The Impact of Various Environmental Changes Surrounding Paddy Field on Its Water Demand in Japan

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ABSTRACT

This review article aims to summarize and analyze comprehensively the impacts of various environmental changes surrounding the paddy fields after the World War II on each component of the irrigation water requirement in the paddy field. And it will serve as an introduction to typical water management and irrigation planning for paddy field in Japan. As a result, it could be explained that many factors such as “separated irrigation and drainage canals”, “pipeline irrigation”, “well-drained field”, “a large-size lot”, “rotational use of paddy field”, “direct seeding”, and “urbanization” enhanced to increase the water requirement and decrease the reuse of irrigation water, which resulted in promoting to increase the total water demand for the paddy field. For this reason, it is difficult to reduce the irrigation water demand with the decrease of paddy field areas.

Keywords
direct seeding, large-sized paddy field, reuse of irrigation water, urbanization, water requirement rate

1. Introduction

In Japan, paddy has always been closely linked to people’s lives and has a long history of 2000 years (Tomita, 2013). In 1945, paddy production occurred lean crop and the crop situation index (the ratio of actual yield per 10 a to the normal yield per 10 a multiplied by 100) was 67 due to the serious damage of war. However, immediately from 1945 after World War II, farmland consolidation had brought a rapid increase in rice production. The yield per 10 a increased by about 30% from an average of 285 kg in three years of 1945-1947 to an average of 369 kg in three years of 1955-1957 (Senboku, 2004). Furthermore, the consumption of rice also got a peak in 1962 with 118 kg per capita per year, however, there occurred an oversupply of rice from the late 1960s due to improvements in production techniques and consumption decrease caused by the changes in eating habits. According to eating habits, consumption of rice has decreased to 54 kg per capita per year in 2016 (MAFF, 2018). Then, production adjustment had been carried out by Japanese government from 1971, which was called Acreage Allotment Programs (Kitahara, 2011) in purpose to solve the problem of oversupply of rice (Amao, 2015). After the oversupply in the 1960s, the cultivated area of paddy fields was reduced by the policy of Acreage Allotment Programs (Tomita, 2013).

Furthermore, the farmland area of Japan has been decreasing year by year with the progress of urbanization (farmland conversion to residential areas, commercial stores, factories, etc.) and the increase of abandoned cultivated land (defined as the farmland which has not been cultivated more than one year and has no plan to be cultivated for several years).
The historical changes of rice production and paddy field after the World War II, oversupply of rice, production adjustment policy (Acreage allotment policy, and option policy etc.), and reduction of paddy field area with the urbanization finally brought a sudden decrease in paddy field areas. Paddy field area was 2,719,000 ha in 1975 and it became 1,478,000 ha in 2016, which meant paddy fields areas reduced 46% for 41 years (Fig.1). Thus, the paddy field has been reduced drastically, however, the amount of irrigation requirement has not been decreased.

Figure 1: The changes of paddy field area, Source: MAFF (2020)

Figure 2: The changes of irrigation requirement, Source: MLIT (2019)
significantly (Satou, 1997). The amount of irrigation requirement was decreased by 5.6% in 41 years from 1975 to 2016 (Fig. 2). In accordance with the reduction of paddy field areas, the regional water requirement of the paddy field should be reasonably reduced much.

On these backgrounds, the purpose of this study is to summarize and analyze several critical factors and explain the reason why it is difficult to reduce irrigation requirement with the reduction of paddy fields areas.

2. The components of total water requirement for paddy field irrigation

In the water requirement design for paddy field area, a unit field is not used as irrigation planning, but a group of several paddy fields having the same characteristics are used as a basic unit. Several kinds of unit blocks will be integrated to form a beneficiary area. Based on unit blocks or beneficiary areas mentioned above, the minimum water requirement of a whole regional area is to be estimated and is called as “regional irrigation requirement” (Mitsuno and Maruyama, 1983; Furuki, 1991).

The components of the total water requirement for paddy field irrigation have been interpreted by the Agricultural Structure Improvement Bureau as shown in Fig. 3 (MAFF, 2010).

Figure 3: Components of total water requirement for paddy field irrigation, Source: MAFF (2010)
Design irrigation water requirement is composed of “unit water requirement” which is the summation of “water requirement rate” and “lot management water requirement”, “facility management water requirement”, and subtracting the “effective rainfall” and the “available water resource in the district” as a part of water resources. Each item will be appropriately determined with considering the characteristics of the beneficiary area such as current water use and future trends.

As shown in Fig.4, flooding water in a paddy field gradually decreases in water depth due to evaporation from the water surface, transpiration by rice plant, and percolation into the soil. This reduction in water depth is called “water requirement rate”, and it is used as a basic parameter to express irrigation water requirement for paddy fields, which most affects the amount of paddy irrigation water. “Evapo-transpiration” (evaporation + transpiration) is influenced by two main factors: meteorological conditions (air temperature, humidity, solar radiation, wind velocity, etc.) and plant growth (species, soil, cultivation method etc.). “Percolation” is divided into two components; vertical and horizontal percolations, which are influenced by hydraulic condition (hydraulic gradient) and soil permeability. Isozaki (1957) proposed the optimum percolation rate to be 10-15 mm/d suitable for rice production.

The “lot management water” is required to enable water management based on various cultivation techniques in a paddy field, which is not only to keep the flooding depth almost constant, but also deep ponding irrigation, intermittent irrigation, and surface flooding irrigation in some cases. These are water management for preventing low or high temperature injury (Tomoshou and Yamashita, 2009), increasing productivity, maintaining crop quality et al. With such water management, the amount of water that flows out of the field in the form of forced outflow or surface runoff due to overflow is called “lot management water”. Watanabe and Maruyama (1984) showed the average value of “lot management water” was 3.5mm/d based on the observed data of 73 fields all over Japan, which was mainly influenced by field area, percolation rate and water management labor.

The “canal-system management water requirement” is composed of the followings; the “conveyance loss” occurred as seepage and evaporation in the water supply system, the “delivery water requirement” necessary for reliable and easy water distribution, and “facility function maintenance water” needed during the non-irrigation
period for maintaining the waterway functions. There is a tendency that “delivery water requirement” and “lot management water” shows a mutually complementary relation, excluding the periods when the water intake is quite low (Toyota et al., 1984; Suzuki, 1994).

On the other hand, “effective rainfall” and “available water resource in the district” can reduce the amount of “irrigation water requirement” as a part of the water supply. The “effective rainfall” is a portion of the rainfall available in the paddy field as a replenishment water in irrigation planning. And “available water resource in the district” is the water amount that can be secured as “supplementary water resource” (pond, stream and small river etc. located inside the beneficiary area) and “reuse of irrigation water” that is inherent in the district and can be considered as a replenishment amount in irrigation planning when it can be effectively used as a stable water source. The representative methods to estimate “reuse of irrigation water” are the CB method and a complex tank model.

The CB method was proposed by Okamoto (1973) to calculate the maximum “paddy field irrigation water requirement” for paddy fields district where water is reused internally, and many researchers applied this method for estimating the water demand of paddy filed area (Satou and Okamoto, 1985; Mitsuno and Maruyama, 1983; Senge et al., 1995). CB method can be applied only for the period when the water flow is stable and the water demand is maximum during continuous dry weather, but it cannot be applied for the rainfall period. In other words, this method does not consider the effect of the precipitation on water requirement. In this method, the paddy field areas in the irrigation planning are regarded as a group of some unit blocks, which are separated into 3-type blocks (CB, NB, and RB) based on the relation of repeated water use between unit blocks as follows; NB block whose water demand is satisfied by the return flow from an upstream block, CB block whose return flow is not used or used by NB block, and RB block whose return flow is used by downstream CB block. Here, the amount of water can be calculated by the equation: RB area × water consumption (evapotranspiration) + CB area × water requirement rate.

The complex tank model was proposed by Maruyama et al. (1979). This method is devised so that the target area is divided into several unit tank models reflecting the land use condition and the change in river discharge can be calculated at any points in the target area. Complex tank model emphasizes on the accurate calculation of unstable flow rate in the target research places and it can response to changes of land use in the basin. However, the main demerit of this method needs a large number of model parameters which must be identified.

3. Farmland consolidation

The purpose of the farmland consolidation is to comprehensively improve the field conditions such as irrigation and drainage, and roads, focusing on the change of plot characteristics of farmland. And also, it attains the field conditions with high productivity such as the efficient use of agricultural machines and rational water management suitable for the future farming style by implementing an integrated use of farmland and systematic land use including non-farm land in order to contribute to the development of principal farmers. In addition, farmland consolidation plays an important role in improving productivity and rural environment, revitalizing the region, etc. through the improvement of field conditions and the regulating the land use under the considerations whose multifunctional effects can be fully exhibited (MAFF, 2013).

Farmland consolidation mainly has two effects. The first effect is to improve agricultural productivity by the modernization of agriculture with large agricultural machinery, high flexibility of water management and improvement of less fertile soil. The second effect is realized as economical rice production from accelerating intensive farmland use by efficient large-scale farmland (Kunimitsu, 2005).

Farmland consolidation includes many kinds of projects such as the independent setting of irrigation and drainage canals, enlargement of the paddy-field lot, establishment of well-drained field and pipelined irrigation canal.
This chapter describes the impact of some typical farmland consolidations to the water requirement of the paddy field.

3.1 Independent setting of irrigation and drainage canals

In case of a dual-purpose canal for irrigation and drainage (see the left side of Fig.5), all paddy fields are restricted by the same water management (irrigation or drainage) of the canal that they rely. When one paddy field is taking water from the dual-purpose canal, the other paddy fields cannot be drained to the same canal due to its higher water level than the ground surface. To solve such difficulties of water management, the irrigation and drainage canals should be set separately (see the right side of Fig.5) by the farmland consolidation. However, this causes the increase in irrigation water because it is difficult to use the irrigation water repeatedly. Furthermore, a “lot management water requirement” through the continuous flowing irrigation and the surface drainage during rainy time will be increased, which causes an increase of a “unit water requirement”. On the other hands, the water level in the drainage canal can be lowered and the difference between the water levels on the paddy surface and in the drainage canal will widen, which also cause the increase of percolation (downward and lateral percolation from paddy field) and, accordingly “irrigation requirement rate” will be increased. Although these phenomena have been qualitatively discussed by many experts (e.g. Toyoshima et al., 1984), no quantitative studies have been found.

Independent setting of irrigation and drainage canals is essential requisite for well-drained paddy field, pipelining, large-sized paddy filed, and rotational paddy field as described below. It surely makes difficult to use a return flow from the upstream paddy fields, and increases the percolation rate due to the lowering of ground water level, which enhance to increase the water demand of paddy field. Furthermore, “a lot management water” increases due to that the precise water management is enabled for a rice cultivation. To integrally summarize the above phenomena, it can be concluded that the irrigation water requirement must increase by the independent setting of irrigation and drainage canals.

Figure 5: Independent setting of irrigation and drainage canals, Source: MLIT (2013)
3.2 Reformation into well-drained paddy field

Conventional paddy fields are always wet field or semi-wet field by always high ground water level, where the water demand is reduced due to low infiltration. However, the ground is always wet due to difficulty of underdrainage. It has two main demerits of high labor force due to difficulty of machinery work such as tractor and low productivity without summer airing of soil.

Reformation into well-drained paddy field is the process of converting the wet and semi-wet fields into the dry fields by lowering the groundwater level. The planned water requirement rate is determined as 10–20 mm/day around in 1950 in Kamedagou district (Mizutani, 1980). However, actual water requirement rate exceeded this value and reached 20–30 mm/day. The main cause of this is the change from wet field and semi-wet field to the dry field. Reformation into well-drained paddy field makes the soil into dry condition. This dry condition can be obtained by deep open-channel drainage, underdrainage, and subsoil breaking. As a result of the dry condition, it is possible to install agricultural working machines and improve labor productivity due to an increase of bearing capacity and trafficability in the field. It can be also expected to enhance the soil fertility through the temperature rising and soil drying effects and stabilize the productivity by increasing the percolation of warm surface water. By converting to dry fields, it is possible to improve land use such as introducing off-season cropping after rice cultivation and adopting paddy-upland rotational farming. However, the increase in irrigation water requirement becomes a problem in the well-drained paddy field. It is said that the increase in the amount of irrigation requirement is caused by the increase in percolation rate accompanied with the well-drained paddy filed (Kano et al., 1961; Nishimura et al., 1984). As introduced above section 2, percolation has two components as vertical (downward) percolation and horizontal percolation (ridges percolation). And the main factors which affect the downward percolation is hydraulic conditions and soil permeability. The hydraulic conditions will have changes due to the under drainage pipes in the paddy field, which causes the increase in hydraulic gradient between soil surface and groundwater level. On the other hands, soil becomes dry due to the lowering the underground water level in non-irrigation season. Therefore, the soil permeability has been increasing year by year after introduction of the under drainage pipes. The changes of the two above factors enhance the increase of downward percolation, which causes to increase the “irrigation water requirement” of a well-drained paddy field.

3.3 Pipelining irrigation canal

Pipelining is aiming to reduce the maintenance cost and ensure stable water supply by creating a pipelining irrigation canal to replace an aged open channel which cannot provide enough water due to deterioration over time. Reviewing the previous research about the effects of pipelining on irrigation water, there are opposite results reported as pipelining increases the irrigation water requirement while it decreases the irrigation water requirement based on the different research districts.

Fujii et al. (2009) indicated that pipelining decreases the irrigation water requirement in Shinotsu District. As a result of calculating the decreasing rate of water requirement by pipelining, it was 21.9% for Tsugigata Shinotsu district, 8.7% for Nakakoya district, 25.8% for Mihara district and 17.5% for Kawaminami district. Tanaka (1979) indicated the amount of irrigation water requirement in the pipelined area is 40% to 50% less than that of the open channel in the two blocks of 10 ha and 15 ha in Toyota City. Toyota et al. (1984) also indicated that irrigation water requirement decreased to 1,296 mm in 1981 from 2,255 mm in 1973 after pipelining in the research place of A district. Pipelining contributes to the decrease of “management water requirement” (Ezaki et al. 1984; Furuki, 1991). On the other hands, Maruyama et al. (1980) pointed out that the pipeline irrigation system could cause a problem of increasing irrigation water due to the following reasons. The most important feature of pipelining is the easiness of
water management. Due to this feature, sufficient management is not performed due to a reduction of labor required for water management, which can increase “lot management water” and “canal-system management water”. Oikawa et al. (2011) indicated that total water intake trends to increase due to pipelining in the research district. Furthermore, since the pipeline system is essentially based on the “independent setting of irrigation and drainage system”, water resource cannot be used repeatedly inside the irrigation area, and the water utilization customary practice will be changed, which may increase the water intake in the area. Also, underground burying type pipelines are generally difficult to maintain and manage, sometimes burst, and difficult to repair, leading to water loss due to water leakage.

According to the report by Miyamoto and Yamamoto (1999), the problems such as difficulty of uniform water distribution and air mixing into the pipeline system occurred even under normal water condition. Especially at the time of drought, water saving rule is difficult to be executed due to the demand-oriented water control in a pipeline system that enable individual farmers to operate water management by each individual decision.

As mentioned above, pipelining canal has two opposite effects; it almost completely reduces “the delivery water requirement” or “management water requirement”, which decrease an irrigation water demand; however, water resource cannot be used repeatedly, which increase an irrigation water demand. On the other hand, it is very difficult to mention whether the easiness of water management by pipelining increases or not an irrigation water demand.

3.4 Enlarging paddy field (large-sized paddy filed)

Large-sized paddy field refers to a field lot larger than 30 a (standard lot: short length× long length, 30 m×100 m); generally, it refers to a lot of 50 a to 1 ha or more. The purpose of enlarging paddy field from the standard size (30 a) to large-sized paddy field is to promote the farmland accumulation and consolidation for production cost reduction and saving labor of farm work in order to respond to the changes in the situation of agricultural and rural areas such as a decrease in the number of agricultural workers due to aging of the labor force, a decrease in agricultural income, and diversification of demand for food and agricultural products (Yamaji, 1990). To reduce the cost of rice production, some main measures were carried out such as saving the labor of water management, the introduction of large agricultural machine, etc., which were attained by the improvement of a drainage system, pipelined, under drainage pipes, separation of irrigation and drainage channel, etc. accompanied by enlarging paddy field (MAFF, 2017). There are two methods to increase the size of the plots; (1) a ridge removal method that expands in the short side direction of the plot (Isozaki, 1989), and (2) a road removal method that replaces the road with a drainage channel and expands in the long side direction. Both methods need to level the field surface inside the field block surrounded by roads and waterways.

The water requirement of the fields will have changes depending on the acreage change by enlarging the paddy field as follows (Fig.6).

1) In general, with the increasing the cultivated area, the following three matters will have changes. The amount of water of per unit area becomes larger. The irrigation time becomes longer. Water intake rate becomes higher. On the other hands, the infiltration ability might be reduced by increasing the distance from the drainage channel (Watanabe and Maruyama, 1989).

2) The long side length of a lot (side length orthogonal to the irrigation canal) affects the amount of required water (Watanabe and Maruyama, 1989). The longer the long side of lot becomes, the longer it takes for the waterfront to reach the downstream end of the paddy field, and the longer the time is required for flooding to the required depth. In addition, the intake flow rate must be increased in order to flood the required depth within the allowable time. These problems occur especially when a non-flooded field is irrigated during puddling (initial irrigation) or after mid-summer drainage. According to the result of test field observation (Lee et al., 2001), an initial irrigation of an
enlarged paddy field is required more than the proportion of field area increase. The loss of water occurs considerably in a field with a high infiltration rate during intermittent irrigation after mid-seasoning. Usually, both plow sole layer and subsoil are dry during this period, and the infiltration rate is significantly greater than the other irrigation period (Yang et al., 1995).

3) The height differences and levelness of soil surface in the large-scale paddy field also become problems. According to the Yamaji (1989), the leveling accuracy of the paddy field generally decreases with the increasing of the cultivated area. This causes an increase in the amount of water, irrigation time, and water intake rate required for flooding the large-scaled paddy fields (Watanabe and Maruyama, 1989).

4) The amount of water consumption is also affected by the uniformity of water management everywhere in large paddy field (Watanabe and Maruyama, 1989), because the field level became unevenness due to the enlarging paddy field (Naganoma, 1995). This causes the difficulty of adjusting the ponding depth all over the paddy field. The management of ponding depth affects a “lot management water requirement”. This situation also sometimes brings the excess water, which is discharged from the water outlet mouth, in order to ensure that the water supply to some critical parts which are difficult to be irrigated. As a result, the difficulty of uniformity of water management due to unevenness of the field level causes the increase of the irrigation water requirement.
5) The percolation capacity of the paddy field has change due to the farmland consolidation. In particular, the large and heavy construction equipment such as bulldozer is often used for land readjustment work, and then the permeability of soil becomes reduced and water requirement rate will also be reduced (Maekawa and Maruyama, 1983; Furuki et al., 1967). In addition, the percolation capacity will be reduced due to the introduction of the agricultural working machine. This causes a decrease of intake water in irrigation season (Watanabe and Maruyama, 1989), and subsurface drainage of the field is also reduced (Naganoma, 1995).

As mentioned above, there are also two opposite effects of enlarging paddy field; Factors to increase the water demand of paddy field are an increase of ponding water depth on field, poor uniformity of field surface, increase of long side length, and difficulty in water management. On the other hand, a factor that reduces the water demand is the reduction of the infiltration capacity due to the compression of cultivated soil by the agricultural working machine. Totally, it is difficult to say whether the water demand increase or not by enlarging paddy field.

4. The influence of rice farming management

4.1 Rotational paddy field

In order to eliminate the overproduction of rice, which became constant in the 1970s, many paddy fields in all Japan were set aside for fallows or crop rotations based on an acreage-reduction policy. Furthermore, since 1974, the use of paddy fields as an upland field has been promoted to meet the demand for agricultural products other than rice. In order to introduce field crops cultivation into the farmland that has the completely different characteristics of a paddy field, an environment suitable for growing field crop such as drainage measures, irrigation method, and lot shape must be created (Adachi, 1988; Furuki, 1991).

If a paddy field was cultivated as a normal field, generally the soil gets dry, and also, soil contraction also occurs which causes cracks in the soil layer. The greater the degree of dryness is received, the lower layers are affected, and the plow sole is destroyed by cracking. Dryness of soil makes the soil hydrophobic and causes the progress of changes in soil quality and soil structure (Nagahori and Takahashi, 1977).

Therefore, the soil condition and hydraulic condition will have big changes in paddy field after using as normal filed (hereafter referred to as “restored paddy field”), consequently irrigation requirements will increase.

Adachi et al. (1976) reported that “water requirement rate” of a restored paddy field after cultivation as the dry field for only one year was about 1.8 times before the mid-summer drainage (Nakaboshi) and 1.4 times after it as compared with that of the consecutive paddy fields (cultivate only rice for many years). Furthermore, “water requirement rate” of a restored paddy field after cultivation as a dry field more than 4 years increased about 2.1 times before the mid-summer drainage and 1.9 times after it as compared with that of the consecutive paddy fields. However, “the water requirement rate” of the restored paddy field gradually decreased when it was consecutively used as a paddy field, and finally approached to the value close to the consecutive paddy fields at four years after conversion from dry field to the paddy field. Furuki and Satou (1979) also showed by field observations that the longer the duration of dry field cultivation was and the higher the soil permeability was, the more the “water requirement rate” of restored paddy field increased.

On the other hands, Sakata et al. (2008) appointed that in the low-lying rice field area, the crop-changed paddy plot influenced the water balance in the adjacent paddy plot. The initial irrigation water of the adjacent paddy plot at the beginning of the irrigation period tended to seepage into the crop-changed plot due to that its soil condition was dry by consecutive crop rotation. As a result, at the beginning of the irrigation period, the amount of the water requirement at the paddy plot adjacent to the crop-changed paddy plot was larger than at the plot sandwiched by paddy plots.
It can be summarized briefly from the previous researches that the “water requirement rate” of the restored paddy field generally becomes higher than the consecutive paddy fields due to the increase of percolation rate by the change of soil permeability during it was used as an upland field.

4.2 Direct seeding rice cultivation

Direct seeding, where rice seeds are directly scattered into a paddy field, can skip raising-seedling and transplanting steps required for the conventional practices as transplanting cultivation. There are various direct seeding methods, which are roughly divided into two groups; submerged direct seeding where seeds are scattered into submerged paddy field after tillage & puddling or without tillage, and dry direct seeding where seeds are scattered into dry paddy field after tillage or without tillage (Fig. 7).

Direct seeding rice cultivation has been focused on the merit of labor saving, reduction of production cost, and expansion of agricultural management (Makiyama et al., 1999). Especially, labor saving of dry direct seeding cultivation is higher because it is omitting the puddling process. However, dry direct seeding is expected to cause an increase in water requirement due to no puddling work. This will lead to an increase in the total irrigation requirement due to higher permeability of plow sole layer compared to transplanting field, finally cause a water shortage by current design irrigation planning (Furuki, 1991).

The results of previous research comparing the water requirement for transplanting and the direct seeding field was introduced as follows.

It was reported by Lee et al. (2003a) based on the 123 data of observed daily water requirement rate for 31 test fields that the average of transplanting cultivation was 13.7 (SD: ±13.6) mm/d, while that of direct seeding on the dry field was 48.3 (SD: ±43.7) mm/d with higher standard deviation (SD), which shows 3.5 times higher than

![Diagram of direct seeding methods]

Figure 7: Type of direct seeding
transplanting cultivation. Furthermore, the water requirement rate of the direct seeding dry paddy tended to be strongly affected by the water level of the drainage channel, which showed an increase of the ridge percolation to the drainage channel in the paddy field without ridge coating. And it was also reported by Lee et al. (2003b) based on water balance observation in 2 test fields for three years that the “water requirement rate” of direct seeding cultivation was 1.75 times the transplanting paddy field (Table 1). While “lot-management water requirement” has strong changes year to year, but that of transplanting cultivation was generally higher than direct seeding cultivation. The average of direct seeding rice cultivation in two years was 1.2 mm/d, while that of transplanted cultivation was about 3.3 times that of 4.0 mm/d. This result was caused by a high water requirement rate of direct seeding dry field, which forced always lower water depth on the field compared to transplanting field.

Sakata et al. (2001) also showed the same results that the total water requirement of dry direct seeding cultivation (2,080 mm) is 1.46 times of submerged direct seeding field (1,421 mm), 1.99 times of transplanted cultivation (1,043 mm). It is also reported by Koshiyama (2015) based on observation of one field under sub-irrigation for three years that the total water supply of direct seeding field before mid-summer drainage was 1.1 times of transplanting field and after mid-summer drainage increased to 1.5 times of transplanting field. And Koshiyama et al. (2017) also reported that the total supply water of submerged direct seeding and dry direct seeding during cultivation were 1.1 times and 1.3 times of transplanting cultivation, respectively. Furthermore, Hisada et al. (2006) showed that the direct seeding dry field kept the ponding water depth higher than the transplanted paddy field, which caused its ridge percolation to increase.

On the other hands, it was reported by Taniguchi and Satoh (2006) based on 4 year-water balance observation comparing 2 fields (direct seeding tilled dry and transplanting fields) that the tillage for plow sole breaking in direct seeding field had effected to promote infiltration at 1st year, but water requirement rate had been decreasing year by year and almost the same as the transplanted field two years later.

Summarizing the above results, it can be concluded that dry direct seeding causes an increase in water requirement compared to the transplanting rice fields due to no puddling and ridge coating.

5. The effect of paddy area decreases due to urbanization

With the progress of urbanization, the area of paddy fields has been rapidly decreasing, especially in the periphery of large cities. To cite an example, in Aichi Prefecture, the area of paddy fields has decreased by 48% between 1960 and 1995 (Satou, 1997). However, the fact is that the actual water intake for paddy field does not decrease so much, even if many paddy fields have been converted to residential land uses due to urbanization and the paddy field area has decreased. The following factors are considered as the reason of the above phenomena.

Generally, agricultural water is distributed to many paddy fields in a wide area using conventional canals (not pipelines, open canals or dual-purpose canal), and the distribution work is carried out by the beneficiary farmers themselves. Therefore, strict and proper allocation of water is a very difficult task, and it is difficult to avoid a

Table 1: Water requirement rate of cultivation methods (Lee et al., 2003b)

| period                  | transplanting | dry direct seeding |
|-------------------------|---------------|--------------------|
| before mid-summer drainage | 25.4          | 38.9               |
| after mid-summer drainage   | 22.2          | 49.5               |
| average for 3 years        | 24.1          | 42.1               |
regional unevenness of water allocation and water shortage in some areas. Some farmers have always wanted to distribute their water more easily by using enough water. Therefore, the amount of water margined by reducing the paddy area is used to more easily allocate water to many paddy fields distributed over a beneficiary area, which does not lead to a reduction in water intake. It means such a margin of water was consumed by implied “delivery water requirement” for saving frame’s labor for water management (Okamoto, 1995).

One of the important characteristics of Japanese agricultural water is the repeated use of water. However, the greatest weakness of this repeated use is water pollution. With the urbanization of the paddy fields, the pollution of reusable water has progressed rapidly, and the problems of repetitive use have been highlighted along with dumping the waste into waterways. At present, irrigation and drainage canals are separated in many areas, resulting in the abandonment of repeated use. What makes this possible in terms of water volume is the “marginal” use of water generated by the reduction of the paddy area. The amount of water marginalized due to the decrease in the paddy field area is used for the abandonment of repeated reuse of water, that is, for the conversion of water sources (Satou, 1997).

On the other hands, Suozhu et al. (2020) suggested that it is necessary to supplement the amount of return flow reduced by the decrease of paddy area as a part of internal demand for “delivery water requirement”. Furthermore, as shown by the current water design (Fig.3), the “reuse irrigation water” related to return flow and “delivery water requirement” are assembled independently as the components of “paddy irrigation water requirement”. As a result, it was pointed out by Suozhu et al. (2020) that the return flow from the paddy field could function as a part of “the delivery water requirement”. However, such a phenomenon was not expressed in the current water design (Fig.3), which could be one of the reasons why the change in “paddy field irrigation requirement” cannot be accurately estimated associated with the decrease in paddy area.

According to the above discussion, the urbanization does not contribute to decrease the irrigation water requirement according to the decrease of paddy field area.

6. Conclusion

This review article aims to summarize and analyze comprehensively the impacts of various environmental changes surrounding the paddy fields after World War II on each component of the irrigation water requirement in the paddy field and will serve as an introduction to typical water management and irrigation planning for paddy field in Japan. Table 2 summarizes the “direct” impacts of various environmental changes surrounding paddy field on its water demand for paddy fields in Japan, based on the discussion mentioned above. Furthermore, it must be noted that the first factor; “separated irrigation and drainage canals” is an essential condition for realizing the other factors; “pipelining” to “direct seeding” in Table 2, which also have the same impacts on the water demand as “separated irrigation and drainage canals” indirectly. “Separated irrigation and drainage canals” have been carried out with the urbanization, which cause the decrease in “reuse of irrigation water”. On the other hands, with the “pipelining”, “the reuse of irrigation water” also decreases due to without inflow of other water resources including runoff and drainage into the pipeline. Therefore, these two factors above cause the increase in totally change. Finally, it could be concluded by this article that most factors listed in Table 2 enhanced to increase the “unit water requirement” and decrease the “reuse of irrigation water”, which resulted in promoting to increase the total water demand for the paddy field. And, this is the reason why it is difficult to reduce water demand for paddy field according to the decrease of the paddy fields areas. As another social factor, the decrease in the farmer population and the aging of farmers have been bringing the changes in water requirement for paddy fields. The farmer population number was 3,120,000 in 2000, and which decreased to 2,155,000 in 2015 (MAFF, 2020a). The ratio of part-time farmers and full-time farmers
was 2/3 and 1/3, respectively, in the total of the population numbers of farmers in 2019 (MAFF, 2020b). Since the part-time farmers cannot spend enough for water management of paddy fields, they waste a lot of water as “lot-management water” and “delivery water”, which leads to an increase in the water demand of the paddy field. As the average age of farmers will increase more and more in the future, paddy field management must be considered about labor and cost saving. Therefore, it is necessary to improve the farmland conditions and rice farming management for labor-saving ability and high productivity by introducing technology such as “smart agriculture” that will utilize the IT technologies such as an automatic water management, etc.

Furthermore, it should be noted that paddy field irrigation water has great function for water purification and conservation of natural ecosystems by undergoing processes such as irrigation, drainage and outflow to rivers. In addition, since the paddy field has a function of mitigating global warming to protect the regional environment, keeping the quality of water and saving the irrigation water by repeated use should be emphasized. Unfortunately, such functions of paddy field water have not be considered in the current irrigation planning in paddy fields.

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