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***Research Paper***

# Assessment of precipitation suitable degree from integrated rice-crayfish farming systems in Jianghan Plain of China

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## ABSTRACT

In recent 10 years, an integrated rice-crayfish farming (IRF) has been developing rapidly in China. However, the IRF mode consumes a large amount of water and brought a great risk of water shortage. In Jianghan Plain, Hubei province, China, there are 4 IRF modes, referring to rotation of rice and crayfish (RRC), rice-crayfish symbiosis (RCS), year-round crayfish farming in paddy fields (YRC), and continuous operation of rice planting and crayfish farming (COR). This study selected the 4 IRF modes to calculate and compare the precipitation suitable degree (PSD) of 17 counties with larger scale of IRF. The results showed that, annually averaged PSD from large to small was ranked as RCS>COR>RRC>YRC. Under monthly scale, the highly suitable period for PSD was from March to July. From December to the next February, the PSD was obviously lower than other stages, with high risk of water deficit at the stage. According to the water demand regulation of the 4 IRF modes, the suitable IRF mode was RRC and YRC for the south, RCS and COR for the north of Jianghan Plain in China.

***Keywords:*** Integrated rice-crayfish farming, water demand, precipitation suitable degree, Jianghan Plain

The differences of climate distribution have led to great differences in the meteorological risks faced by integrated rice-crayfish farming development each county, especially in the satisfaction of water resources. Integrated rice-crayfish farming (IRF), an efficient stereoscopic planting paddy field pattern, has been practiced for long-term history in South China (Clasen *et al.* 2018). Since 2012 it has developed quickly in Jianghan Plain of Hubei Province in China. According to the China Crayfish Industry Development Report (NATES 2021), an area of IRF in China reached more than $126\times10^4$ ha in 2020, and the total output of crayfish from rice field is $20.6\times10^4$ tons.

Hubei is a principal province in China in IRF development, with 37.8% of the national IRF area and 40.5% of the national output of crayfish. In Hubei province and other provinces from the middle and lower reaches of the Yangtze River, low-lying paddy field is planted with mid-season rice owing to high groundwater table, and annually average income from such field is generally 1,387 dollars $ha^{-1}$ (Si *et al.* 2017). After field engineering transformation, IRF mode is practiced in such kind of paddy fields, and by which farmers' income increases significantly, and the annually net income may reach 11,562-18,500 dollars $ha^{-1}$ (Cao *et al.* 2017). The IRF and similar integrated farming not only increase farmers' income but influence soil quality indicators (Si *et al.* 2017; Yuan *et al.* 2020) and ecological environment of paddy fields (Clasen B *et al.* 2018; Yu *et al.* 2018; Hu *et al*. 2021; Yuan et al. 2021). IRF also plays an important role in regulating and storing floods, regulating climates, and reducing flood disaster losses (Leigh *et al*. 2017; Quach *et al*. 2017; Leigh *et al*. 2020).

However, according to the needs of crayfish farming in paddy field, aquaculture ditches and field surface should keep a deep water level in crayfish farming season every year. Moreover, in the process of crayfish farming in paddy field, frequent water exchange is used for improving the water quality that is mainly to increase the dissolved oxygen and reduce the ammonia nitrogen content (Dien *et al*. 2018), which means that IRF requires more water than traditional production in paddy field, so that excessive expansion of IRF will

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aggravate the contradiction between supply and demand of water resources under certain or insufficient precipitation for a region (Leigh *et al*. 2020). With the rapid increment of the area of IRF, the risk of water shortage is gradually increasing in the Jianghan Plain with abundent rainfall. It is reported that Qianjiang City diverted 6.5 billion cubic meters of water from Xinglong reservoir from 2014 to 2020 (Li *et al.* 2020), and according to our investigation most of water diverted from the reservoir were used for those paddy field for IRF. That is, annual precipitation in Qianjiang city located in central Jianghan Plain is insufficient to sustain crayfish aquaculture in paddy field due to rapid development of IRF.

The most prominent water problem in the IRF is mainly manifested in two aspects: one is the large amount of irrigation; the other is the large amount of drainage and large non-point source risk. According to our local observation in Hubei, the annually average irrigation amount under the rotation and continuous cropping of rice-crayfish is 1200 mm, which is 3.2 times higher than that of rice-wheat (oilseed rape) planting mode and 2.2 times higher than that of mid-season rice-renewable rice planting mode. The annually average external drainage was 950~1150 mm, about twice as much as that of planting modes of rice-wheat (oilseed rape) and mid-season rice-renewable rice. The average annual loss of nitrogen (26.25 kg $ha^{-1}$) and phosphorus (3.45 kg $ha^{-1}$) was 1.9 times as much as that of rice-wheat (oilseed rape) and 7 times as much as that of mid-season rice-renewable rice. Therefore, ignoring the carrying capacity of water resources and blind expansion of IRF will inevitably exacerbate seasonal water shortage and non-point source risk.

Currently there are relatively mature methods available for calculating the field water demands of rice. In which the method recommended by FAO (Allen *et al*. 1998) has been adopted popularly, and by this method many research results have been obtained including the variation characteristics and influencing factors of rice water requirement in different regions etc (Li *et al.* 2011; Mehta and Pandey 2015; Kumar *et al*. 2017; Nie *et al*. 2019; Cao *et al*. 2020). Generally, water balance method is used for calculation of field water supply-demand balance, and the factors to be considered include field evapotranspiration, soil leakage, precipitation, artificial irrigation, runoff or drainage, groundwater supplement, and so on (Zhao *et al*. 2015; Leigh *et al.* 2017). However, after IRF was carried out in paddy fields, the water management mode changed, resulting in corresponding changes in the balance of water supply and demand in paddy fields (Quach *et al.* 2017). Therefore, it is necessary to explore field water demands of IRF, so as to provide with scientific base for sustainable development of the IRF in Jianghan Plain, Hubei Province, China. This study proposed the IRF suitability evaluation method based on precipitation, and evaluated its suitability of 17 counties in Jianghan Plain at the annual and monthly levels (Fig 1).

## MATERIAL AND METHODS

### *Modes of IRF*

In Jianghan Plain, mid-season rice is usually transplanted to the field from late May to early June and harvested in late September, and IRF was initially developed in winter fallow fields where only one season of middle rice can be planted. There are 4 IRF modes in Jianghan Plain.

(1) **RRC** refers to a productive mode of a seasonal or interannual alternation for rice planting and crayfish farming in the same paddy filed ecosystem. Usually, crayfish farming in the paddy field is conducted from rice harvested for 20-30 days later to the next spring and early summer, commonly known as “one rice, one crayfish”. During the crayfish farming, the water level of paddy fields was dynamically managed with seasonal changes. Field water management during rice cultivation is the same as that in ordinary paddy fields.

(2) **RCS** refers to crayfish farming in paddy fields only during the rice growing, which is a productive mode of crayfish and rice growing together in paddy fields. This mode does not need to dig special ditches in rice field for crayfish farming under appropriate water management. If the ridge height is not less than 30 cm it can meets the needs of crayfish farming and rice planting, it can be called paddy field ditchless cultivation of crayfish. The mode does not affect the planting of overwintering crops, oilseed rape or winter wheat is usually planted after rice (crayfish) growing season.

(3) **YRC** refers to the productive mode of crayfish farming conducted continuously in the same paddy field ecosystem during non-rice cultivation and rice cultivation, that is, paddy fields are used for crayfish farming during non-rice cultivation and rice-crayfish symbiosis during rice cultivation, it can be considered as a special rotation of rice and crayfish, commonly known as “one rice, two crayfish”. The field water management of this mode is the same as that of the rice-crayfish rotation during crayfish farming (from the autumn to next spring). Its particularity lies in that the field water level management in the rice growing stage must meet the basic water depth (5-10 cm) required for the growth of crayfish, and the water depth should be maintained at 10-20 cm when the temperature is above 30℃.

(4) **COR** refers to that rice-crayfish coculture is conducted in a sequential manner in the same paddy field ecosystem in different seasons, it usually refers to rice-crayfish coculture conducted continuously in early rice season and late rice (or ratooning rice) season, namely rice-crayfish coculture is completed in the same field in different seasons, commonly known as “two rice, two crayfish”.

### *Water balance calculation in IRF*

With the growing period changes of rice and crayfish, the water content of the rice-crayfish co-cropping field fluctuated greatly. The water balance model aims at exploring the balance relationship among water input, water storage, and water output during a period for IRF ecosystem.

The input items include irrigation, precipitation, and groundwater recharge, while the output items include evapotranspiration, drainage/runoff, and groundwater discharge. On the basis of the changes of field water layers, irrigation, precipitation, evapotranspiration, and seepage, a field water balance model was established, shown as Eq. (1).

**Fig. 1:** Location of the study area in China

**Table 1:** Crop coefficient and leakage amount of paddy and crayfish ditches during rice growing.

| IRF Mode | Date | Growth stage | $K_c$ | $S_r$ | $S_d$ |
|---|---|---|---|---|---|
| RRC RCS YRC | Jun 11-Jun 20 | Seedling | 1.08 | 1.7 | 1.7 |
| | Jun 21-Jul 26 | Tillering | 1.32 | 1.4 | 1.7 |
| | Jul 27-Aug 2 | Late tillering (sunning fields) | 0.79 | 0 | 1.7 |
| | Aug 3-Aug 20 | Booting | 1.57 | 1.7 | 1.7 |
| | Aug 21-Sept 3 | Heading and flowering | 1.57 | 1.7 | 1.7 |
| | Sept 4-Sept 17 | Maturing | 1.37 | 1.2 | 1.7 |
| | Sept 18-Oct 10 | Yellow maturity | 0.88 | 0.2 | 1.7 |
| | Oct 11-Jun 10 | Crayfish culture/Rape planting | -[1]/1.06 | 1.7/-[2] | 1.7 |
| COR | Apr 28-May 3 | Regreening | 0.74 | 1.7 | 1.7 |
| | May 4-May 24 | Tillering | 0.86 | 1.5 | 1.7 |
| | May 25-May 31 | Late tillering (sunning fields) | 0.98 | 0 | 1.7 |
| | Jun 1-Jun 14 | Booting | 1.12 | 1.6 | 1.7 |
| | Jun 15-Jun 24 | Heading and flowering | 1.25 | 1.5 | 1.7 |
| | Jun 25-Jul 7 | Maturing | 1.06 | 1.3 | 1.7 |
| | Jul 8-Jul 21 | Yellow maturity | 0.68 | 0.2 | 1.7 |
| | Jul 22-Jul 27 | Soaking | - | 1.7 | 1.7 |
| | Jul 28-Aug 4 | Regreening | 0.98 | 1.7 | 1.7 |
| | Aug 5-Aug 24 | Tillering | 1.12 | 1.7 | 1.7 |
| | Aug 25-Aug 29 | Late tillering (sunning fields) | 1.14 | 0 | 1.7 |
| | Aug 30-Sept 10 | Booting | 0.92 | 1.5 | 1.7 |
| | Sept 11-Sept 24 | Heading and flowering | 1.45 | 1.3 | 1.7 |
| | Sept 25-Oct 6 | Maturing | 1.38 | 1 | 1.7 |
| | Oct 7-Oct 24 | Yellow maturity | 1.02 | 0.1 | 1.7 |
| | Oct 24-Apr 27 | Crayfish culture | - | 1.7 | 1.7 |

1 In the RCS mode, after the rice(crayfish) growing stage, rape is usually planted in the field, and the crop coefficient is 1.06, and no seepage;
2 In the RRC and YRC mode, the field should contain high water level, and no crop is planted, then there is no crop evapotranspiration.

$$P + I + E = ET + D + S + \Delta W \quad (1)$$

where, $P$ is rainfall, $I$ is irrigation, $E$ is the upward recharge of groundwater, $ET$ is evapotranspiration, $D$ is runoff or drainage, $S$ is soil seepage, $\Delta W$ is the change of soil moisture content, all in mm.

The $ET$ consists of two parts that are paddy transpiration (calculated by the Penman-Monteith method) and water surface evaporation from crayfish farming ditch (obtained by water surface evaporation data of meteorological observation station). $ET$ can be calculated by Eq. (2).

**Table 2:** Surface water depth in different modes of rice-crayfish farming (cm).

| IRF mode | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RRC | 40-50 | 40-50 | 20-30 | 30-40 | 0-40 | 3-10 | 5-10 | 5-10 | 0-5 | 0-10 | 20-30 | 40-50 |
| RCS | 0 | 0 | 0 | 0 | 3-5 | 5-10 | 10-20 | 10-20 | 0-5 | 0 | 0 | 0 |
| YRC | 40-50 | 40-50 | 20-30 | 30-40 | 0-40 | 5-10 | 10-20 | 10-20 | 0-5 | 0-10 | 20-30 | 40-50 |
| COR | 0 | 0 | 0 | 3 | 15 | 15 | 0-15 | 3-15 | 15 | 0-15 | 0 | 0 |

**Table 3:** Precipitation suitability grade(PSG) according to PSD.

| PSG | PSD range |
|---|---|
| Highly suitable | PSD ($\overline{PSD}$) +δ |
| Generally suitable | $\overline{PSD}$ δ ≥ PSD> $\overline{PSD}$ |
| Barely suitable | $\overline{PSD}$ ≥ PSD>$\overline{PSD}$ − δ |
| Unsuitable | PSD≤ $\overline{PSD}$ – δ |

$$ET = \begin{cases} \frac{k_c \cdot ET_0 \cdot A_r + E_d \cdot A_d}{A_r + A_d}, & \text{(at Rice − crayfish coculture stage)} \\ E_d, & \text{(at Crayfish culture stage)} \end{cases} \quad (2)$$

where $ET_0$ is the reference crop evapotranspiration; $K_c$ is the crop coefficient, Table 1 shows $K_c$ at the vital growing stages of rice (Liu *et al.* 2019a, 2019b; Pan *et al.* 2019); $A_r$ is the paddy field area, $A_d$ is the area of crayfish farming ditch; $E_d$ is the water surface evaporation from crayfish farming ditch, mm.

In Eq. (1), $S$ includes leakage from paddy and crayfish ditch, it can be calculated by Eq. (3).

$$S = \frac{S_r \cdot A_r + S_d \cdot A_d}{A_r + A_d} \quad (3)$$

where $S_r$ and $S_d$ are paddy field and crayfish ditch seepage intensity, respectively, mm/d. Table 1 presents the seepage amount in different stages of growing rice and crayfish.

In Eq. (1), $E$ and $\Delta W$ should be ignored due to both are smaller than the other parameters as compared with irrigation and precipitation. A water dynamic balance model in rice-crayfish fields was established based on the parameters of water depth change, expressed as Eq. (4).

$$\Delta w = I_{i-1} - D_{i-1} = H_i - H_{i-1} - P_{i-1} + ET_{i-1} + S_{i-1} \quad (4)$$

where $\Delta w$ is the net change of field water or water deficit, $H_i$ *and* $H_{i-1}$ are initial water depth respectively at the i-th day and i-1th day, in mm; $P_{i-1}$, $I_{i-1}$, $ET_{i-1}$, $D_{i-1}$, and $S_{i-1}$ are respectively rainfall, irrigation, evapotranspiration, runoff or drainage, and soil seepage at i-1th day, all in mm. $i$=2, 3, 4, ... On the basis of production experiences, Table 2 gives the water depth in the rice field in different IRF modes.

Aiming at the IRF, using meteorological data in 2011-2018 of Jianghan Plain to analyze the water deficits at monthly and annual scales. The 17 counties are Jingmen (JM), Zhongxiang (ZX), Jingshan (JS), Yingcheng (YC), Tianmen (TM), Jingzhou (JZ), Shayang (SY), Zhijiang (ZJ), Xiantao (XT), Hanchuan (HC), Caidian (CD), Songzi (SZ), Qianjiang (QJ), Shishou (SS), Gong'an (GA), Jianli (JL), and Honghu (HH).

### *PSD calculation*

PSD, namely precipitation suitable degree, it is defined as the ratio of precipitation each month (year) to total water requirement of IRF at the same period, expressed as Eq. (5). Precipitation suitability grade (PSG) is classified to four levels according to PSD: highly suitable, generally suitable, barely suitable, and unsuitable (Table 3).

$$PSD = P/(\Delta w + P) \quad (5)$$

## RESULTS AND DISCUSSION

### *Annual PSD and PSG*

PSD described the satisfaction of annual precipitation to water demand for IRF. In the study area, analysis showed that annual PSD of different IRF modes was 0.61-0.96 for COR, 0.53-0.86 for RRC, 0.52-0.85 for YRC, and 0.74-1.06 for RCS. Different IFR modes have different suitability in different counties or cities, for COR there are only one highly suitable county (HH), 9 generally suitable, 5 barely suitable, and 2 unsuitable (JM and ZX); for RCS there are 10 highly suitable counties, 5 generally suitable, 2 barely suitable (JM and ZX); for RRC and YRC modes, the spatial distribution of PSD are basically same, the amount of counties of generally suitable, barely suitable and unsuitable are 3, 8 and 6, respectively, and the suitability of precipitation to RRC is slightly higher than that to YRC (Fig. 2).

Fig. 2 described the annual PSG spatial distribution of the 4 IRF modes, it indicated that the imbalance between water supply and demand is an objective existence in the 17 counties. Our calculation and analysis showed that on the basis of making full use of local precipitation it was necessary to supplement irrigation more than 300 mm to meet the needs of IRF at least. In particular, JM and ZX in the north of Jianghan Plain needed more supplementary irrigation water for IRF development. The supplementary irrigation water required by different IRF modes was RCS 323.9 mm, COR 609.8 mm, RRC 839.4 mm, and YRC 856.7 mm.

As can be seen, the annual precipitation in the southeast of the line of GA-JZ-QJ-TM-YC is generally suitable for COR and highly suitable for RCS, and that in the northwest plain of the line is generally suitable for RCS. For RRC and YRC, annual precipitation reached to generally suitable level is only JL and HH in the south of Jianghan Plain.

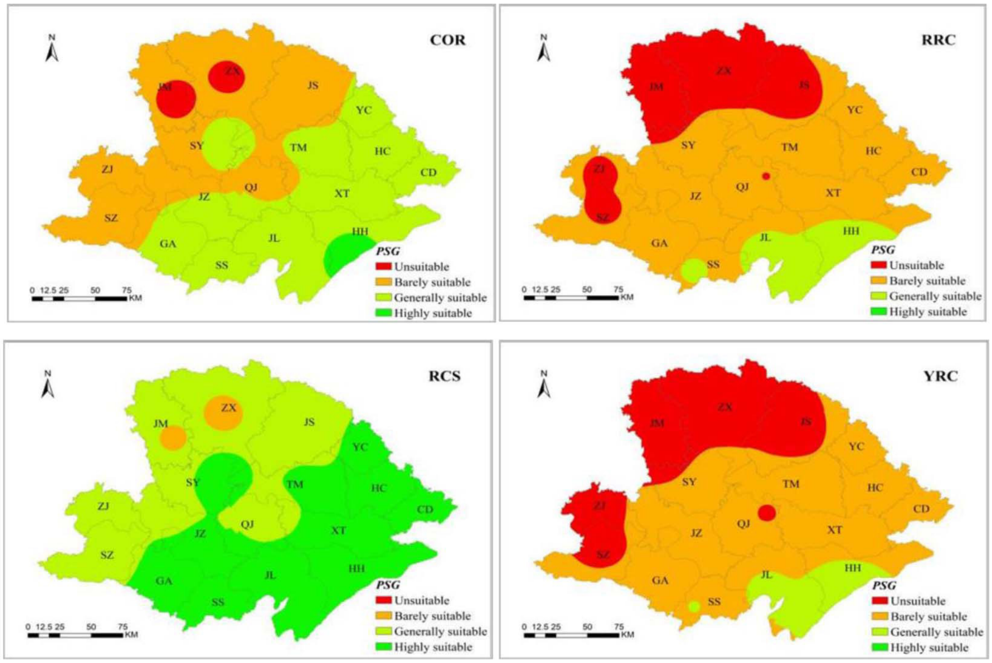


**Fig. 2:** PSG spatial distribution of IRF in the Jianghan Plain.

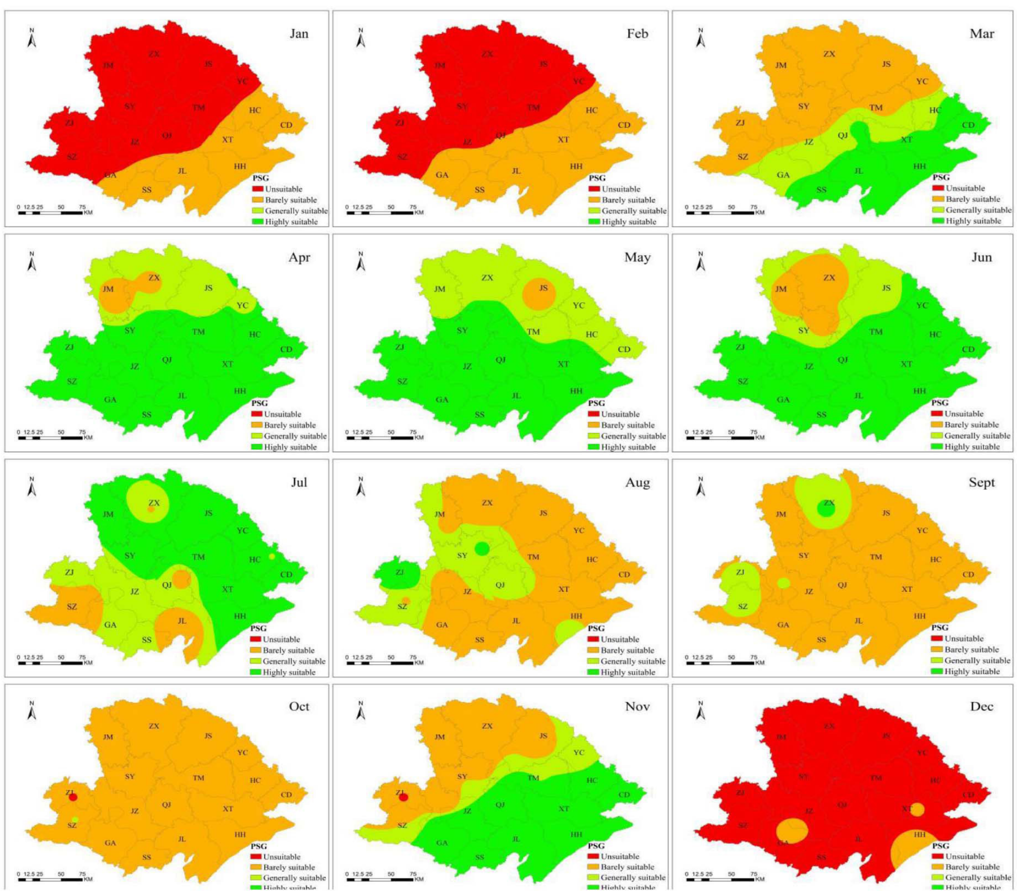


**Fig. 3:** Monthly PSG spatial distribution of COR in Jianghan Plain.

***Monthly PSD and PSG***

According to the monthly PSD of the 17 counties in Jianghan plain, Fig. 3-Fig. 6 gave spatial distribution of monthly PSG. For COR, PSG is usually low in winter (from December to next February). In March, and August to October, the PSG is barely

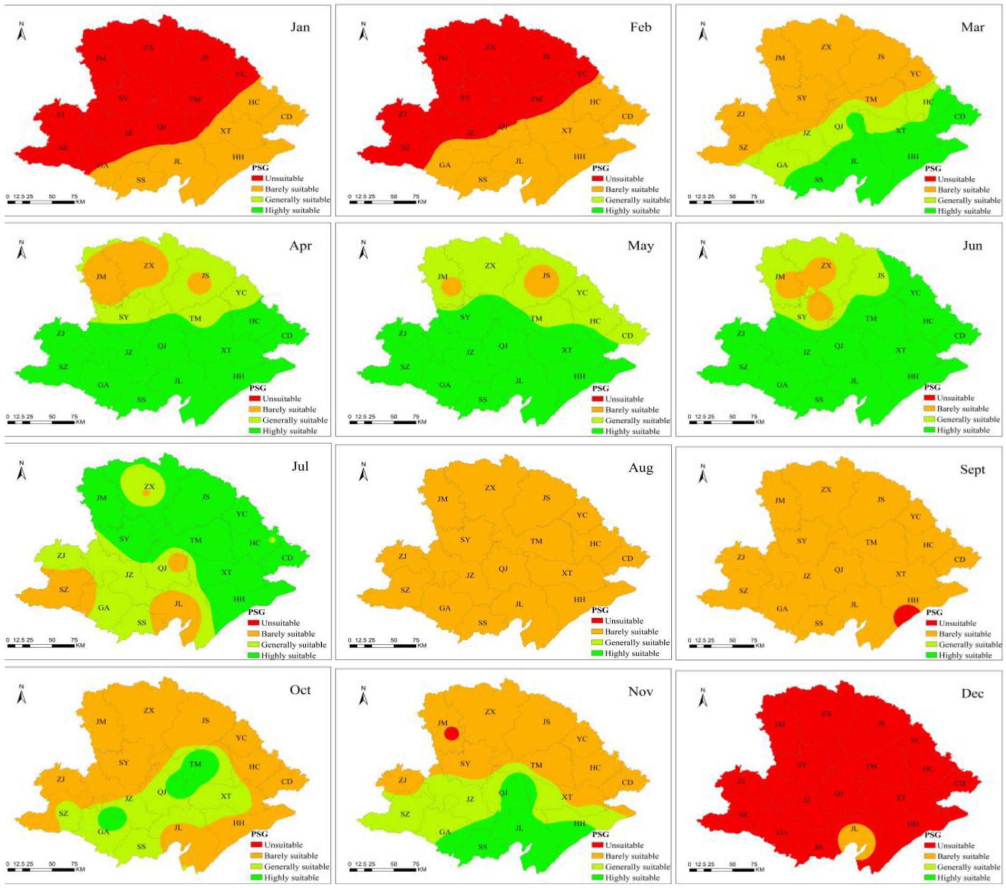


**Fig. 4:** Monthly PSG spatial distribution of RRC in Jianghan Plain.

suitable or generally suitable, while in the other period usually highly or generally suitable in the plain (except JM, ZX and JS), such as in crayfish farming season in spring, early rice season, and yellow maturity of late rice. In general, COR mode is not suitable for northern Jianghan plain, more suitable relatively for most counties in southern Jianghan plain, but the late rice season and the crayfish culture season of spring are the two low PSD stages, during these two stages, irrigation replenishment is very important.

For RRC and YRC, monthly PSD is very close, the stage with higher PSG is April to July, which is conductive to crayfish farming in spring and early summer, and rice growing. In the following months, the PSG become lower and lower, among them the PSG is unsuitable in most counties in winter, and is barely suitable in autumn, except for a few counties in the south of Jianghan plain. According to compared PSD values of COR and RRC (YRC), the PSD of COR is a little higher than RRC (YRC) in the rice growing season, and the PSD is close in winter.

For RCS, winter is a low PSD stage too, similar to COR. Except winter, the duration from booting to maturing of rice (July to September) is another low PSD stage for RCS, usually with PSD about 0.4-0.6. Analysis showed that March to June (spring to early summer) is a higher PSD stage, with a PSG highly suitable for RCS. Viewed from the regional suitability, RCS is barely suitable for northern Jianghan plain, generally suitable or highly suitable for most counties/cities in southern Jianghan plain, but the field irrigation should be strengthened in the rice season.

According to compared monthly PSD value, winter is the period of minimum PSD value in Jianghan plain, during which the precipitation is difficult to meet the need of water resource for crayfish farming, and it's necessary to find available water sources for crayfish farming in winter. August to October is another period with low PSD, which is the period of rice vigorous growth, with large evapotranspiration and high temperature, and it's necessary to reduce the harm of high temperature to rice and crayfish under RCS mode by increasing field water depth. During March to July with high PSD, the coordination degree is higher between precipitation and field water demand, it is suitable for crayfish farming in spring, and also meet the needs of water use for early rice-ratooning rice and medium rice. At the period, there is no water shortage generally, but sometimes the field water level is prone to surge due to excessive precipitation, resulting in farmland waterlogging and crayfish escape, therefore, more attention should be paid to drainage rather than irrigation.

By comparing precipitation suitability among the 4 IRF modes, the PSD of RCS is higher than the other modes in the same period. Obviously, the northern Jianghan Plain with relatively low precipitation is more suitable for this mode to reduce the risk of water deficit.

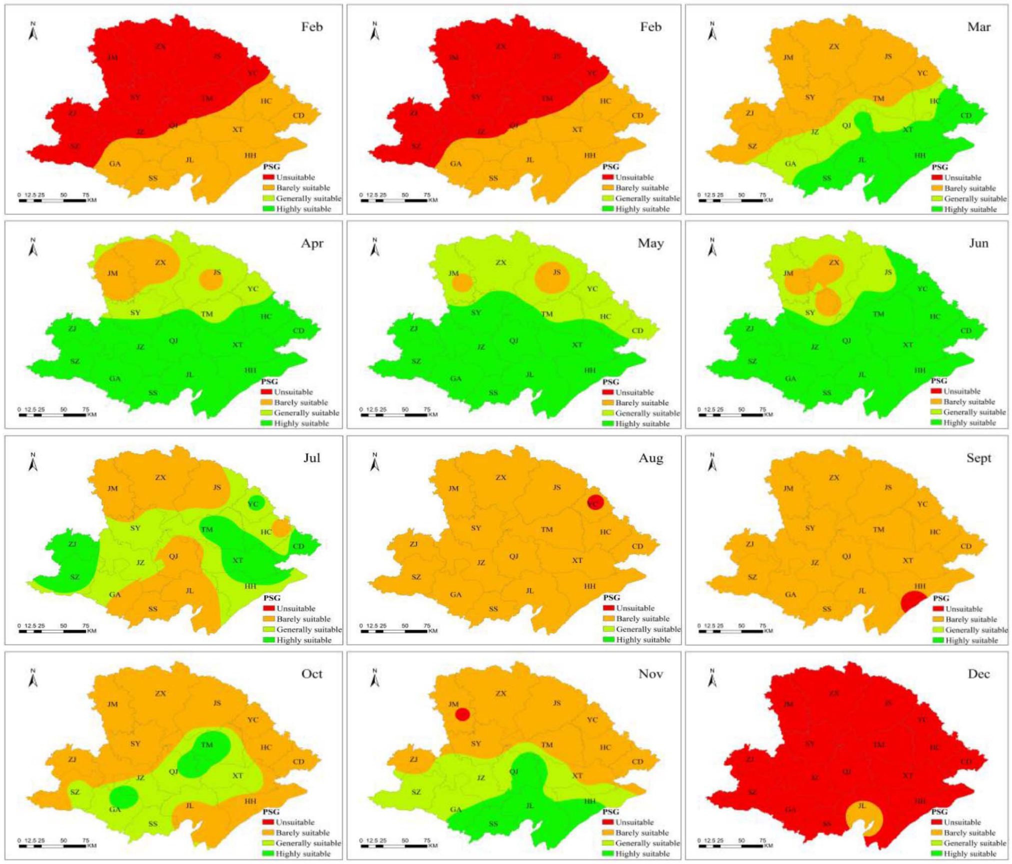


**Fig. 5:** Monthly PSG spatial distribution of YRC in Jianghan Plain.

***Effects of long-term IRF on soil environment***

For most IRF modes the paddy fields usually are continuous flooded for most of the year. Particularly for YRC and RRC modes, paddy fields are almost flooded all year round, so that more water resources are consumed off. Meanwhile, under long-term flooding condition the soil quality of paddy field decreased year by year, its significant characteristics are soil secondary leiing (Si *et al*. 2017; Zhang *et al*. 2021), reduction of redox potential (Akter *et al.* 2018), transformation of iron and manganese from oxidation state to reduction state (Kögel-Knabner *et al.* 2010), accumulation of soil toxic substances and promotion of $CH_4$ emission (Bhattacharyya *et al.* 2013; Xu *et al.* 2017), which is not good for reducing carbon emission. It was reported that, the ferrous accumulation increased from 0.23 cmol kg$^{-1}$ to 0.62 cmol kg$^{-1}$, and redox potential decreased from 271.1 mv to 210.0 mv in paddy fields where crayfish were cultured for 4-6 years (Yuan 2020), and finally decreased the yield of crayfish and rice (Tang 2019). Therefore, in order to eliminate these negative effects, it is suggested that paddy field used for RCS (or COR) mode should be changed to other farming system for 1 year or 2 years, such as IRF replaces with rice and wheat (oilseed rape) rotation for 1 year or 2 years after IRF was conducted for 5 years.

***Water pollution risk by IRF***

In general, IRF requires more water resources, and also a considerable part of them has to be discharged from rice fields into drainage ditches after crayfish farming, which objectively may result in a greater risk of non-point source pollution. Usually, March is the period of young crayfish to be put to paddy field, and from late May to early June is the transition period between crayfish cultivation and rice cultivation. At the same time, March to June is also the period of high rainfall in Jianghan Plain, so a large amount of drainage is inevitable in the production process. What's more, only 20%-30% of feed nitrogen may be used by crayfish (Hu *et al.* 2016), the excreta and feed residues of crayfish in the process of crayfish farming increased the nutrient concentration in water (Cao *et al.* 2017; Hou *et al.* 2021; Wei *et al.* 2021). So directly draining water from paddy field to drainage ditch undoubtedly increase the risk of agricultural non-point source pollution. Obviously, effective measures should be taken to avoid this situation, such as the water are used to irrigate other cropland or drained away after purification.

***Other factors affecting PSD***

Water supply for IRF is related to not only precipitation, but also hydraulic engineering settings and hydrological conditions of river, reservoir, and lake. In order to scientifically determine whether IRF is suitable or not for an area and how much its appropriate scale is, it is not enough to only consider precipitation in the area, still many important factors should be considered, such as the distance of water intake, the amount of water available from

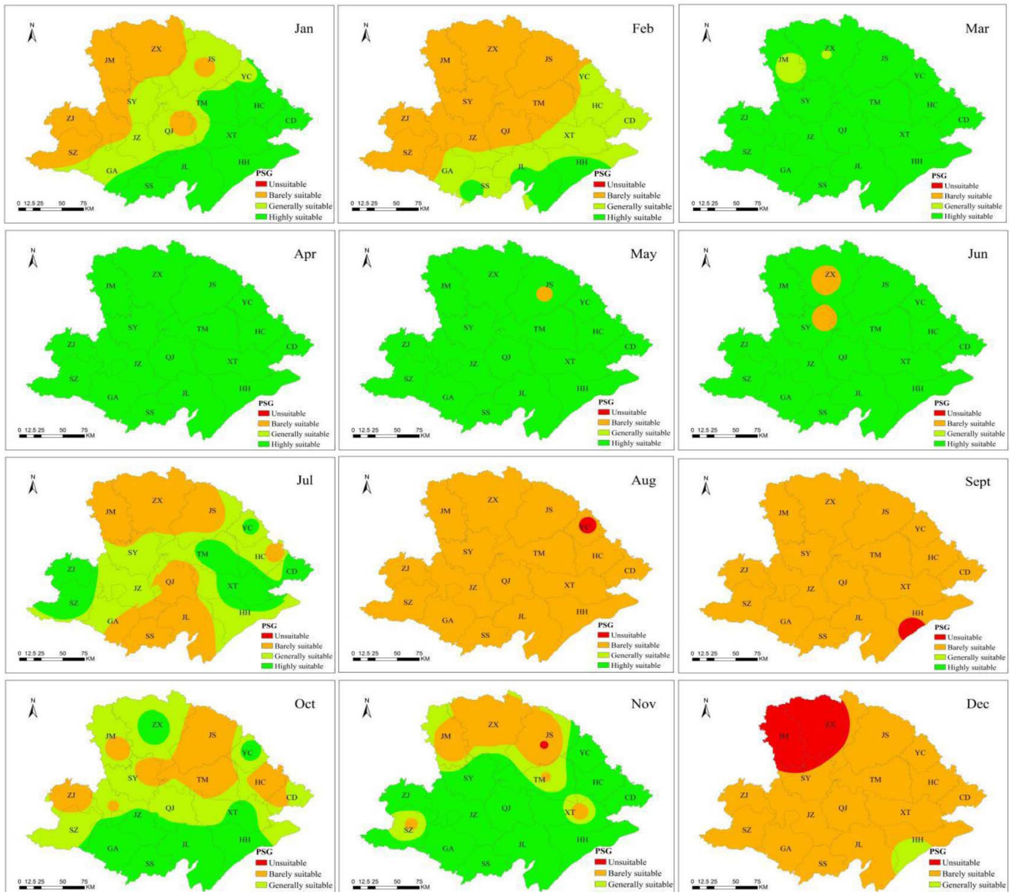


**Fig. 6:** Monthly PSG spatial distribution of RCS in Jianghan Plain.

a source (canal, river, lake, or reservoir), and supporting conditions of irrigation and drainage project, and so on.

## CONCLUSIONS

From the perspective of annual PSD, its variation range is 0.52-1.06, the order of average PSD from large to small is RCS > COR > RRC > YRC respectively. Generally, the counties with abundant precipitation in the south of Jianghan plain can develop IRF mode with high water demand such as RRC and YRC, and can also develop RCS and COR according to local conditions. The counties with less precipitation (north of Jianghan Plain) are suitable for RCS, COR, while the counties with low PSD, are only suitable for RCS mode moderately rather than trying other modes with large water consumption. For RCS or COR mode, it is suggested to replaces with rice and wheat (oilseed rape) rotation for 1-2 years after 5 years of IRF.

In terms of water supply-demand balance in the IRF cycle, December to next February (crayfish hibernation period) and August to October (rice vigorous growth period) are two risk periods of water deficit, and finding available water source is more important. March to July (crayfish culture period) is a high PSD period, more attention should be paid to drainage rather than irrigation, and effective measures should be taken to avoid the agricultural non-point source pollution.

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