (2019) states that Sidenuk is an irrigated lowland rice variety, having the yield potential of 9.1 ton ha^{-1} and the average yields of 6.9 ton ha^{-1} of dry grains. Inpari-42 is a lowland rice variety, with the potential yields of 10.58 ton ha^{-1} and the average yields of 7.11 ton ha^{-1} of dry grains. Sidenuk, Inpari-42 and Situbagendit produced high dry straws (6.053 to 8.049 ton ha^{-1}), carbon absorption in grains (2.637 to 3.471 ton ha^{-1}) and carbon absorption in straws (2.800 to 3.723 ton ha^{-1}).

The increase of rice cropping index in the second growing season provides higher carbon absorption than groundnuts, with higher yield. The groundnut pod yield was 2.177 ton ha^{-1} and the biomass (leave, stem and root) was 3.151 ton ha^{-1}, with carbon absorption in pods of 0.930 ton ha^{-1} and biomass of 1.519 ton ha^{-1}, lower than those of the three rice varieties (Table 3). There was an increase in yield from groundnuts to rice plants. Based on the data Table 3, rice yields were 177% to 269% higher than groundnut yields, with carbon absorption ranging from 169% to 254% higher, and dry biomass yields were 92% to 155% higher, with carbon absorption ranging from 84% to 145% higher. Based on the contribution of dry grain, biomass and carbon absorption, the increase of rice cropping index in second growing season has the potential to multiply productivity of grain yields and biomass, reduce carbon dioxide concentrations from the air with carbon absorption and increasing soil health with recycling rice biomass. High straw productivity leads to the sustainability of the agricultural system. The return of straw increases the organic carbon content of the soil (Anshori et al., 2018; Syamsiyah et al., 2019; Anshori et al., 2020), further improving the physical, chemical and biological properties of soil (Anshori et al., 2016). Soil health is strongly influenced by the source and availability of soil carbon. The absorption of carbon dioxide through photosynthetic reactions reduces the concentration of carbon dioxide in the air (Tkemaladze and Makhashvili, 2016).

Table 3. The dry harvested grains and straws, and carbon absorption at second growing season

Comodity/ rice variety	Dry		Carbon absorption	
	Harvest grain	Straw	Grain	Straw
	ton ha^{-1}			
Groundnut	2.177±0.186#	3.151±0.068*	0.930±0.080#	1.519±0.033*
Situbagendit	6.041±0.190a	6.053±0.314a	2.637±0.083a	2.800±0.145a
Inpari-42	7.873±0.336b	7.688±0.327b	3.393±0.145b	3.556±0.151b
Sidenuk	8.025±0.287b	8.049±0.253b	3.471±0.124b	3.723±0.117b

Note: # = pod; * = leaf, stem and root of groundnut. The numbers followed by the same letter in the same column show no significant difference in the DMRT of 5%

Analysis of economy

The feasibility of farming analysis shows that the increase in rice cropping index in the second growing season supported by groundwater irrigation in the dryland deserves to be developed, with a B/C value of 0.95 to 1.54 (Table 4). According to Hendayana (2016) and Priatmojo et al. (2019) positive of B/C value means feasible to developed.

Groundwater irrigation increases the success rate of rice cultivation, although it increases the farming costs. Farmers' income is determined by the level of farming feasibility from the B/C value. Grain is the main component of revenue in farming. Cost component consists of farming materials, labor and supplementary irrigation cost. The increase of rice cropping index in the second growing season supported by groundwater irrigation in dryland still provides benefits to farmers. Economically, the technology is profitable and feasible to be developed.

Groundnut cultivation on the third growing season

Groundnuts were planted in the third growing season, dry season, days without rain. Local varieties of groundnuts were grown in tiles of 25 cm x 25 cm. The groundnut water was supported by irrigation from groundwater pumps. Irrigation was done every 7 days, with a total of 9 irrigation times or based on plant and environmental conditions. Irrigation was provided in during the harvest time to ensure that the soil moisture and facilitate the harvesting process. Groundnuts required less water than rice and the duration of irrigation was longer. Dose of NPK was 200 kg ha^{-1} and N fertilizer 100 kg ha^{-1}. Manual weed control was applied. The groundnut harvest yield and economic analysis can be seen in Table 5.

Groundnut productivity was 2.026 ton ha^{-1}. Farmers profit was 15,572,000 IDR ha^{-1}, with B/C of 1.78. The irrigation costs reached 1,800,000 IDR ha^{-1}, 20.59% of the total production cost. Irrigation from groundwater increased the cropping index from 2 to 3, contributing to biomass, carbon dioxide absorption from the air and profit for farmers. Groundnut cultivation in third growing season is feasible to be developed.

Cropping pattern, aquifer and sustainability

In general, dryland productivity is low, because the main source of water only comes from rainfall. The dryland is often cultivated without irrigation infrastructure, thus, irrigation is difficult to develop. Rainwater can only support rice and/or other crops a maximum of once or twice a year. Supplementary irrigation is needed to increase the rice cropping index in dryland (Viandari and Anshori, 2021). This additional water can come from utilizing water harvested from surface runoff or groundwater wells.

The determination of cropping patterns with supplementary irrigation must strike a balance between water demand, reserves and input (Zhang et al., 2014). The sustainability of water resources becomes important (Hassen et al., 2016), plant production per drop of water is high, transpiration efficiency is required to increase (Basso and Ritchie, 2012), and water use must be efficient, crops are chosen for water requirements rather than for economic returns (Basso et al., 2013). The cropping pattern is filled with water in space and time. A combination is formed from water consumption, water availability, crop yields optimization and economy escalation (Terán-Chaves and Polo-Murcia, 2021).

The use of groundwater for agriculture must also pay attention to other sectors, such as human consumption. water as a resource for human, animal and plant (Ameur et al., 2015). Groundwater is one of the most important water resources. Human activities often threaten groundwater resources by changing their quality, quantity and distribution (Hamzaoui-Azaza et al., 2013). Groundwater utilization must be based on a feasibility, both in quantity and quality (Hassen et al., 2016).

Table 4. Economic analysis for groundnuts and all rice varieties in the second growing season

Component	Groundnuts	Situbagendit	Inpari-42	Sidenuk
	IDR ha^{-1}			
Material (seed, fertilizer, pesticide)	2,140,000	1,605,000	1,605,000	1,605,000
Labor	4,800,000	7,800,000	7,800,000	7,800,000
Water for irrigation	1,800,000	3,600,000	3,600,000	3,600,000
Total cost	8,740,000	13,005,000	13,005,000	13,005,000
Receipt	26,124,000	25,372,000	33,066,000	33,705,000
Profit	17,384,000	12,367,000	20,061,600	20,700,000
B/C	1.99	0.95	1.54	1.54

Table 5. The groundnut harvest yields and economic analysis in the third growing season

Yield	ton ha^{-1}
Harvested pod	2.026±0.353
Dry biomass*	3.006±0.183
Carbon absorption in pod	0.542±0.094
Carbon absorption in biomass*	1.490±0.091
Economic analysis	**IDR ha^{-1}**
Material	2,140,000
Labor	4,800,000
Water for irrigation	1,800,000
Total cost	8,740,000
Receipt	24,312,000
Profit	15,572,000
B/C	1.78

Note: * leaf, stem and root of groundnut

Groundwater is stored and flows in an aquifer. Aquifer capability is determined by porosity and hydraulic conductivity (Sudarmaji, 2013). The structure and type of rock affect the availability of groundwater. The space between grains is a water storage (Fetter, 1994) and the ability of rocks to conduct water (Kruseman and de Ridder, 1994). Grain size, compaction of the stratum, shape and distribution of pore, and time of drainage determine the specific yield of aquifer. Specific yield is "the ratio of volume of the water, that after saturation, can be drained by gravity to its total volume" (Todd and Mays, 2005). Next, the concept of a safe yield was developed. The safe yield is "the amount of water which can be annually withdrawal without producing a undesirable result". Furthermore, evolving, the concept of safe yield is included hydrological, economic, quality and legal considerations. Term of the sustainable yield appeared later. A new approach to aquifer management is managed yield. Managed yield is defined "the amount of water available from an aquifer, including the safe limit, so that changes in the aquifer no reach an undesirable condition" (Meyland, 2011).

There are many terms in groundwater management. However, according to Putranto and Setiawan (2019) groundwater conservation is carried out to maintain the quality and quantity of groundwater. Groundwater conservation can also increase the carrying capacity of the soil, restore groundwater and reduce groundwater pollution such as nitrates (Young et al., 2017), thus maintaining the sustainability of the aquifer system (Danaryanto et al., 2007). The use of groundwater for agriculture is emphasized the sustainable aspect, to more.

CONCLUSIONS

The cropping pattern of rice-groundnut-fallow changed to rice-rice-groundnut is possible with the support of irrigation from groundwater. The increase in the rice cropping index from 1 to 2 was made in the second growing season. The increase in the cropping index from 2 to 3 was made in the third growing season. Rice in the second growing season and groundnuts in the third growing season have improved the harvest yield (grain and biomass) and absorption of carbon dioxide, when compared to the existing cropping pattern. The development of groundwater irrigation facilities must take into account the safe yield of aquifer and agricultural development plans to ensure the sustainability of groundwater irrigation utilization. The results of this study can be applied to the agroecosystems, commodities and management with similar settings based on the groundwater or aquifer conditions.

ACKNOWLEDGEMENT

The authors are grateful to the Indonesian Agency for Agricultural and Research Development, Ministry of Agriculture, Republic of Indonesia, through the Assesment Institute for Agricultural Technology of Yogyakarta for supporting this research. The authors would like to thank Mr. Suyanto and Mrs. Puji Catur Sriwiyati, field extension officers, for their assistance in this research.

REFERENCES

Adunya, T., & Benti, F. (2020). The impacts of climate-induced agricultural drought on four cereal crops: A case study in Bako

Tibe District, Oromia National Regional State, Ethiopian. *Caraka Tani: Journal of Sustainable Agriculture*, *35*(1), 135–146. https://doi.org/10.20961/carakatani.v35i1.35749

Ameur, M., Hamzaoui-Azaza, F., & Gueddari, M. (2015). Suitability for human consumption and agriculture purposes of Sminja aquifer groundwater in Zaghouan (north-east of Tunisia) using GIS and geochemistry techniques. *Environmental geochemistry and health*, *38*(5), 1147–1167. https://doi.org/10.1007/s10653-015-9780-2

Anshori, A., Pramono, A., & Mujiyo. (2020). The stratification of organic carbon and nitrogen in top soils as affected by the management of organic and conventional rice cultivation. *Caraka Tani: Journal of Sustainable Agriculture*, *35*(1), 126–134. https://doi.org/10.20961/carakatani.v35i1.34488

Anshori, A., Riyanto, D., Sukristiyonubowo, Widodo, S., & Suradal. (2021a). The increase of rice cropping index supported by river dam irrigation in dryland. *IOP Conference Series: Earth and Environmental Science*, *653*, 012074. https://doi.org/10.1088/1755-1315/653/1/012074

Anshori, A., Sunarminto, B. H., & Haryono, E. (2016). Aliran bahan organik pada sawah padi organik di Dusun Jayan Desa Kebonagung Kec. Imogiri Kab. Bantul D.I. Yogyakarta. *Caraka Tani: Journal of Sustainable Agriculture*, *31*(1), 45–50. https://doi.org/10.20961/carakatani.v31i1.11942

Anshori, A., Sunarminto, B. H., Haryono, E., & Mujiyo. (2018). Potential production of CH_4 and N_2O in soil profiles from organic and conventional rice fields. *Sains Tanah Journal of Soil Science and Agroclimatology*, *15*(1), 54–60. https://doi.org/10.15608/stjssa.v15i1.19324

Anshori, A., Suswatiningsih, T. E., Viandari, N. A., Mujiyo, & Rajiman, R. (2021b). Effect of supplementary irrigation on rice yield in dryland during rainy season. *IOP Conference Series: Earth and Environmental Science*, *824*, 012091. https://doi.org/10.1088/1755-1315/824/1/012091

Anshori, A. (2020). Strategi peningkatan indeks pertanaman padi di Kabupaten Gunungkidul. *Prosiding Seminar Nasional Pertanian Peternakan Terpadu Ke-3 Universitas Muhammadiyah Purworejo*, 238–247. Retrieved from http://eproceedings.umpwr.ac.id/index.php/pertanian/article/view/1310

Arifin, Biba, M. A., & Syafiuddin. (2021). Determinants of production and income risks of rainfed lowland farming: A case study in Maros Regency, Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *36*(2), 319–328. https://doi.org/10.20961/carakatani.v36i2.47713

Basso, B., & Ritchie, J. T. (2012). Assessing the impact of management strategies on water use efficiency using soil-plant-atmosphere models. *Vadose Zone Journal*, *11*(3), vzj2011-0173. https://doi.org/10.2136/vzj2011.0173

Basso, B., Kendall, A., & Hyndman, D. W. (2013). The future of agriculture over the Ogallala Aquifer: Solutions to grow crops more efficiently with limited water. *Earth's Future*, *1*(1), 39–41. https://doi.org/10.1002/2013EF000107

Bekchanov, M., Ringler, C., Bhaduri, A., & Jeuland, M. (2015). How would the Rogun Dam affect water and energy scarcity in Central Asia? *Water International*, *40*(5–6), 856–876. https://doi.org/10.1080/02508060.2015.1051788

Bouimouass, H., Fakir, Y., Tweed, S., & Leblanc, M. (2020). Groundwater recharge sources in semiarid irrigated mountain fronts. *Hydrological Processes*, *34*(7), 1598–1615. https://doi.org/10.1002/hyp.13685

Butler Jr., J. J., Whittemore, D. O., Wilson, B. B., & Bohling, G. C. (2018). Sustainability of aquifers supporting irrigated agriculture: A case study of the High Plains aquifer in Kansas. *Water International*, *43*(6), 815–828. https://doi.org/10.1080/02508060.2018.1515566

Center for Agricultural Technology Studies and Development. (2017). *Panduan dukungan inovasi pertanian untuk peningkatan indeks pertanaman (IP) padi jagung kedelai (Pajale) lahan kering dan sawah tadah hujan*. Jakarta: Indonesian Agency for Agricultural Research and Development

Chen, H., Gao, Z., Zeng, W., Liu, J., Tan, X., Han, S., Wang, S., Zhao, Y., & Yu, C. (2018). Scale effects of water saving on irrigation efficiency: Case study of a rice-based groundwater irrigation system on the Sanjiang Plain, Northeast China. *Sustainability*, *10*(1), 47. https://doi.org/10.3390/su10010047

Danaryanto, Titomiharjo, H., Setiadi, H., & Siagian, Y. (2007). *Kumpulan pedoman teknis pengelolaan air tanah*. Bandung: Badan Geologi. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Kumpulan+pedoman+teknis+pengelolaan+air+tanah&btnG=

Department of Agriculture and Food of Gunungkidul. (2022). *Laporan kinerja instansi pemerintah*. Department of Agriculture and Food of Gunungkidul.

El-Gafy, I., Grigg, N., & Reagan, W. (2017). Water-food-energy nexus index to maximize the economic water and energy productivity in an optimal cropping pattern. *Water International*, *42*(4), 495–503. https://doi.org/10.1080/02508060.2017.1309630

El-Gafy, I. (2013). Decision support system to maximize economic value of irrigation water at the Egyptian governorates meanwhile reducing the national food gap. *Water Science Journal*, *27*(54), 1–18. https://doi.org/10.1016/j.wsj.2013.12.001

Erythrina, E., Anshori, A., Bora, C. Y., Dewi, D. O., Lestari, M. S., Mustaha, M. A., Ramija, K. E., Rauf, A. W., Mikasari, W., Surdianto, Y., Suriadi, A., Purnamayani, R., Darwis, V., & Syahbuddin, H. (2021). Assessing opportunities to increase yield and profit in rainfed lowland rice systems in Indonesia. *Agronomy*, *11*(4), 777. https://doi.org/10.3390/agronomy11040777

Eviati & Sulaeman. (2009). *Petunjuk teknis analisis tanah, tanaman, air dan pupuk*. Bogor: Indonesian Soil Research Institute. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Petunjuk+teknis+analisis+tanah%2C+tanaman%2C+air+dan+pupuk+eviati+dan+sulaean&btnG=

Fetter, C. W. (1994). *Applied hydrogeology*. Columbus, Ohio: Merrill Publishing Co. Retrieved from http://sutlib2.sut.ac.th/sut_contents/H109081.pdf

Hamzaoui-Azaza, F., Tlili-Zrelli, B., Bouhlila, R., & Gueddari, M. (2013). An integrated statistical methods and modeling minerals-water interaction to identifying hydrochemical processes in groundwater in southern Tunisia. *Chemical Speciation and Bioavailability*, *25*(3), 165–178. https://doi.org/10.3184/095422913X13785679075430

Hassen, I., Hamzaoui-Azaza, F., & Bouhlila, R. (2016). Application of multivariate statistical analysis and hydrochemical and isotopic investigations for evaluation of groundwater quality and its suitability for drinking and agriculture purposes: Case of Oum Ali-Thelepte aquifer, Central Tunisia. *Environ Monit Assess*, *188*(3), 1–20. https://doi.org/10.1007/s10661-016-5124-7

Hendayana, R. (2016). *Analisis data pengkajian*. Jakarta: The Indonesian Agency for Agricultural Research and Development (IAARD) Press. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Analisis+data+pengkajian+Hendayana&oq=Analisis+data+pengkajian+h

Inayah, L., Siswoyo, H., & Fidari, J. S. (2022). Pemetaan nilai indeks kualitas air tanah untuk irigasi di Kecamatan Negara Kabupaten Jembrana Provinsi Bali. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *2*(2), 80–91. Retrieved from https://jtresda.ub.ac.id/index.php/jtresda/article/view/80

Indrawan, E., Lestari, S. U., Thiasari, N., & Sasongko, P. (2020). The pruning effect on the storage root yield and starch content of sweet potato clones planted at dryland. *Caraka Tani: Journal of Sustainable Agriculture*, *35*(2), 289–298. https://doi.org/10.20961/carakatani.v35i2.34480

Kartiwa, B., Rejekiningrum, P., Sosiawan, H., Sutrisno, N., Heryani, N., Talaohu, S. H., Sudarman, K., Hamdani, A., Haryono, Jayanto, G., Harmanto, & Nursyamsi, D. (2017). *Petunjuk teknis implementasi infrastruktur panen air*. Jakarta: Indonesian Agency for Agricultural Research and Development (IAARD)

Kruseman, G. P., & de Ridder, N. A. (1994). *Analysis and evaluation of pumping test data*, *p. 200*. Wageningen, The Netherlands: International institute for land reclamation and improvement. Retrieved from https://hwbdocuments.env.nm.gov/Los%20Alamos%20National%20Labs/General/31955.pdf

Las, I., Makarim, A. K., Sumarno, S. P., Mardikarini, M., & Kartaatmadja, S. (1999). *Pola IP padi-300, konsepsi dan prospek implementasi sistem usaha pertanian berbasis sumberdaya*. Jakarta: Indonesian Agency for Agricultural Research and Development (IAARD). Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Pola+IP+Padi+300%E2%80%AF%3A+Konsepsi+dan+Prospek+Implementasi+Sistem+Usaha+Tani+Berbasis+Sumberdaya&btnG=

Liu, J., & Che, H. (2020). Conjunctive use of groundwater and surface water for paddy rice irrigation in Sanjiang plain, North-East China. *Irrigation and Drainage*, *69*, 142–152. https://doi.org/10.1002/ird.2459

Mainuddin, M., Maniruzzaman, M., Alam, M. M., Mojid, M. A., Schmidt, E. J., Islam, M. T., & Scobied, M. (2020). Water usage and productivity of Boro rice at the field level and their impacts on the sustainable groundwater irrigation in the North-West Bangladesh. *Agricultural Water Management*, *240*, 106294. https://doi.org/10.1016/j.agwat.2020.106294

Makarim, A. K., Abdulrachman, S., Ikhwani, Agustiani, N., Margaret, S., Wahab, M. I., Rachmat, R., & Guswara, A. (2017). *Teknik ubinan pendugaan produktivitas padi menurut sistem tanam*. Sukamandi, Jawa Barat: Indonesian Institute for Rice Research. Retrieved from http://bbpadi.litbang.pertanian.go.id/index.php/en/publikasi/panduan-teknis/item/692-teknik-ubinan-pendugaan-produktivitas-padi-menurut-sistem-tanam

Mao, M., Jia, J., Liu, C., & Hou, Z. (2005). A simulation and prediction of agricultural irrigation on groundwater in well irrigation area of the piedmont of Mt. Taihang, North China. *Hydrological Processes: An International Journal*, *19*(10), 2071–2084. https://doi.org/10.1002/hyp.5667

Meyland, S. J. (2011). Examining safe yield and sustainable yield for groundwater supplies and moving to managed yield as water resource limits become a reality. *WIT Transactions on Ecology and the Environment*, *145*, 813–823. https://doi.org/10.2495/WRM110731

Mulyani, A. (2015). Potensi ketersediaan lahan kering mendukung perluasan areal pertanian pangan. In *Pasandaran, E., R. Heriawan dan Syakir, M. (Eds.) Sumberdaya lahan dan air: Prospek pengembangan dan pengelolaan.* Jakarta: Indonesian Agency for Agricultural Research and Development (IAARD) Press. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Potensi+ketersediaan+lahan+kering+mendukung+perluasan+areal+pertanian+pangan&btnG=

Nurasa, T., & Supriadi, H. (2012). Program sekolah lapang pengelolaan tanaman terpadu (SLPTT) padi: Kinerja dan antisipasi kebijakan mendukung swasembada pangan berkelanjutan. *Kebijakan Pertanian*, *10*(4), 313–329. Retrieved from http://repository.pertanian.go.id/bitstream/handle/123456789/4459/PROGRAM%20SEKOLAH%20LAPANG%20PENGELOLAAN%20TANAMAN%20TERPADU%20(SL-PTT)%20PADI-%20KINERJA%20DAN%20ANTISIPASI%20KEBIJAKAN%20MENDUKUNG%20SWASEMBADA%20PANGAN%20BERKELANJUTAN.pdf?sequence=1

Nurcholis, M., & Supangkat, G. (2011). Pengembangan integrated farming sistem untuk pengendalian alih fungsi lahan pertanian. *Prosiding Seminar Nasional Budidaya Pertanian*, *pp. 71–84*. Retrieved from http://repository.umy.ac.id/bitstream/handle/123456789/29649/New%20C.7-Gatot%20S.pdf?sequence=3&isAllowed=y

Osama, S., Elkholy, M., & Kansoh, R. M. (2017). Optimization of the cropping pattern in Egypt. *Alexandria Engineering Journal*, *56*(4), 557–566. https://doi.org/10.1016/j.aej.2017.04.015

Pakparvar, M., Walraevens, K., Cheraghi, S. A. M., Ghahari, G., Cornelis, W., Gabriels, D., & Kowsar, S. A. (2017). Assessment of groundwater recharge influenced by floodwater spreading: An integrated approach with limited accessible data. *Hydrological Sciences Journal*, *62*(1), 147–164. https://doi.org/10.1080/02626667.2016.1183164

Priatmojo, B., Adnyana, M. O., Wardana, I. P., & Sembiring, H. (2019). Kelayakan finansial dan teknis cara tanam padi jajar legowo super di sentra produksi padi kawasan Sumatera. *Penelitian Pertanian Tanaman Pangan*, *3*(1), 9–15. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Kelayakan+Finansial+dan+

Teknis+Cara+Tanam+Padi+Jajar+Legowo+Super+di+Sentra+Produksi+Padi+Kawasan+Sumatera&btnG=

Putranto, T. T., & Setiawan, D. (2019). Penentuan zona konservasi dan pemanfaatan air tanah akuifer bebas pada cekungan air tanah Pati-Rembang, Provinsi Jawa Tengah. *RISET Geologi dan Pertambangan*, *29*(2), 203–213. https://doi.org/10.14203/risetgeotam2019.v29.1025

Ravindran, A. A., Mondal, N. C., Ramanujam, N., & Srinivasamoorthy, K. (2015). Aquifer assessment for agriculture through geophysical, hydrochemical and hydrogeological approaches around Perumattunallur lake, Southern India. *Sustainable Water Resources Management*, *1*(2), 137–154. https://doi.org/10.1007/s40899-015-0011-x

Rengganis, H. (2016). Potensi dan upaya pemanfaatan air tanah untuk irigasi lahan kering di Nusa Tenggara. *Jurnal Irigasi*, *11*(2), 67–80. https://doi.org/10.31028/ji.v11.i2.67-80

Riyanto, D., Yustisia, Anshori, A., & Srihartanto, E. (2021). Application of rice-corn intercropping as an optimization of the land use utilization and increasing of farmer income in Playen Gunungkidul. *E3S Web of Conferences*, *232*, 01033. https://doi.org/10.1051/e3sconf/202123201033

Sasmita, P., Satoto, Rahmini, Agustiani, N., Handoko, D. D., Suprihanto, Guswara, A., & Suharna, S. (2019). *Deskripsi varietas unggul baru padi*. Badan Penelitian dan Pengembangan Pertanian. Kementerian Pertanian. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Deskripsi+varietas+unggul+baru+padi+sasmita&oq=Deskripsi+varietas+unggul+baru+padi+sasmi

Shoidah, F., & Adnan, A. (2021). Pertumbuhan dan produktivitas 5 varietas unggul baru padi di lahan bukaan baru Kabupaten Boven Digoel. *Agrosains: Jurnal Penelitian Agronomi*, *23*(1), 6–11. https://doi.org/10.20961/agsjpa.v23i1.44200

Singh, A. K., Chakraborti, M., & Datta, M. (2014). Improving rice-based cropping pattern through soil moisture and integrated nutrient management in mid-tropical plain zone of Tripura, India. *Rice Science*, *21*(5), 299–304. https://doi.org/10.1016/S1672-6308(13)60190-0

Steel, R. G. D., & Torie, J. H. (1978). *Principles and procedures of statistics: Biometrical Approach*. New York, USA: Mac Graw Hill Inc. Retrieved from https://www.cabdirect.org/cabdirect/abstract/19810721475

Sudarmaji. (2013). *Mata air: Perspektif hidrologis dan lingkungan*. Yogyakarta: Penerbit Sekolah Pascasarjana Universitas Gadjah Mada. Retrieved from https://scholar.google.co.id/scholar?hl=id&as_sdt=0%2C5&q=Mata+air%E2%80%AF%3A+Perspektif+hidrologis+dan+lingkungan&btnG=

Suparman, & Abdurahman. (2003). Teknik pengujian galur kacang tanah toleran naungan di bawah tegakan pohon kelapa. *Buletin Teknik Pertanian*, *8*(2), 76–79. Retrieved from https://lib.ui.ac.id/file?file=pdf/metadata-67340.pdf

Supriyadi, Pratiwi, M. K., Minardi, S., & Prastiyaningsih, N. L. (2020). Carbon organic content under organic and conventional paddy field and its effect on biological activities (A case study in Pati Regency, Indonesia). *Caraka Tani: Journal of Sustainable Agriculture*, *35*(1), 108–116. https://doi.org/10.20961/carakatani.v35i1.34630

Supriyadi, Vera, I. L. P., & Purwanto, P. (2021). Soil quality at rice fields with organic, semi-organic and inorganic management in Wonogiri Regency, Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *36*(2), 259–269. https://doi.org/10.20961/carakatani.v36i2.42556

Suryana, A. (2014). Menuju ketahanan pangan Indonesia berkelanjutan 2025: Tantangan dan penanganannya. *Forum Penelitian Agro Ekonomi*, *32*(2), 123–135. https://doi.org/10.21082/fae.v32n2.2014.123-135

Sutrisno, N., Hamdani, A., & Sosiawan, H. (2016). Pengelolaan sumber daya air mendukung indeks pertanaman padi. *Proceeding Seminar Nasional*, pp. 48–62.

Retrieved from http://repository.ut.ac.id/6373/1/FMIPA2016_06.pdf

Suwarno. (2010). Meningkatkan produksi padi menuju ketahanan pangan lestari. *Jurnal Pangan*, *19*(3), 233–243. Retrieved from https://www.jurnalpangan.com/index.php/pangan/article/view/150

Syamsiyah, J., Sunarminto, B. H., Hanudin, E., Widada, J., & Mujiyo. (2019). Carbon dioxide emission and carbon sequestration potential in Alfisol. *Bulgarian Journal of Agricultural Science*, *25*(1), 42–48. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20203368618

Terán-Chaves, C. A., & Polo-Murcia, S. M. (2021). Cropping pattern simulation-optimization model for water use efficiency and economic return. *Journal of Agricultural Engineering*, *52*(4). https://doi.org/10.4081/jae.2021.1197

Tkemaladze, G., & Makhashvili, K. A. (2016). Climate changes and photosynthesis. *Annals of Agrarian Science*, *14*(2), 119–126. https://doi.org/10.1016/j.aasci.2016.05.012

Todd, D. K., & Mays, L. W. (2005). *Groundwater hydrology* (3rd editio). New York, USA: John Wiley and Sons Inc. Retrieved from https://books.google.co.id/books?hl=id&lr=&id=X3T6DwAAQBAJ&oi=fnd&pg=PA16&dq=Groundwater+hydrology&ots=TWM9nXXiDR&sig=JR-ZlebmBlCpHgqRFacmw6N6q8A&redir_esc=y#v=onepage&q=Groundwater%20hydrology&f=false

Viandari, N. A., & Anshori, A. (2021). Rice cultivation on dryland during dry season supported by deep well irrigation and soil amelioration. *IOP Conference Series: Earth and Environmental Science*, *672*, 012019. https://doi.org/10.1088/1755-1315/672/1/012019

Viandari, N. A., Wihardjaka. A., Pulunggono, H. B., & Suwardi, S. (2022). Sustainable development strategies of rainfed paddy fields in Central Java, Indonesia: A review. *Caraka Tani: Journal of Sustainable Agriculture*, *37*(2), 275–288. https://doi.org/10.20961/carakatani.v37i2.58242

Wahdah, R., Langai, B. F., & Sitaresmi, T. (2015). Keragaman karakter varietas lokal padi pasang surut Kalimantan Selatan. *Jurnal Penelitian Pertanian Tanaman Pangan*, *31*(3), 158–165. Retrieved from http://repository.pertanian.go.id/handle/123456789/1334

Witjaksono, J. (2018). Kajian sistem tanam jajar legowo untuk peningkatan produktivitas tanaman padi di Sulawesi Tenggara. *Jurnal Pangan*, *27*(1), 1–8. Retrieved from https://jurnalpangan.com/index.php/pangan/article/view/400

Young, D, B., Rosen, T., Fisher, T, R., Moorshead, T., & Koslow, D. (2017). Dynamics of nitrate and methane in shallow groundwater following land use conversion from agricultural grain production to conservation easement. *Agriculture, Ecosystems and Environment*, *248*, 200–214. https://doi.org/10.1016/j.agee.2017.07.026

Zhang, C., McBean, E. A., &·Huang, J. (2014). A virtual water assessment methodology for cropping pattern investigation. *Water resources management*, *28*(8), 2331–1349. https://doi.org/10.1007/s11269-014-0618-y