Soil clay contributing to determination of growing period in rainfed lowland rice

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Abstract

Rainfed lowland rice ecosystems in the Mekong region receive high annual rainfall, but the rice plants often encounter drought throughout the growing season because coarse-textured soils have large water losses due to deep percolation. Field water availability during the growing season, and the length of growing period (LGP) are measures used to provide the geographical dimensions of soil hydrological patterns for various rice growth environments. The FAO approach to zoning LGP is not regarded as sufficiently reliable for rainfed lowland rice environments where there is often standing water with high deep percolation losses in light-textured soils, because it does not take into account the effect of soil characteristics on deep percolation in determining the availability of water for rice cultivation. In this study, we evaluated the effect of soil texture on LGP using a soil water balance model for calculating the amount of water held in storage for the growth of rainfed lowland rice, and then mapped the LGP in Savannakhet province, Laos. The LGP was very sensitive to low soil clay content as variation in the downward water loss was large when clay content was low. The LGP map revealed that the LGP decreases with declining clay content from the eastern to western parts of the province.

Key Words

Oryza sativa, percolation, soil texture, water balance

Introduction

As rainwater is the only source of water input to most lowland rice fields in the Mekong region, there are two major problems encountered by rice producers in relation to water availability during the period of wet-season cropping: (i) uncertainty regarding to the timing of the onset of wet-season and the effects of this uncertainty on timely sowing and transplanting and (ii) potential late wet-season drought which can affect the reproductive stage of plant growth and development. As a result, there is considerable year-to-year variation in rice production in the region. To improve the productivity of rainfed lowland rice, it is necessary to quantify the agro-hydrological patterns of water availability in the growing environment during the wet-season.

The FAO approach to estimating the length of growing period (LGP) defined as the period during a year when rainfall exceeds a half of potential evapotranspiration (PET) (FAO, 1996), is not regarded as sufficiently reliable for rainfed lowland rice environments. Soil characteristics such as water-holding capacity and field water losses through runoff, deep percolation and lateral seepage, all have a significant impact in determining the availability of water for rice cultivation, but the FAO approach does not take account of those effects. In this study, using a soil water balance model, we have defined LGP as the period when soil water content is above a threshold value. We then carried out sensitivity analysis to investigate the effects of soil physical properties, particularly clay content, on LGP for rainfed lowland rice, and mapped the LGP to provide the geographical dimensions of soil hydrological patterns for various rainfed lowland rice environments.

Methods

The study presented here focused on rainfed lowland rice areas in Savannakhet province in the lower central agricultural region of Laos (Figure 1). This province has the largest area of lowland rice of any single province in the country, accounting for 23 % of the lowland rice area of the country (about 0.6

million ha). These lowlands often encounter drought and were therefore selected for the case-study for the determination of changes in field water storage, in order to delineate the LGP zones. The province is subject to a monsoonal climate, with the southwest monsoons being associated with distinct wet (May-October) and dry (November-April) seasons. Mean annual rainfall distribution in the province decreases from 1900 mm in the east to 1400 mm in the west.

Soils with clay contents of 0-10 % occupy 63 % of the total area of the province, while soils with a clay content exceeding 20 % account for 20 % of the total area. The clay content decreases generally from the eastern to western parts of the province. Agricultural land in the province is about 0.24 million ha (19 % of the total area), as indicated in Figure 1, of which about two thirds is associated with soils with a low clay content (0-10 %). The total lowland rice area is about 0.14 million ha and is distributed predominantly in the eastern part of the province. Almost all the rice field soils are Acrisols (Phommachak and Vonghachak, 1998).

The LGP was determined by quantifying the amount of stored soil water available for crop growth with a water balance model. This was done for estimating the amount of water storage in a soil profile being divided into two layers: (i) the surface soil layer (0-200 mm, i.e. the effective root zone immediately above the hardpan created in the process of puddling) and (ii) the subsoil layer (200-1000 mm). When soil water content within surface soil layer reaches saturation, standing water appears in the field. Components of the water balance in the surface layer are rainfall, evapotranspiration estimated using the FAO crop coefficient approach (Allen et al., 1998), downward water flow (D) determined from clay content of the topsoil, and runoff when the free water level exceeds the bund. In the subsoil layer, the water balance consists of input water from the topsoil layer, i.e. D, and deep percolation. The start of LGP was defined as the time when water storage within the surface layer is greater than soil water content at field capacity. The end of LGP was defined as the time when water storage within the surface layer is lower than soil water content at wilting point. The soil moisture characteristics (saturation, field capacity and wilting point) were determined by the method of Saxton and Rawls (2006).

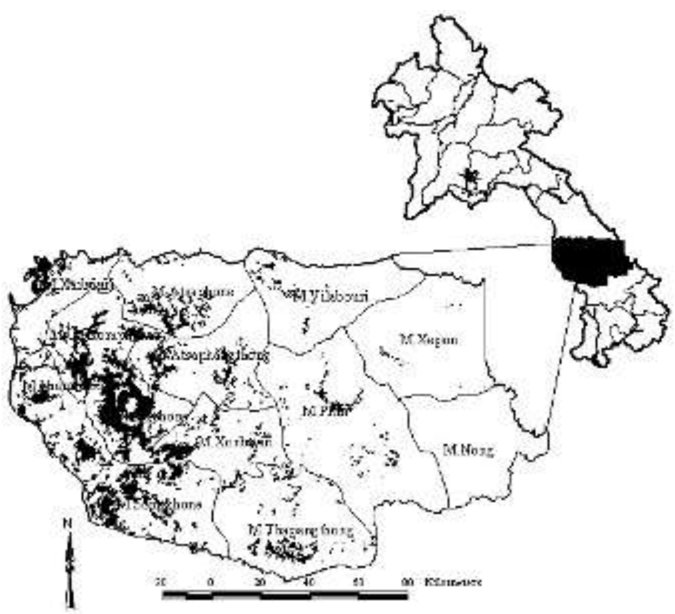

Figure 1. Savannakhet province, Laos: districts and agricultural land areas (black).

As for the estimation of D, Tsubo et al. (2007) developed an empirical relationship between D and clay content of topsoil above the hardpan when there was standing water in the field using the data collected from field experiments at six locations in Northeast Thailand. In the Northeast Thailand dataset, the soil clay content ranged from 4 to 47 % and the relationship showed D decreased as the clay content increased. A number of field experiments were conducted in Laos and Cambodia, and the results of D and clay content were added to the datasets from Northeast Thailand. A regression relationship between clay content and downward water loss rate was established using the new databases, and the equation (D=18.7/C-0.16 where D is percolation rate in mm per day and C is soil clay content in %) was employed to estimate the D component of the water balance model. Water loss from the subsoil layer through deep percolation was also estimated by applying the same approach as used for the topsoil layer.

The effect of clay content on LGP was investigated by running the soil water balance model using climatic data for the 2004 season under conditions of differing soil water characteristics (field capacity, wilting point, saturation, and differing downward water loss rates) in relation to changes in clay content value in the top and subsoil layers. Soils information was based on data relating to rice fields in Khanthabouli district of Savanakhet province where the average topsoil and subsoil clay content is 12% and 25%, respectively. The climatic data was obtained from the Savannakhet meteorological station (16?33'N, 104?45'E). The LGP responses to various soil texture types, i.e. sandy soil (SA), sandy loam (SL) and clay loam (CL) at a rice field in Khanthabouri district were also investigated, using 1985-2004 rainfall data recorded from the Savannakhet meteorological station.

For spatial characterisation of LGP, the median climate event, presenting 50 % cumulative probability level of climate for weekly rainfall were computed for 63 point locations; 44 locations were within the country (32 meteorological and 12 hydrological stations), while 19 were meteorological stations in nearby Northeast Thailand. The median climate for PET was computed for 22 meteorological stations where all the required weather data were available. These point-based weekly values (by station and by week) were then interpolated to generate gridded surfaces of the median weekly rainfall and PET (for 52 weeks). The field water balance model was run using these climatic inputs, together with soil water characteristics for each grid cell, to create a gridded surface of occurrence for the LGP map.

Results

When the topsoil clay content was decreased from 12 to 5 %, the model simulated a small effect on LGP, with the LGP being a week shorter (25 weeks) for soils with a low clay content (5 %), relative to the control (LGP = 26 weeks). However, the LGP decreased greatly when topsoil layer had clay content of less than 5 % (LGP = 21 weeks for the topsoil with 2 % clay content). When the topsoil clay content was increased from 16 to 22 %, the model gave similar results with the start and end of the LGP being in weeks 19 and 45, respectively. However, further increase in topsoil clay content (above 32 %) did not show increasing in LGP (start at week 20 and end at week 45). Changes in subsoil clay content had no any effects on LGP, though there were some variations in the soil water storage profile. As for the effect of soil texture on LGP, CL had the longest growing period with a mean LGP of 28 weeks and the LGP ranged from 23 to 32 weeks over the 20 years, whereas in SA the growing period was comparatively shorter than those soils that have higher in clay content. The average LGP for this sandy soil was 25 weeks with the range of 22 to 30 weeks. The mean LGP for SL (27 weeks with the range of 23 to 31 weeks) was shorter and longer than those for CL and SA, respectively. These simulated results indicated that clay content in the soil is a major factor that governs reduction of downward water movement. A high clay soil also allows more water to be maintained and increases the probability of standing water level above the soil surface during crop growing period. This enables soils with higher clay content to lengthen the LGP and reduce the effect of water stress at the end of the crop season.

The LGP for the median climate event of 1985-2004 was estimated for rice planted in Savannakhet province (Figure 2a). The shorter LGP tended to be associated with rice fields in the western part of the province (Outhomphone, Songkhone, Khanthabouli and Xaibouri districts), the LGP varying mostly from 21 week to 25 weeks. Approximately 8,800 ha of rice fields in Outhomphone, 3,500 ha in Songkhone, 2900 ha in Khanthabouli, and 1000 ha Xaibouri districts, totalling approximately 12 % of the lowland rice area in Savannakhet, had the shortest LGP, ranging between 21 to 25 weeks. Generally the rice fields in the central and eastern parts of the province had the longest LGP, more than 27 weeks. Long LGPs were found to be associated with soils with high in clay content, as found in almost all the rice fields in central and eastern part of the province. In contrast, short LGPs were associated with soils with a high sand content, as found in the west of the province. The trend of decreasing rainfall from the eastern to western parts of the province also influences the determination of LGP, especially for rice fields in the western part of the province where the areas received mean annual rainfall of less than 1500 mm. As shown in Figure 2b, week 17 (late April) to week 19 (early May) is considered to be the probable beginning of the growing season for almost all rice growing areas in the province; except some parts of rice areas in Khanthabouli, Outhomphone and Xaibouri, where the growing season starts between weeks 19 and 21. The timing of the ending of the growing season varied greatly across the province, from week 39 (early October) to week 49 (early December). As depicted in Figure 1c, the growing season ended earlier in the western part of the province than the central and eastern parts. This reflected the prevalence of soils with a low clay content, in combination with a general trend of declining rainfall from the eastern to western parts of the province.

Conclusion

The results of the sensitivity analysis are in agreement with the general finding that soils with a high clay content generally have a high soil water holding capacity and slow water movement; soil moisture stored in the profile of higher clay content soils will therefore retain more water for longer periods at the end of growing season, while sandy soils with a high drainage ability and low soil water holding capacity, have a correspondingly shorter growing period. The water balance model accordingly provides reasonable outputs that can determine the water availability for quantifying the duration of crop growing period for rainfed lowland rice field in Laos, as shown in the LGP maps, which depict the growing period shortens from the eastern to western parts of the province. The LGP maps presented in this study have not been validated with measured data; however, we are planning field measurements during the growing season in 2008. Once the proposed maps are validated, they will be employed for extension strategy, selection of rice varieties and timely planting in the drought-prone areas.

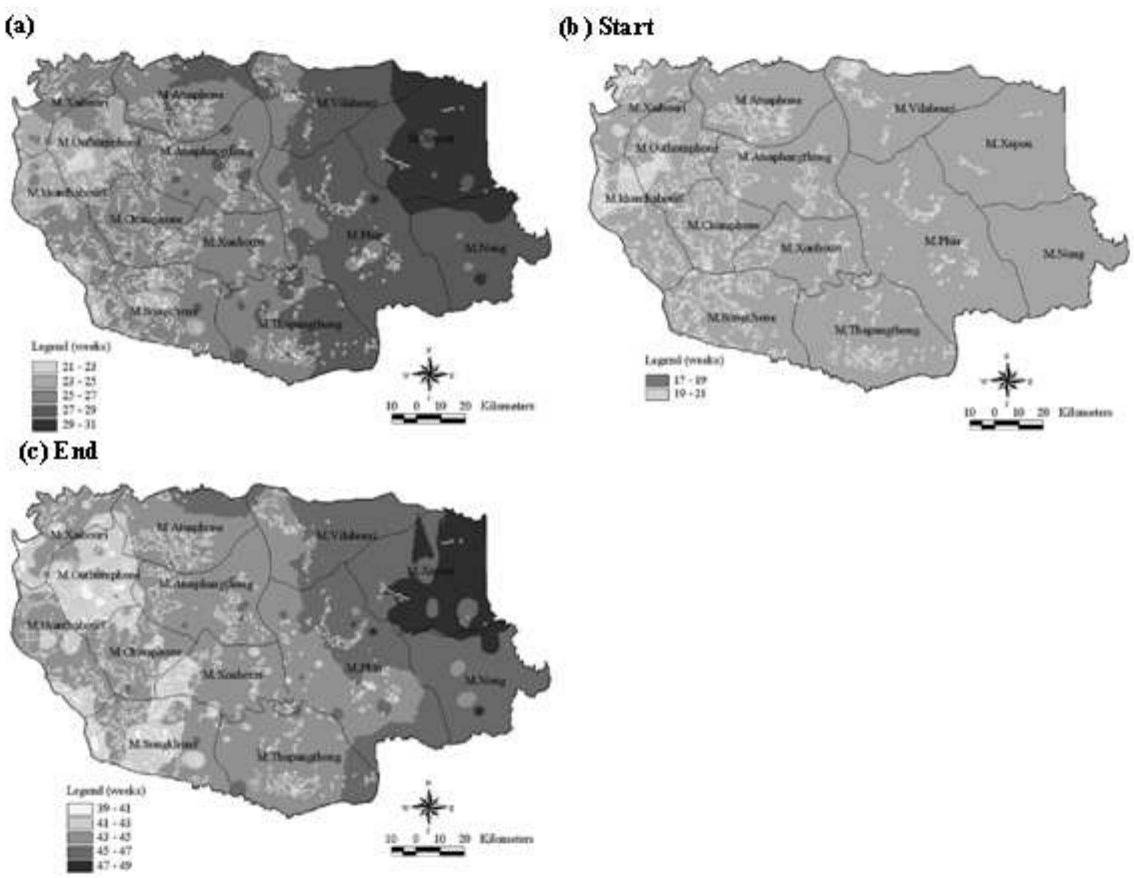

Figure 2. Duration (weeks) for the length of growing period (a), week of the year for the start of the growing period (b), week of the year for the end of the growing period (c) as estimated by the soil water balance method.

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