Effects of Land Use Patterns on Land Production Potential of Purple Soil

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Abstract: The purple soil land production potential of different use patterns was surveyed, tested, and analyzed. Peas, tobacco, peanuts, watermelons and oranges were planted on both natural sloping lands and level terraces tillage. Bare sloping lands of purple soil were used as the contrast site. The result shows: (1) In the test site, during the period from April to October, the photosynthesis production potential makes up 70% output of the whole year, and the photo-temperature production potential makes up 74% of the whole year. Therefore, from April to October is the primary period for agriculture production. (2) The climate-soil production potential of level terraces is 40%—60% higher than that of the natural sloping lands tillage, while the climate-soil production potential of the bare sloping lands is nearly zero. (3) When “terrace plus multiple cropping” method is used, the light and temperature resources can be fully utilized and the soil erosion can be much reduced. It is an excellent development-utilization use pattern that improves both the climate production potential and the climate-soil production potential.
Keywords: land production potential, use pattern, purple soil

Land is the most important natural resources for human survival and development. In China, land is a scarce resource. The average tilled land per capita is only 0.12hm^2, less than half of the world average 0.287hm^2. In addition, with the agriculture productivity level being low and the population growing, the conflicts between the demands of social-economic development and the supply of the land resources are more and more acute. However, it is common that there are abusive or unreasonable utilizations of land, which cause a large amount of land waste and degeneration. To guide the rational development and utilization of land resources, it is of high value in both practice and scientific research that we study the effects of various land use patterns on land production potential, which is the general indicator of land quality.

1 Outline of the test site

The test site is located in the purple soil region in XingGuo County, Jangxi province. It is between longitude 115°01′—115°51′E, and latitude 26°03′—26°41′N. Yearly average temperature is 18℃. Mean annual precipitation is 1600mm. There are 280 frost-free days a year. Maximum and minimum temperatures are 39.4℃ and —5.2℃ respectively. Annual radiation is 112cal/cm^2. The yearly sunshine duration is 1,929.3 hours. The altitude rang from 300m—500m above sea level. It is part of the subtropical monsoon zone.

2 Research contents and methods

The goal of the research is to protect and cultivate the land production potential. It uses both field survey and controlled observation methods. Land production potential was studied by planting peas, tobacco, peanuts, watermelons and oranges on natural sloping tillage and level terrace tillage. Bare sloping lands are used as the contrast. The contents and methods are as following:

(1) Survey of land use patterns. Various land use patterns of purple soil are investigated, and categorized, in which a few major ones are selected for further controlled observation study.

(2) Physical-chemical properties. During the controlled observation test, sampled the soil in spring and fall, with the maximum soil depth. There were 3 samplings for each land. Then, laboratory analyses were carried out for the following physical-chemical properties: usable nitrogen, usable phosphorus, usable potassium, grading, moisture content, moisture-absorbing coefficient, bulk density.

(3) Observation of crop phronological phases. They include seedtime, germination stage, offshoot stage, florescence and frutescence. The observation time was designed so that no phonological phase would be missed. Therefore, there was one observation every 7 days. Fixed plants were used. There were 20 plants for each crop.

(4) The soil moisture content. It was measured in the spring and fall, before the crops were sown. For each measurement, there were 3 repeats, and their average was used.

(5) Crop root study. Each phronological phase is further split into 3 sub-periods: incipient, middle and telophase. For each sub-period, a root study was carried out, using digging soil profile.

3 Research result and analysis

3.1 The effect of land use patterns on land physical-chemical properties

Different land use patterns leads to different capabilities of maintaining water, soil and nutrient, which in turn leads different land production potentialities. The observation results are shown in Table 1.

Table 1 The effect of land use patterns on land physical-chemical properties

Use patterns	Moisture Content (%)				Grading (mm)			usable nitrogen	usable phosphorus	usable potassium	bulk density
	96.9.21	96.11.5	97.3.15	97.9.12	<0.002	0.002~0.05	0.05~2	(mg/kg)	(mg/kg)	(mg/kg)	(g/cm^3)
Bare Sloping Land	4.5	1.46	2.4	10.6	13.70	25.49	60.81	7	0.09	84.1	1.62
Natural Sloping Tillage	7.9	3.1	10.2	15.4	20.36	35.02	44.62	16.0	5.7	50.5	1.46
Level Terrace Tillage	10.3	4.5	12.1	21.7	18.96	32.67	48.37	46.2	4.64	64.6	1.31

Table 1 shows that for moisture content, level terrace tillage has the highest; natural sloping tillage, the second; and bare sloping land, the lowest. However, from soil structure perspective, there is no big difference between sloping tillage and level terrace tillage, because both are loam. Therefore, the moisture content difference is not caused by the difference of the moisture-maintaining capabilities of the soil themselves. Table 1 also shows that the use patterns affect the soil nutrient. The usable nitrogen in level terrace tillage is 3 times of that in natural sloping tillage, and 6.6 times of that in the bare sloping land. The first one reached the grade 5 of the National Standard of Soil Grades, but the second and the third ones are only in grade 6. For usable phosphorus, usable potassium, there is no significant difference between the natural sloping tillage and the level terrace tillage, and both are in the same grade. However, bare sloping land is different. Comparing with the natural sloping tillage and the level terrace tillage, its usable phosphorus is significantly lower, while the usable potassium is higher. The latter may be caused by the fact that the original purple soil contains rich potassium.

3.2 The effect of land use patterns on the climate production potential

The production potential can be categorized into the following: photosynthesis production potential, photo-temperature production potential, climate production potential, climate-soil production potential and actual productivity. Photosynthesis production potential is the maximum amount of the dry material produced plants, determined only by the total amount of the sun's radiation, without considering other natural constraints. Photo-temperature production potential is the maximum amount of the dry material produced plants, determined by both the light energy and temperature, assuming all other conditions are appropriate. Climate production potential is the maximum amount of the dry material produced plants, determined by the actually climate conditions, e.g. light energy, temperature, and precipitation. Climate-soil production potential is the maximum amount of the dry material produced plants, determined by the actually climate conditions (e.g. light energy, temperature, and precipitation), and the soil condition. In the real production process, for large areas, it is difficult to change the two factors of light energy and temperature. Furthermore, other conditions cannot reach the ideal level, esp. the soil's moisture and nutrient levels, which are determined by the level of soil erosion, which in turn is affected by the land use patterns. Therefore, to recognize and understand all the related factors that determine the land production potential, we need to focus on the climate production potential and the climate-soil production potential. To determine it quantitatively, this study uses successive subtraction method to compute these potentials.

(1) Photosynthesis Production Potential and Photo-Temperature Production Potential

According to Huang Binwei's study, the photosynthesis production potential can be expressed as:

$$Y = 0.123Q$$

In which, Y is the photosynthesis production potential (kg/(hm^2 • a)), Q is the total amount of sun's radiation (cal/(cm^2 • a)), the 0.123 is the Huang Binwei's coefficient.

According to successive subtraction method, the photo-temperature production potential can be computed from multiplying photosynthesis production potential by the temperature attenuation coefficient:

$$Y\mathrm{mp} = Yf(t)$$

In which, Ymp and Y are photo-temperature production potential and photosynthesis production potential respectively, $f(t)$ is the temperature attenuation coefficient, as expressed by the following formula, which is suggested by Gao Guoli:

$$f(t) = \begin{cases} 0 & t \quad 5 \\ t/15 & 5^{\circ}\mathrm{C} < t \quad 15 \\ 1 & 15^{\circ}\mathrm{C} < t \quad 25 \\ 2 - t/25 & 25^{\circ}\mathrm{C} < t \quad 35 \\ 0 & t > 35 \end{cases}$$

In which t is the average temperature.

According to the meteorological record in the past twenty years, applying the above formula, we have Table 2.

Table 2 Photosynthesis production potential and photo-temperature production potential (kg/hm^2)

Month	Radiation	photosynthesis production potential	Average Temperature	F(t)	photo-temperature production potential
1	6,144.0	755.71	7.9	0.5267	398.03
2	5,997.4	737.1	9.2	0.6133	452.06
3	7,365.3	905.9	14.7	0.98	887.78
4	8,334.3	1,025.1	17.9	1	1,216.9
5	9,893.1	1,216.9	22.5	1	1,216.9
6	10,913.4	1,342.4	27.1	0.916	1,229.64
7	15,058.8	1,852.2	29.9	0.804	1,489.17
8	14,251.1	1,752.9	28.3	0.868	1,521.52
9	11,407.9	1,403.1	25.2	0.992	1,391.88
10	9,356.8	1,150.9	19.7	1	1,150.9
11	7,152.3	899.7	16.2	1	899.7
12	6,223.6	765.5	9.6	0.64	489.92
Whole Year	112,097.7	13,787	19.0		12,152.6

From Table 2, the photosynthesis production potential of the whole year is 13,787 kg/hm^2, which is relatively low. During the year, in spring, summer, and fall (from March to November), the average temperature reaches or closes to the fittest temperature range (15℃—25℃), and so no constrains on crops. However, in winter, the temperature is low, there is some constrains. In general, there is a match between light energy and temperature, which leads the little difference between photo-temperature production potential and photosynthesis production potential

For individual crops, further computation gives the following results for their photo-temperature production potential in their post-emergence: peas, 2,085.79 kg/hm^2; tobacco, 5,504.01 kg/hm^2; peanuts, 5,263.49 kg/hm^2; watermelons 3,952.02 kg/hm^2; and oranges 12,152.6 kg/hm^2.

(2) Climate Production Potential

Climate production potential can be computed by the following formula：

$$Yw = Ymp \cdot \prod_{j=1}^{n} \left[1 - Ky_j \left(1 - \frac{Eta_j}{Etm_j} \right) \right]$$

$$Etm = \sum_{i=1}^{k} Etoi \cdot K_C \cdot di$$

$$Etoi = C\,(WRs)$$

$$Rs = (0.25 + 0.5N / N_0)\,Ra$$

In which, Yw, Ymp are the climate production potential and the photo-temperature production potential（kg/hm^2）respectively; Ky_j is the yield coefficient for j postemergence; Eta_j is actual evapotranspiration capacity（mm/d）for j postemergence; Etm_j is the maximum evapotranspiration capacity（mm/d）for j postemergence; n is the amount of postemergences for the crop; K_C is the crop coefficient; *Etoi* is the referential evapotranspiration capacity of the i-th month in this postemergence; *di* is the days in the *i*-th month in *j*-th postemergence; *k* is the amount of months for the postemergence; *C* is the correction coefficient; *W* is the weight coefficient determined by elevation and temperature; *Rs* is the quantity of short-wave impinging radiation（mm/d）; *N* is the measured real average sunshine time（hr/d）; N_0 is the maximum day light time; *Ra* is the quantity of extraterrestrial radiation（mm/d）。

Actual evapotranspiration capacity per month in crop's postemergence（*Eta*）can be computed by effective soil moisture index（*ASI*）. *ASI* is the degree to which effective soil moisture can satisfy the need of the crop（*Eta*=*Etm*） in a postemergence. Combining *ASI*, maximum evapotranspiration capacity（*Etm*）and residual effective soil moisture [(1–*P*) *SaD*], we can obtain the average *Eta* for a postemergence The formula is as the following:

$$ASI = \frac{In + Pe + Wb - (1-P) \cdot SaD}{Etm}$$

In which, *In* is irrigation water consumption in postemergence（mm）; *Pe* is effective precipitation in postemergence（mm）; *Wb* is effective moisture content in incipient of postemergence（mm）; *P* is proportion of effective moisture in soil; *Etm* is the maximum evapotranspiration capacity for postemergence; *Sa* is total effective soil moisture content (mm/m); *D* is effective moisture depth (m).

Applying the above formula, we can compute the climate production potential for crops under different use patterns.

Table 3 shows that in the test site, there is plenty precipitation in summer, hence abundance water supply. The crop's climate production potential is not affected by the difference of the soil's moisture-maintaining capabilities caused by the different use patterns. Therefore, in general, there is a match between climate production potential and photo-temperature production potential in summer. However, in winter, there is less precipitation, therefore, the soil's moisture-maintaining capability has greater impact on its climate production potential. This is demonstrated by the facts that in winter, climate production potential is lower than photo-temperature production potential, and, the climate production potential of level terrace tillage is higher than that of natural sloping tillage, which in turn is higher than that of bare sloping land. In general, in the test site, the precipitation and temperature are basically synchronized, which is very beneficial for agriculture.

Table 3 Climate production potential by use patterns and crops (kg/hm^2)

Use Patterns	Pea	Tobacco	Peanut	Watermelon	Oranges
Bare Sloping Land	1,960.64	5,504.01	5,058.22	3,952.02	11,058.87
Natural Sloping Tillage	2,064.93	5,504.01	5,263.49	3,952.02	11,544.97
Level Terrace Tillage	2,085.79	5,504.01	5,263.49	3,952.02	12,152.6

3.3 The effect of land use patterns on the climate-soil production potential

Besides the climate production potentiality, land use patterns can also affect the climate-soil production potential, which can be obtained by multiplying climate production potential with the soil's attenuation coefficient:

$$Ys = Yw\,f\,(s)$$

In which, Ys、Yw are climate-soil production potential and climate production potential respectively (kg/(km^2 • a))； f（s） is the soil's attenuation coefficient。

This study uses usable nitrogen, usable phosphorus, usable potassium, which are the most important nutrients for crops growth, as the parameters for computing the soil's attenuation coefficient, and uses the minimum factor principle in the computation, with the formula as the following:

$$f(s) = \begin{cases} 0 & B = 0 \\ B/A & 0 < B < A \\ 1 & B \quad A \end{cases}$$

In which, B is the soil nutrient content, A is the amount of the nutrient to satisfy the climate production potential.

According to tests and related reference data, Table 4. shows the ratio of crop's demand and soil's supply of nutrients by different use patterns, and Table 5.shows their climate-soil production potential.

Table 4 The demand and supply of nutrients by use patterns

Use Patterns	Supply of Fertilizing Factor（kg/hm^2）		The ratio of crop's demand and soil's supply of nutrients				
			Pea	Tobacco	Peanut	Watermelon	Orange
Bare Sloping Land	N	2.27	0.037	0.01	0.01	0.02	8.41×10^{-3}
	P	0.03	1.78×10^{-3}	3.63×10^{-4}	4.88×10^{-4}	5×10^{-4}	1.74×10^{-4}
	K	27.2	0.47	0.08	0.22	0.34	0.10
Natural Sloping Tillage	N	70.08	>1	0.36	0.33	0.70	0.26
	P	24.97	>1	0.30	0.40	0.42	0.14
	K	221.2	>1	0.62	>1	>1	>1
Level Terrace Tillage	N	484.30	>1	>1	>1	>1	>1
	P	47.37	>1	0. 5 7	0.71	0.79	0.27
	K	677.10	>1	>1	>1	>1	>1

Table 5 Climate-soil production potential by use patterns (kg/hm^2)

Use Patterns	Pea	Tobacco	Peanut	Watermelon	Oranges
Bare Sloping Land	3.49	2.00	2.50	1.98	1.92
Natural Sloping Tillage	2,064.93	1,651.20	1,736.95	1,559.85	1,616.30
Level Terrace Tillage	2,085.79	3,137.29	3,737.08	3,122.10	3,281.20

Different use patterns correspond to different ratios of soil's supply and crop's demand of nutrients: natural sloping tillage is significantly better than bare sloping land, and level terrace tillage is better than natural sloping tillage. This means that level terrace tillage has relatively stronger soil and nutrient conservation capabilities, and its supplies of usable nitrogen, usable potassium can meet crop's demands. For all three use patterns, the demand-supply ratios for usable phosphorus are the lowest among nutrients. It shows that for purple soil, phosphorus is the primary constrain factor for crop high productivity. This is reflected on the land production potential (comparing Table 5 and Table 3). In general, it is because of the insufficient and imbalance supply of soil nutrient that the climate-soil production potential is far lower than the climate production potential (except pea), and usable phosphorus is the primary factor. Therefore, to increase the land production potential for purple soil, the major procedure is to enhance the supply level of phosphorus and its effectiveness. Level terrace tillage has relatively stronger soil and nutrient conservation capabilities, and so its climate-soil production potential is significantly higher than that of natural sloping tillage (except pea), while the soil and nutrients are washed away fast on bare sloping land, its climate-soil production potential is almost zero. However, individual crops have significant impact also. Pea can adapt well to natural sloping tillage and yields relative high climate-soil production potential, while summer crops adapt to level terrace tillage better and yield better climate-soil production potential. To obtain high productivity, procedures must be designed for individual crops. For different crops and utilization methods, different nutrients and their amount need to be supplemented, so that the land production potentials can be increased and continuously sustained. For the elements that have already met the demand of the crop, applying the amount of nutrients that is consumed by the crop can sustain a relatively high level of supply for the next season. However, for the elements that cannot meet the demand, if we only supply the consumed amount, then, it will still be in the lacking status for next season and impact the productivity. Therefore, we must apply more amounts of nutrients than that consumed by the crop, to sustain and continuously improve the land potentials.

4 Conclusion

From this research, the following conclusion can be reached:

(1) For the test site, the photosynthesis production potential and photo-temperature production potential are 13,787kg/hm^2 and 12,152.6kg/(ha • a), respectively. Although the photosynthesis production potential is relatively low, the light and temperature resources match well, which leads the little difference between photo-temperature production potential and photosynthesis production potential.

(2) Level terrace tillage can improve the conditions of the soil moisture and enhance the water utilization ratio. Level terrace tillage's climate potential is larger than that of natural sloping tillage's, which in turn is larger than that of bare sloping land's.

(3) The key for fully increasing the photo-temperature and climate potentials is to take full advantage of the temperature and water resources, so multiple cropping can be used. Proper irrigation may be needed.

(4) Level terrace tillage has better water, soil, and nutrient conservation capabilities, and can significantly increase the climate-soil production potential. However, in this study, for both level terrace tillage and natural sloping tillage, the soil supplies of the nutrient (esp. phosphorus) cannot meet the demands of most testing crops. Therefore, applying proper amount of supplemental nutrients (esp. phosphorus) is important to improve the productivity and sustain the land's potentials.

(5) Multiple cropping can fully utilize the light, temperature, water, and soil resources, and so should be used properly. However, to reach high productivity, proper fertilization and irrigation are required.

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