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Determination of Suitable Plant Types in an Irrigation Command Area Using IWQI Method

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ABSTRACT

Irrigation water quality of has an essential roles in growing crops by farmers. Agricultural crops can produce superior products if they have good irrigation water quality. Irrigation water quality index (IWQI) is a method to evaluate the quality of irrigation water. This research aim at applying the IWQI in the Sukorejo Secondary Channal to determine suitable plants within the command area with the criteria of tolerance relative to salt. The research was performed by measuring some parameters including the content of Na+ (sodium), Cl– (chloride), HCO3– (bicarbonate), electrical conductivity (EC), and sodium adsorption ratio (SAR), as well as soil permeability. Results of this study showed that the Sukorejo Secondary Channal delivering irrigation water IWQI value of 61.54. Measurements also revealed the soil has a moderate to high level of permeability. Recommendation that can be given is the use plants with moderate amounts of water consumption with moderate tolerance to salt levels. Recommended plants according to IWQI value include corn, soybean, wheat, rice, tomato, cabbage, tobacco, mustard greens, celery, lettuce, papaya, pineapple, pumpkin, peanuts, cucumber, broccoli, tomato, cabbage, eggplant, spinach, potato, watermelon, radish.

1. INTRODUCTION

Water quality is a quality characteristic that is utilized from various water sources with certain criteria (Astuti, 2014). The criteria for water quality that have become quality standards as a requirement for water quality can be utilized by living things. Measurement of water quality can be adjusted to the intended use of the water, for example measuring the quality of water used for irrigation can be done using the irrigation water quality index (IWQI) method. According to Ayers & Westcot (1985) this method classifies types of plants according to the quality of irrigation water.

Irrigation is a process of flowing water using a system that functions to regulate the flow of water so that it can be utilized by the community in agriculture, households and others (Yusuf, 2014). This is the same as at the research location which is in Sukorejo Village, Bangsalsari District, Jember Regency. Farming communities use the Sukorejo Secondary Channel to meet their needs in their agricultural cultivation. Irrigation water used for agriculture apart from the quantity aspect, another aspect that needs to be considered is the quality aspect of irrigation water which must meet plant needs, for example mineral content (calcium and magnesium) in waters. Things that can cause mineral deficiencies are salinity and alkalinity problems in the waters distributed to agricultural land.

According to (Siswoyo *et al*., 2020a) an important factor affecting agricultural land is the quality of irrigation water. Therefore, to get good results, it is necessary to determine whether the quality of irrigation water is appropriate or not. The IWQI value represents the problem of salinity and alkalinity of irrigation water that flows into the soil, as well as the potential for toxicity (poison) problems to plants. The parameters of this method consist of sodium adsorption ratio (SAR), HCO_3^- (bicarbonate), Na^+ (sodium), Cl^- (chloride), and electrical conductivity (EC), (Siswoyo *et al*., 2020a). The IWQI method aims to determine the types of plants having relative tolerance criteria to salt, and classify plants according to the quality of their irrigation water. As a supporting factor in recommending plant types, additional things that need to be done are knowing the soil conditions on agricultural land that is watered by irrigation water. The measurements include soil permeability, aiming to determine the infiltration rate of the soil.

The purpose of this study was to determine the calculated value of the irrigation water quality index (IWQI) and soil permeability in the Sukorejo Secondary Canal. Based on the the values of soil permeability and irrigation water quality index (IWQI) resulted from this research, recommendation about suitable plant species can be proposed based in the command area of Sukorejo Secondary Canal.

2. MATERIALS AND METHODS

2.1. Location

The research was conducted in January 2022 at the the Sukorejo Secondary Canal. The Sukorejo Secondary Channel is within Bedadung Irrigation Scheme originating from the Bedadung Dam where the water was delivered to the Bedadung Primary Canal, then to the North Primary Canal, and finally to the Sukorejo Secondary Canal to be used as irrigation water (Figure 1).

The measurements of the quality of irrigation water was purposed to validate the research that was conducted in 2021 on the Bedadung River which is the source of water for the Sukorejo Secondary Canal. This research calculates the optimization of pollution load on the Bedadung river in the study area from Rambipuji District to District Balung (Chotimah, 2021). As a start in applying the IWQI method to Bedadung Irigation Scheme which has 21 secondary canals, the selection of research locations was based on the secondary canals closest to the previous study area (Rambipuji to Balung Districts).

Sampling of irrigation water was carried out at 1 point downstream of the Sukorejo Secondary Canal which irrigates 98 ha with coordinates (8°14'15.0"S, 113°31'31.7"E) and elevation 28 m above sea level (masl), located in Sukorejo Village, Bangsalsari District, Jember Regency. Testing of water quality samples was carried out in the field. The water quality was also analyzed at the PUSLIT Laboratory (Jember Regency) and at the Sucofindo Laboratory in Surabaya. Soil samples were taken at a location with the coordinates (8°14'15.1"S 113°31'31.2"E) and elevation 28 masl which was irrigated by the Sukorejo Secondary Canal. The map of the soil type was presented in Figure 2.

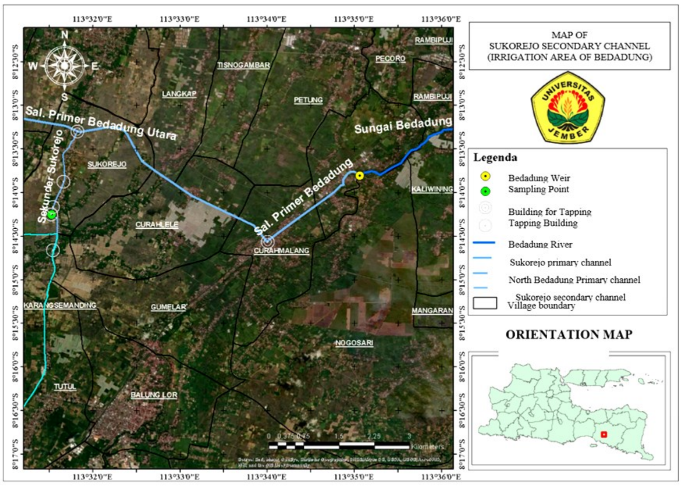

Figure 1. Sukorejo secondary channel

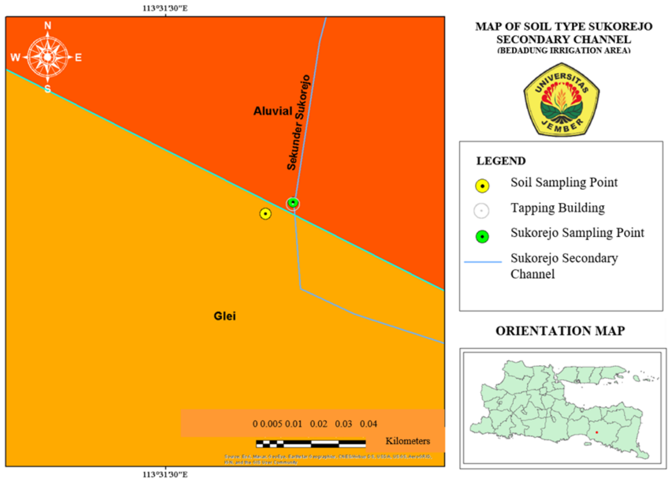

Figure 2. Map of soil type at the Sukorejo secondary channel

2.2. Materials

The tools used in the study included EC meters, GPS, cell phone cameras, cool boxes, sample bottles, sample rings, shovels and knives, plastic bags, plastic pipes, plastic wrap, cloth, rubber, measuring cups, atomic absorption spectrophotometer (AAS), funnels glass, measuring flask, beaker, measuring pipette, test tube, spray flask, filter paper, Maxi mix II tool, argentometry, beaker glass, pH meter, and pipettes. The materials used in this experiment included water samples, soil samples, distilled water, chloride reagent (Cl^{-}), H_2SO_4 solution, and $AgNO_3$ solution.

2.3. Analysis Methods

2.3.1. Water Sampling

Water sampling was performed according to the Indonesian National Standard (SNI) No 6989.57-2008 (BSN, 2008), concerning surface water sampling methods. Water sampling was conducted by using a bottle with the lid open and then directed in the opposite direction to the river flow until the bottle is completely filled with water. The process of taking water was carried out in the middle of the channel to maintain the original characteristics of the water sample. The bottle was then placed in a cool box.

2.3.2. Soil Sampling

Soil sampling was carried out by cleaning the soil surface, then digging the soil to a certain depth (5-10 cm), then leveling the soil with a knife. The copper tube was erected on the surface of the soil perpendicular to the ground, then using a small block placed on the surface of the tube, press the tube into the soil until three-quarters of the way. Place another tube on top of the first tube, and press it 1 cm into the soil. Separate the upper tube from the lower cylinder. Dig up the tube using a spade with the tip of the spade must be deeper than the end of the tube so that the soil under the tube is also lifted. Slice the excess topsoil carefully so that the surface of the soil is the same as the surface of the tube, then close the tube using the plastic cap provided (Suganda *et al*., 2006).

2.3.3. Calculation of Sodium Absorption Ratio (SAR)

Calculation of the sodium absorption ratio (SAR) value is based on the Equation (1) (Lesch & Suarez, 2009):

$$SAR = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca+Mg}}{2}}} \tag{1}$$

where Na is the sodium cation Na+ (meq/L), Ca is the calsium cation Ca+ (meq/L), and Mg is the magnesium cation Mg2+ (meq/L).

2.3.4. Calculation of Water Quality (qi)

The value of measured water quality (qi) was based on Equation 2 (Meireles *et al*., 2010).

$$q_i = q_{imax} - \left[\frac{(\mathrm{X_{ij}} - \mathrm{X_{inf}}).q_{\mathrm{iamp}}}{\mathrm{X_{amp}}}\right] \tag{2}$$

where q_{imax} is the maximum value q_i of class (Table 1), q_{amp} is the range of class, X_{amp} is the class range of a parameter, X_{ij} is the observed parameter, and X_{inf} is the value correspond to the lower limit of the parameter class.

Table 1. The values used in the calculation of water quality (q_i)

q_i	EC (µS/cm)	SAR (meq/L)	Na^+ (meq/L)	Cl^- (meq/L)	HCO_3^- (meq/L)
85-100	200 ≤ EC < 750	SAR < 3	2 ≤ Na^+ < 3	Cl^- < 4	1 ≤ HCO_3^- < 1,5
60-85	750 ≤ EC < 1.500	3 ≤ SAR < 6	3 ≤ Na^+ < 6	4 ≤ Cl^- < 7	1,5 ≤ HCO_3^- < 4,5
35-60	1.500 ≤ EC < 3.000	6 ≤ SAR< 12	6 ≤ Na^+ < 9	7 ≤ Cl^- < 10	4,5 ≤ HCO_3^- < 8,5
0-35	EC < 200 or EC ≥ 3000	SAR ≥ 12	Na^+ < 2 or Na^+ ≥ 9	Cl^- ≥ 10	HCO_3^- < 1 or HCO_3^- ≥ 8,5

Source: Ayers & Westcot (1994)

2.3.5. Calculation of Irrigation Water Quality Inddex (IWQI)

The IWQI method has previously been adapted by (Siswoyo *et al*., 2016) in Indonesia, especially in the Malang region, so that the provisions of the weight parameters have been adapted to conditions in Indonesia. The calculation of the value of IWQI was based on Equation (3) (Meireles *et al*., 2010).

$$IWQI = \sum_{i-1}^{n} q_i \cdot w_i \quad (3)$$

where IWQI values range (0–100), and w_i is weighing factor of the i^{th} parameter as listed in Table 2. Based on the IWQI value, the crop type can be recommended as in Table 3.

Tabel 2. Weighing factor (w_i) of parameters to calculate IWQI

Parameter	Weight factor (w_i)
EC	0.211
SAR	0.189
Na^+	0.204
Cl^-	0.194
HCO_3^-	0.202

Source: Ayers & Westcot (1994)

Tabel 3. Recommended crop type based on IWQI value

IWQI	**Water Utilization**	**Recommendation**	
		Soil	**Crop**
85 - 100	No limit	Low incidence of sodicity and salinity problems.	No risk of toxicity for most crops.
70 - 85	Low	Soil with light texture or soil with moderate permeability.	Not for salt sensitive crops.
55 - 70	Moderate	Soil with moderate to high permeability class, and is supported by a salt washing action.	Crops with moderate tolerance to salt can grow.
40 - 55	High	Soil with high permeability class without a compacted layer.	Crops with moderate to high level of tolerance to salt, accompanied by efforts to control salinity.
0 - 40	Critical	Avoid using it for irrigation under normal conditions, to prevent salt accumulation.	Plants with high tolerance to salt.

Source: Meireles *et al.* (2010)

2.3.6. Calculation of Soil Permeability

Calculation of soil permeability was carried out with undisturbed soil sample with 3 repetitions in the measurement. The sampling location was chosen in the area irrigated by the downstream Sukorejo Secondary Canal with an area of 98 ha. Calculation of soil permeability was based on Equation 4 (Suganda *et al*., 2006).

$$K = \frac{VxL}{HxAxt} \quad (4)$$

where K is soil permeability (cm/h), V is the volume of water stored (mL), L is the height of ring, H is the height of PVC tube, A is the surface area of the soil (equal to cross area of sample ring), and t is time (h).

2.3.7. Cation (Na^{+},Ca^{2+}, Mg^{2+}) Measurement

According to Eviati & Sulaeman (2009) analysis for sodium, calcium, and magnesium levels using Atomic Absorption Spectrophotometer (AAS), need that water samples were filtered to avoid impurities from the collection site, then diluted with distilled water. Dilution (depending on the concentration in the water sample) was purposed to improve the accuracy of readings on the spectrophotometer. The calculation was presented in Equation 5.

$$Cation\ (\mathrm{mg/L}) = C \times fp \tag{5}$$

where C is cation content from measurement (mg/L), and *fp* is dilution factor.

2.3.8. Analysis Cl^{-} (Argentometry Method)

The chloride content was measured using argentometry equipment with red silver-chromat formation. In this case, similar preparation for cation measurement was applied. The calculation for chloride was presented in Equation 6 (Eviati & Sulaeman, 2009).

$$Chloride\ \left(\frac{\mathrm{mgCl^-}}{\mathrm{L}}\right) = \frac{(A-B)\times N \times 35450}{V} \times fp \tag{6}$$

where *A* is the volume of $AgNO_3$ solution used for titration of water sample (mL), *B* the volume of $AgNO_3$ solution used for blank titration, *N* is the normality of $AgNO_3$, and *V* is the volume of water sample.

2.3.9. Analysis for HCO_3^-

The content of HCO_3^- in water samples was determined using the acid-base titration method. The water sample was put into the beaker glass, then the pH meter was put into the beaker glass, then titrated with H_2SO_4 solution until the pH become 4.5. The volume of H_2SO_4 used in the titration process was recorded. Calculation for HCO_3^- was presented in Equation 7 (Hidayat & Putra, 2014).

$$HCO_3^- = \frac{A \times N \times 50000}{V} \tag{7}$$

where A is the volume of H_2SO_4 for titration of water sample (mL), and *N* is the normality of H_2SO_4.

2.3.10. Electrical Conductivity

According to the Indonesian National Standard Number 06-6989.1-2004 (BSN, 2004), the electrical conductivity (EC) is measured with an EC meter. First, the electrode is rinsed with the water sample 3 times, then the electrode is inserted into the water sample until the EC meter shows a fixed reading, then the scale or number reading is recorded on the EC meter display and the temperature of the water sample is recorded.

3. RESULTS AND DISCUSSION

3.1. Values of IWQI

3.1.1. Irrigation Water Quality Parameters

Irrigation water quality parameters based on the IWQI method that have been calculated include sodium (Na^{+}), electrical conductivity (EC), chloride (Cl^{-}), bicarbonate

(HCO_3^-), and sodium adsorption ratio (SAR). Data on the results of water quality measurements in the Sukorejo Secondary Canal are presented in Table 4.

Table 4. Water quality parameters in the Sukorejo Secondary Canal and their classification

No	Parameter	Unit	Result	Classification
1	Natrium (Na^+)	meq/L	0.25	Good
2	Electrical conductivity (EC)	µS/cm	185	Good
3	Chloride (Cl^-)	meq/L	0.12	Good
4	Bicarbonate (HCO_3^-)	meq/L	1.69	Adequate
5	Sodium Adsorption Ratio (SAR)	meq/L	0.33	Good

Based on Table 4, the results of measuring the sodium parameter in the study (0.25 meq/L) in the irrigation water of the Sukorejo Secondary Canal was classified as good because in the range of 0-3 meq/L. The sodium content in irrigation water is suitable for various types of agricultural crops. The lower the sodium value in the irrigation water indicates that the quality of the irrigation water is in good condition, and vice versa if the sodium is high it will affect the movement of water though osmosis and the balance of calcium and magnesium ions in plants (Mindari, 2009).

The parameter of electrical conductivity (EC) of the water sample is 185 µS/cm. This value is included in the good classification because lower than 750 µS/cm. This value has no salinity potential. According to (Siswoyo *et al*., 2020a) salinity and electrical conductivity have a directly proportional relationship, meaning that as the salinity is low, the electrical conductivity is also low. According to Ashraf & Harris (2004) high salinity can affect productivity, especially rice plants because it can reduce chlorophyll and mineral content.

The chloride parameter value obtained was 0.12 meq/L, and this value was included in the good classification because lower than 4 meq/L. Based on Government Regulation Number 22 of 2021 (Presiden RI, 2021), the chloride value is below the maximum limit for irrigation water, namely maximum of 8.57 meq/L. Low chloride values do not have the potential for salinity problems in irrigation water and agricultural land. Low chloride elements in irrigation water can play a role in plant growth processes including distributing water into photosynthetic oxidation sites, enzyme activity, limiting ions to transfer cations, regulating stomata opening in plants, as well as regulating osmosis process (Purwono *et al*., 2020).

The bicarbonate (HCO_3^-) parameter at the study site was 1.69 meq/L, which is in the range of 1.5-8.5 meq/L, and therefore is classified as moderate. The bicarbonate value obtained has the potential to cause high alkalinity problems. Bicarbonate is the main constituent of alkalinity in irrigation water. If the bicarbonate value is high compared to other elements, it will affect several types of agricultural crops. Bicarbonate in water relates to the degree of saturation of calcium carbonate ($CaCO_3$) (Perdana & Susanti, 2017). Therefore, it is necessary to reduce the bicarbonate content in order to avoid the occurrence of alkalinity problems on agricultural land.

Calculation of the sodium adsorption ratio (SAR) obtained a value of 0.33 meq/L, which is included in the good classification with a low range of less than 3 meq/L. The SAR value does not have a potential danger of sodium for agricultural land. According to (Siswoyo *et al*., 2020b) the SAR value represents the danger index of sodium in water used for irrigation. If irrigation water has a high SAR value, it will have a negative impact on soil and plants because the high sodium (Na^+) content can inhibit photosynthesis; conversely if the SAR value is low then the water has good quality for soil and plants (Farruq, 2018).

3.1.2. Calculation of IWQI

Based on the calculation using the IWQI method that has been carried out, the parameters Na^+, EC, Cl^-, HCO_3^-, and SAR as in Table 4 are used to determine the water quality value (q_i) for each parameter. The results of the calculation of measured water quality (q_i) and the IWQI with are shown in Table 5.

Table 5. The calculated value of measured water quality (q_i) and IWQI

No	Parameter	Nilai (q_i) Hasil Penelitian	Bobot (w_i)	IWQI
1	Na^+ (meq/L)	30.55	0.204	6.23
2	EC (µS/cm)	2.63	0.211	0.55
3	Cl^- (meq/L)	99.54	0.194	19.31
4	HCO_3^- (meq/L)	83.43	0.202	16.85
5	SAR (meq/L)	98.37	0.189	18.59
		Total		61.54

Based on Table 5, the measured water quality (q_i) multiplied by the weighing factor (w_i) results in an IWQI total value of 61.54. The IWQI values obtained in this work falls within the range of 55–70, which is classified as moderate use of irrigation water for plants according to the classification of IWQI values in Table 3. Irrigation water quality with a moderate IWQI value can be used for plants with moderate salt tolerance. The IWQI value at the study site has the potential for alkalinity problems caused by the bicarbonate content. One alternative that can be done to reduce bicarbonate is using the phytoremediation method. This can be carried out by providing plants that have the ability to reduce the risk of contaminants by removing polluting ingredients (Retnaningdyah & Arisoesilaningsih, 2018). Some plants for phytoremediation include Mendong (*Fimbristylis sp.*). Wlingi grass (*Scirpus*), dlingo (*Acorus calamus*), taro (*Colocasia esculenta*), lotus (*Nymphaea sp.*), and kale (*Ipomoea aquatica*). Phytoremediation plants can be placed on tertiary channals. The recommendations for the IWQI method for determining plant species according to Ayers & Westcot (1985) is shown in Table 7.

Table 6. Recommended plant species based on IWQI values

IWQI	Water Utilization	Plant criteria based on IWQI method	Recommended plant type
85 - 100	No limit	No toxcisity for all plants.	Most plants can be grown
70 - 85	Low	Not for salt sensitive plants.	Peanut, corn, soybean, sugarcane, green beans, onion, Pomelo (Bali oranges), srikaya, avocado, lime, mango.
55 - 70	Moderate	Plants with moderate tolerance to salt can be grown.	Corn, soybean, wheat, paddy, tomato, cabbage, tobacco, mustard, celery, lettuce, papaya, pineapple, pumpkin, peanuts, grape, strawberries, cucumber, broccoli, mulberry, cabbage, eggplant, spinach, potato, watermelon, turnip, sorghum cowpea.
40 - 55	High	Plants with moderate to high tolerance to salt accompanied by efforts to control salinity.	Sorghum, cowpea, wheat, soybean, papaya, pineapple
0 - 40	Critical	Plants with high tolerance to salt.	Cotton, sugar beets, and barley

Source: Ayers & Westcot (1985); Syahputra (2021)

3.1.3. Soil Permeabilitas

Soil permeability is closely related with the IWQI method because there are recommendations from IWQI for soil permeability criteria in each class of IWQI values. The area that represents the measurement is 98 ha with the map shown in Figure 2. Results of soil permeability measurements at the study site is shown in Table 7.

Table 7. Soil permeability values

Soil permeability	Permeability class	Criteria soil permeability with IWQI method
1.75 cm/h	Slow	Soils having a moderate to high permeability class, and supported by salt washing action

Soil permeability in the study area is classified as slow with a value of 1.75 cm/h. Soil texture in the study area is physically clay. Slow soil permeability inhibits the rate of infiltration. Infiltration rate and soil permeability are directly proportional, if the infiltration rate is slow then the permeability of the soil is also slow. Infiltration rate is the amount of water that enters the soil per unit time (Siswoyo & Kurniawan, 2021). One of the factors causing the slow permeability of the soil at the research location is due to the alluvial soil type which has a dense soil structure and is categorized as the semi-clay, clay, or sandy loam. Glei soil type is also a factor because it has a sandy loam to sandy clay texture, has a crumb and cube structure (Tufaila, 2014). Based on soil permeability at the research location, it implied that the soil needs to be improved. This can be done by providing ameliorant materials such as compost, manure, and humus. Provision of ameliorants which have the ability as a soil enhancer in the form of organic and inorganic materials can increase soil fertility, helps in the absorption of nutrients, has a lot of nutrient content which is good for plant growth, and can increase soil permeability (Afrina *et al*.. 2020).

3.2. Determination of Plant Type

In addition to the quality of irrigation water and soil permeability, the thing that also needs to be adjusted is the type of plant. The type of plant can be adjusted according to the IWQI value. Adjustment of plant type based on the value of the IWQI method can be taken into consideration by farmers at the research location. Recommendations based on the IWQI values in Table 6 are then adjusted according to the abilities of farmers in the research locations which have been recorded by the Central Statistics Agency (BPS, 2020), Bangsalsari District, Jember Regency as shown in Table 8.

Table 8. Plant types reccomended for farmer at the research location

IWQI	Water utilization	IWQI value	Plant Recommendation
55 - 70	Moderate	61.54	Corn, soybean, wheat, rice (superior varieties: Mekongga and Ciherang), tomato, cabbage, tobacco, mustard, celery, lettuce, papaya, pineapple, pumpkin, peanuts, cucumber, broccoli, tomato, cabbage, eggplant, spinach, potato, watermelon, turnip.

Types of plants recommended for planting by farmers are selected by considering the selling value. For example, vegetable are classified as high-economic crops because the demand for organic vegetables and nutritious food products is increasing over time along with a healthy lifestyle in society. In addition, palawija plants (tuber and sereals) are an option when entering the rainy or dry season, because it does not require much water compared to rice plants. At the research location, palawija crops which are often planted are corn and soybeans. Likewise, rice plants are included in the obligatory seasonal crops that have been determined by the government to meet the needs of the community as a staple food.

Based on the IWQI assessment at research locations that fall into the range of 55-70 there are several types of plants that are recommended for alternative farmers. At the research location, farmers generally cultivate lowland rice with 2 dominant varieties, namely Mekongga and Cibogo varieties. Rice plants are classified as plant with medium tolerance to sensitive to salinity, depending on the variety (Mindari, 2009). According to Syahputra (2021), Ciherang and Mekongga varieties are among the superior rice having good resistance from soil salinity and alkalinity problems based on the germination, vegetative, and generative groth phases. Farmers who use irrigation water from the Sukorejo Secondary Canal are recommended to cultivate both rice varieties.

4. CONCLUSIONS

Based on the research results obtained the following conclusions: 1) the IWQI value in the Sukorejo Secondary Canal are 61.54 in the range (55-70) and the soil permeability is 1.75 cm/h. Based on IWQI values, the soil is classified as having moderate to high levels of permeability. The IWQI value can be increased by lowering the bicarbonate ion. Likewise, soil permeability needs to be increased by adding ameliorants. The higher the IWQI and soil permeability values, the better the irrigation water quality and infiltration rate. 2) Plant species recommended at research sites based on IWQI values including corn, soybean, wheat, paddy, tomato, cabbage, tobacco, mustard, celery, lettuce, pawpaw, pineapple, pumpkin, peanuts, cucumber, broccoli, tomato, cabbage, eggplant, spinach, potato, watermelon, radish, and peanuts. It is necessary to measure all irrigation water from secondary canals as well as water from drilled wells in Jember Regency to avoid problems of salinity and alkalinity in irrigation water and to keep high plant productivity.

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