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不同土壤覆盖物对旱作水稻生长和产量影响

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摘要:在四川盆地通过田间试验研究了不同覆盖物对旱作水稻植株生长及产量的影响。结果表明,在有效铁含量较高而有效锰含量较低的土壤上,覆地膜及传统淹水处理在整个生育期没有表现缺锰症,而覆麦秆处理前期分蘖能力差,生长缓慢,表现严重的缺锰症。在覆麦秆处理裂区灌施 2‰的 $MnSO_4$ 溶液(每次 450kg/hm²)两次后,水稻株高、分蘖和生物量都迅速增加,说明覆麦秆处理水稻受到了锰的胁迫。其原因与地膜处理明显提高土壤温度,而覆麦秆处理却具有降温作用有关。试验还发现,灌施锰肥能够补偿温度降低所造成的不利影响。水稻产量以覆地膜处理最高,其次是覆麦秆灌锰处理,再次是传统淹水处理,覆麦秆未灌施锰肥处理产量最低,后者与其它处理差异也达极显著水平。覆地膜条件下,水稻产量随施氮量的提高而提高,但当施氮量为 150kg/hm² 后产量变化不大。与传统淹水相比,覆盖旱作处理显著降低总耗水量,节水率达 63.1%;并在产量基本不变或有所提高的前提下,提高水分利用效率 2～3 倍。

关键词:旱作水稻;缺锰;土壤覆盖物;产量;节水

The Effect of Different Soil Mulch Materials on the Growth and Yield of Rice

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Abstract: With the development of water crisis, water-saving cultivation techniques are paid more and more attention in agriculture production. Rice production with soil mulch materials, as a new cropping system to save irrigation water, has been introduced to China since 1980's. In order to know if this new technique is suitable in Sichuan basin, a field experiment was carried out to study the growth characteristics and yields of rice mulched by different materials in an alluvial paddy soil. The experiment included three rice cultivation systems: traditional flooding (TF), mulch of plastic film without flooding (PM), and mulch of wheat straw without flooding (SM) at 150 N kg/hm² as urea, 75 P_2O_5 kg/hm² as calcium superphosphate and 75 K_2O kg/hm² as KCl, respectively. In addition, two Mn levels (0 and 1.8 Mn kg/hm² as 0.2% $MnSO_4$ solution with foliage dressing) in SM system, and four N levels (0,75, 150 and 225 N kg/hm²) in PM system were included to determine the effect of Mn and N supply on growth and yield of mulched rice. All the N, P, K fertilizers were applied as basal application before rice transplanting. The plot size was 3 m × 8m. Each treatment had three replicates. The rice variety used was Hybrid rice "Gangyou 527".

The results showed that soil temperatures were 10 ℃ (at surface soil) and 6 ℃ (at 10 cm depth of soil) higher in PM treatment than in TF treatment at early tillering stage (17 days after rice

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transplanting). On the contrary, soil temperatures in SM treatment were 7 ℃ (at surface soil) and 5 ℃ (at 10 cm depth of soil) lower than in traditional flooding treatment at the same stage. The effects of increasing or decreasing soil temperature by soil mulch materials lasted more than 50 days after rice transplanting. In accordance with changes of soil temperature, the growth of rice was enhanced by PM treatment but inhibited by SM treatment especially at nutritional growing stage compared with TF treatment. In addition, serious Mn deficient symptom and lower Mn concentration in shoot of rice in SM treatment were observed at tillering stage, which led to the delayed regreening of rice, the decline in plant height, tiller number and shoot biomass. When 0.2% $MnSO_4$ solution (two times, 450 kg/hm^2 each) was dressed to root zone of rice at regreening stage in SM system, the plant height, tiller number and shoot biomass of rice were basically recovered compared with traditional flooding rice, suggesting that the growth decline and Mn deficiency by low temperature could be compensated by the application of Mn fertilizer. The fact that soil available Mn (DTPA extractable) was not different among TF, PM and SM cropping systems further supported the negative effect of low soil temperature on rice Mn nutrition. The yield of rice followed the sequence of PM＞TF and SM＋Mn＞SM. There were no significant yield differences among PM, TF and SM＋Mn treatments except for the difference between SM and other three treatments. The yield response of rice to N fertilizer in PM systems was conspicuous only when the N rate was not higher than 150 N kg/hm^2. Furthermore, the yield of rice at rate of 75 N kg/hm^2 in PM system was equivalent to that at 150 N kg/hm^2 in TF system, which means that PM system has the potential to save the amount of N fertilizer compared with TF system from short-term effects.

Because of no obvious water layer maintained on surface soil in PM and SM systems, water consumption in soil mulch treatments were saved by 63.1% compared with traditional flooding treatment. Meanwhile, water use efficiency in soil mulch treatments was 1-2 times greater than in traditional flooding treatment. For PM system, the growth and yield of rice were not affected by the large reduction of irrigation water. For SM system, however, the growth and yield of rice declined in relation to Mn deficiency, which mainly caused by low soil temperature at early growth stage of rice. The rice growth as well as yield in SM system could also maintain at the same level of TF system when Mn requirement was met during rice growth period. Comparison of overall shoot growth, yield and water consumption in three rice cropping systems (PM, SM and TF) revealed the facilitation of soil mulch cultivation especially with plastic film mulch in water saving without the loss of yield. Thus, mulched rice cultivation especially with plastic film could have a wide prospect in Sichuan basin considering its advantage in water saving and yield increase.

Key words: aerobic rice; Mn deficiency; soil mulch materials; yield; water saving
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由于传统水稻栽培方法耗水量达到 10500～13500 m^3/hm^2，有些地方甚至高达 30000 m^3/hm^2，所以在我国水源、能源十分紧张的情况下，水稻节水灌溉具有十分重要的经济、社会和生态效益。而按中国水稻研究所和其它省的试验研究与实践，水稻需水量只要达 4500 m^3/hm^2 左右就可使产量达 6000 kg/hm^2[1]，由此可以知水稻节水潜力十分巨大。

20 世纪 80 年代以来，以间歇、湿润等为代表的水稻节水灌溉技术发展较快，节水可达 20%～40%，且水稻产量比传统淹水更高[2～5]。地膜覆盖技术在我国旱地农业中已被广泛推广和应用，成为许多旱地作物产量水平再上一个新台阶的重要措施[6,7]。它的增产机制主要在于改善了土壤水、热状况[6,8～10]和作物根际的微生态环境。把地膜覆盖技术应用到水稻栽培中，就形成了水稻旱作覆膜栽培技术，这是在水源不足地区首先发展起来的节水种植方式[1]，具有明显的增产和稳产效果。覆膜旱作水稻技术因其比间歇、润湿灌

溉更具有显著的节水效应，近几年受到了许多研究者的重视。

与此同时，在20世纪70年代末至80年代初相继在中国[11]和印度[12]发现水旱轮作土壤上小麦缺锰问题；20世纪90年代的一系列研究发现造成小麦缺锰的主要原因是由于传统淹水条件下，土壤淋溶和淹灌水稻植株对锰的奢侈吸收所致[13]，所以要保持水旱轮作土壤的锰素肥力，就要改变水稻传统的水分管理，减少土壤有效锰的损失[14]。

近年来随着社会经济的发展，成都平原农民露天焚烧小麦秸秆的现象日益普遍，给社会、环境、生态造成了严重的影响，小麦秸秆的有效利用也成为当务之急。为此于1999年水稻季开始在四川省温江县进行了不同覆盖条件下的旱作水稻试验，目的在于比较不同覆盖物对旱作水稻生长及其产量的影响，以揭示不同覆盖物改善土壤生态环境，影响水稻植株的生长机理。

1 材料与方法

1.1 供试土壤及降水

试验在四川省温江县天府镇的灰色冲积性水稻土上进行，土壤pH 6.5，有机质30.4 g/kg，有效Mn 2.7 mg/kg，有效Fe 58.5 mg/kg，有效Zn 0.65 mg/kg，有效P 5.2 mg/kg，全Mn 430 mg/kg，全Fe 28.6 g/kg。水稻整个生育期降水量在1999年为749.9 mm和2000年为455.5 mm。

1.2 试验方案

试验小区长8 m、宽3 m，小区间隔0.5 m，重复间间隔2 m。淹水小区四周用厚塑料膜纵向隔开，防止水分侧渗影响旱作小区。所有处理均施过磷酸钙750 kg/hm^2、氯化钾150 kg/hm^{2}做基肥。试验共设6个处理：①旱作覆膜N_1(0 kg N/hm^2)；②旱作覆膜N_2(75 kg N/hm^2)；③旱作覆膜N_3(150 kg N/hm^2)；④旱作覆膜N_4(225 kg N/hm^2)；⑤ 旱作麦秸覆盖N_3(150 kg N/hm^2)；⑥传统淹水栽培N_3(150 kg N/hm^2)。N肥为尿素，均做基肥于移栽前一次施入。另外，由于麦秆覆盖旱作处理在水稻移栽后不久植株表现出明显的缺锰症，因此在第5处理裂区为不施锰和灌根施锰处理，施锰裂区所施锰肥为2‰的硫酸锰溶液，每次施用量为450 kg/hm^2，施锰时间为移栽后第15天和第20天。所有处理重复3次。

1.3 栽培管理及取样方法

各旱作小区施肥后，覆地膜和麦秸(5250 kg/hm^2，相当于上季小麦单位面积的秸秆产量)。地膜紧贴地面，并用土点压防风吹起；麦秸均匀覆盖地表，不露土面。水稻供试品种为岗优527杂交稻。插秧密度为行株距均30cm，计180000株/hm^2。旱作处理栽秧用小铲挖穴、插苗；并在水稻整个生育期不灌水；传统处理按当地淹水管理；其它管理均同当地管理方法。小区植株取样为具有代表性3穴/小区。植株含锰量采用硫酸-高氯酸消煮，原子吸收分光光度计测定。

2 结果与分析

2.1 不同覆盖处理对土壤温度及有效锰、铁含量的影响

2.1.1 土壤温度 观测发现，在水稻分蘖初期覆地膜与覆麦秸处理地表温度最高相差近20℃；在地下10cm处温度也相差10℃。淹水处理地表温度虽不如覆地膜处理高，但也比麦秆覆盖处理高10℃；在地下10cm处最高也相差7～10℃。从图1还可知，在分蘖旺期覆地膜与传统淹水处理不论在地表，还是在地下10cm处的温度都比覆小麦秸秆处理温高，但是差异变小。这是由于随着植株的生长，对地表的遮荫增加，而使增温效果有所下降。在分蘖后期不同处理无论地表还是地下温度都没有前期差异大，这是由于植株完全遮荫和覆盖秸秆处理的麦秆腐烂所致。由此结果可以得出，地膜覆盖处理在分蘖初期有较大的增温作用，后期相对较小。

2.1.2 土壤有效锰、铁含量 试验发现水稻移栽后不久覆麦秆处理植株生长缓慢，叶色淡黄，从其症状特征与报道的水稻旱育秧苗缺锰症类似[15]。同时，这一缺锰现象也为分蘖期水稻地上部和根系锰含量明显低于的结果证实(图2)。为此，于移栽后第15和第20天分两次灌施2‰的$MnSO_4$溶液，并在移栽后第33天取土样测定土壤有效锰和有效铁的含量，结果见表1。从表中可以看出，供试田块土壤的有效锰含量比较低，而有效铁含量相对较高，水稻覆盖旱作与传统淹水处理之间也无显著差异，但覆麦秆处理施锰后土壤有效锰含量显著提高，增幅达2.7 mg/kg。以上结果说明，覆麦秆旱作水稻缺锰不是土壤有效锰不足所致，

而是由于前期土壤低温引起根系吸锰能力下降所造成。

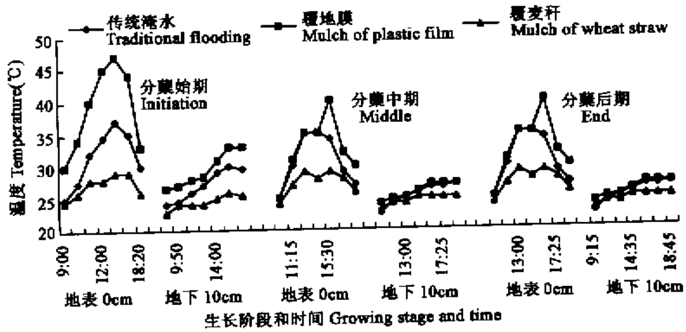

图 1 不同覆盖处理对不同分蘖时期地表(0cm)和亚表层(10cm)温度日变化的影响

Fig. 1 The changes of soil surface (0cm) and subsurface (10cm) temperature within one day as affected by different soil mulch systems during rice tillering stages

表 1 水稻分蘖初期不同覆盖处理土壤有效锰和有效铁的含量(mg/kg)

Table 1 Available Fe and Mn contents in different treatments at the beginning of tillering stage

项目 Items	传统淹水 Traditional flooding	覆地膜 Mulch of plastic film	覆麦秆 Mulch of wheat straw	覆麦秆+Mn Mulch of wheat straw+Mn
有效锰 Available Mn	3.06±0.2	2.95±0.35	3.49±0.87	6.15±0.51
有效铁 Available Fe	33.25±14.21	23.40±2.69	26.05±6.43	26.35±4.45

2.2 不同覆盖物处理对旱作水稻生长的影响

2.2.1 株高 在不同覆盖物条件下,水稻植株高度变化明显不同(图 3)。水稻株高在前期以传统淹水处理最高,而到后期覆地膜处理最高,覆麦秆不施锰处理的株高最低,而该处理灌施锰肥后其株高迅速增加,但最终其株高还是略低于覆地膜和传统淹水处理(图 3)。

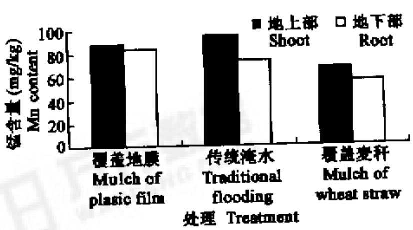

图 2 施锰前不同覆盖处理水稻植株锰含量

Fig. 2 Plant Mn concentration of rice in different mulch treatments before the application of Mn fertilizer

2.2.2 分蘖和成穗 从图 4 可知,旱作覆膜处理水稻具有分蘖早、分蘖多,其有效分蘖率高(达 60%)的特点。传统淹水处理分蘖没有覆地膜处理快,且分蘖成穗率较低(56%)。这说明覆地膜处理移栽后具有生长恢复快、返青早,无效分蘖少的特性。从图 4 还可知,覆麦秸施锰处理在移栽初期分蘖缓慢,而施 Mn 后随着体内锰吸收量的增加,其分蘖迅速增加,后期甚至超过了传统淹水处理。其成穗率也高达 60%,而覆麦秸不施锰处理的分蘖最慢、成穗率也相对最低(43%)。有效穗是构成产量的重要因子,较高的分蘖和较高的成穗率,才有可能会有较高的产量。在生产上常常采取一些措施来促蘖、控蘖、调整有效分蘖使水稻达到一定产量水平。

2.2.3 生物量累积 从图 5 可知,地膜覆盖处理生物量累积较快,而覆麦秆处理施锰肥的裂区水稻生物量比不灌锰对照增加迅速,同时施锰后水稻叶色也逐渐变深。到移栽后 46d,施锰肥处理的生物量比对照不施 Mn 处理已有明显的差异。在收获期该处理与传统淹水和覆地膜处理的生物量已经无明显差异。在同一田块施肥处理相同,但覆盖物不同造成其生物量的差异,进而会造成产量的差异。不同覆盖处理对水稻根系的影响最大。覆麦秆处理开始根系生长极为缓慢(见图 6),而淹水与覆地膜处理在移栽后恢复快、返青早,生长迅速。从图 6 中还可知,覆麦秆处理灌施锰肥后,根系生长比对照快,发达的根系为养分的吸收及灌浆奠定了基础。传统淹水处理到后期根系生物量下降较多,这与作者所发现的淹灌水稻后期根系早衰

(灌浆一半根系先死亡，地上部也随即干枯)的现象是相符的。

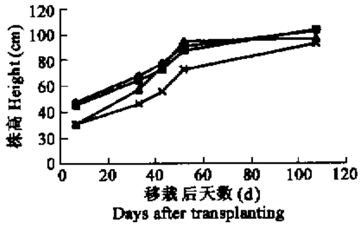

图 3 不同覆盖处理水稻株高的变化

Fig. 3 The change of plant height as affected by different soil mulch treatments and Mn application

■地膜覆盖 ●传统淹水 ▲覆麦秆+Mn ×覆麦秆

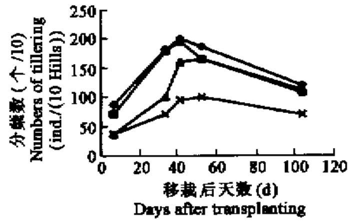

图 4 不同覆盖处理水稻分蘖的变化

Fig. 4 The change of tiller numbers as affected by different soil mulch treatments and Mn application

●覆地膜 ■传统淹水 ▲覆麦秆+Mn ×覆盖秆

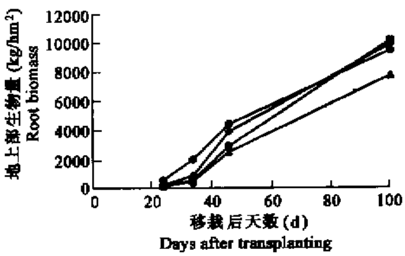

图 5 不同覆盖处理水稻地上生物量的变化

Fig. 5 The plant shoot biomass changes for different mulch material treatments

♦传统淹水 ●覆地膜 ▲覆麦秆 ■覆麦秆+Mn

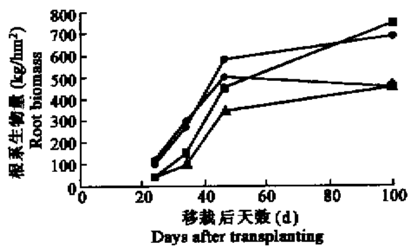

图 6 不同覆盖处理水稻地下部生物量的变化

Fig. 6 The plant root biomass changes for different mulch material treatments

♦传统淹水 ●覆地膜 ▲覆麦秆 ■覆麦秆+Mn

2.3 不同覆盖物对产量及产量构成因子的影响

不同处理的水稻产量见表 2。从表中可看出，常规施氮条件下(150 kg/hm²)覆地膜处理水稻产量最高，传统淹水处理次之，覆麦秆处理最低，三者之间的差异均达到显著水平；而覆麦秆处理灌施锰肥后水稻产量显著提高，并与传统淹水和覆地膜处理的产量无明显差异，这说明覆麦秆旱作处理水稻前期生长虽然较差，但如果及时追施锰肥，能够在很大程度上补偿因缺锰所造成的产量损失。从表 2 还可知，覆地膜处理旱作水稻的产量随氮肥用量的增加而增加，但在施氮量达 150 kg/hm² 以后产量基本持平不再明显变化，说明覆地膜条件下旱作水稻施氮量不应超过 150 kg/hm²。

表 2 不同覆盖物处理对水稻产量的影响 (kg/hm²)

Table 2 Effect of different mulch treatments on rice yield

施氮量 N application rate (N kg/hm²)	传统淹水 Traditional flooding	覆地膜 Mulch of plastic film	覆麦秆 Mulch of wheat straw	覆麦秆+Mn Mulch of wheat straw +Mn
0		4318 d		
75		5268 bc		
150	5609 b	6512 a	4799 c	6013 ab
225		6525 a		

所有处理无相同字母间表示差异达 5%的显著水平(邓肯法) Values in all treatments without same words represent significant difference at 5% probability level (Duncan's method)

表 3 进一步列出各覆盖处理水稻的考种结果。结合图 3 和表 3 可知，覆地膜处理的植株最高，有效穗最

多，千粒重也最重，但其实粒数较低，空壳率较高。这可能是在生殖生长阶段受到了一定水分胁迫缘故。尽管如此，由于覆膜的增温作用对灌浆有利，再加上有较高的有效分蘖，所以产量仍以该处理最高。覆麦秸不灌施锰肥处理的株高最小，虽然其单穗实粒数最高、空粒数较少，但覆麦秆使根际温度降低对灌浆不利，千粒重最低，再加上有效分蘖少，因而产量最低；同样在该处理由于灌施锰肥解决了前期旱作水稻的锰营养胁迫问题，所以各种性状都得到改善，尤其是穗粒数、有效穗都有所增加，其产量也比较高，且与覆地膜处理无明显差异。

表 3　不同覆盖物处理对水稻产量构成因子的影响

Table 3　Effect of different mulch treatments on rice yield components

处理 Treatments	有效穗 Available panicle (10^4/hm^2)	单穗实粒数 The full grains each panicle (number/panicle)	单穗空粒数 The empty grains each panicle (number/panicle)	空壳率 The percentage of empty grain (%)	千粒重 The weight per thousand grains (g)
传统淹水 Traditional flooding	187±28	110±18	36±14	24.7±2.0	27.4±0.1
覆地膜 Mulch of plastic film	200±31	103±15	50±15	32.4±5.6	28.0±1.0
覆麦秆 Mulch of wheat straw	176±22	120± 8	51±19	29.8±8.7	26.5±1.1
覆麦秆＋Mn Mulch of wheat straw＋Mn	192±33	145±23	57±10	28.4±5.0	26.1±1.0

综上结果可知，不同覆盖物所造成的温度差异，使得覆地膜水稻具有良好的生长环境，既有利于旱作水稻根系的生长，也有利于对土壤养分的吸收，所以在土壤有效锰含量较低的情况下，覆地膜水稻没有表现出缺锰现象，其生物量及产量都为最高。而覆秸秆旱作水稻由于覆麦秆的降温效应，造成其根系活力的下降，对养分吸收能力尤其是对锰吸收能力降低，因而在分蘖初期表现出缺锰症。而对于传统淹水处理由于土壤氧化还原电位较低，高价锰易转化为 Mn^{2+}，所以也不会表现出缺锰症状。由此推断覆地膜能够改善土壤环境条件，有利提高旱作水稻根系活力，促进对养分的吸收；同时增温、保湿作用又有利于土壤养分的转化，提高了土壤养分的生物有效性，所以地膜处理生长良好。而麦秆覆盖处理，如果对土壤中的生长限制因子如缺锰进行施肥等调控，就能弥补由于麦秆覆盖使温度降低造成分蘖初期生长不良的问题，从而使麦秆覆盖处理也能取得可观的产量。

2.4　不同覆盖旱作水稻的节水效应

表 4 总结了不同覆盖物处理下旱作水稻的水分消耗和水分利用效率及节水的情况。从表中可以看出，覆盖旱作的总耗水量大大低于传统淹水处理，其节水率达 63.1%，这在降雨量一致的条件下灌溉水数量的大量节省是覆盖旱作水稻省水的关键。同时，表 4 结果还表明水分的利用效率依次是覆地膜处理＞覆麦秆处理＞传统淹水处理，而覆麦秆＋Mn 处理的水分利用效率与覆地膜处理接近，这说明只要保证锰素等营养的供应，覆麦秆旱作也能象覆地膜旱作一样在不降低产量的前提下显著提高水稻的水分利用效率，实现了在高产条件下的水分资源高效利用。

3　讨论

水稻覆膜旱作具有增温、保水作用，从试验结果看还具有加快水稻返青和提高分蘖的作用。这些作用有利于在冷凉、水分供应不稳定的地区推行水稻这一栽培方式[16]。目前在四川省低温山区和缺水的丘陵区所进行的水稻覆膜试验均取得了一定的进展。作者 1997 年在四川省温江县所进行的水稻覆盖旱作试验中曾发现覆膜旱作水稻有分蘖过旺的现象，而从本试验的结果看虽然覆地膜旱作水稻分蘖最快、最多，但还是处于正常分蘖生长状态。这也许与试验田基础肥力有关。

表 4 不同覆盖物条件下旱作水稻的水分消耗及节水潜力

Table 4 Water consumption and water saving potential of aerobic rice under different mulch materials

项目 Items	传统淹水 Traditional flooding	覆地膜 Mulch of plastic film	覆麦秆 Mulch of wheat straw	覆麦秆＋Mn Mulch of wheat straw ＋ Mn
降雨量(mm) Amount of rainfall	787.4	787.4	787.4	787.4
灌溉量(mm) Amount of irrigation	1681	123	123	123
总耗水量(mm) Total water consumption	2468.4	910.4	910.4	910.4
水分生产效率(g grain/kg water) Water use efficiency	0.23	0.72	0.53	0.66
节水率(%) Percentage of water saving	—	63.1	63.1	63.1

麦秆覆盖旱作水稻处理受到土壤低温的不利影响，使其生长缓慢、分蘖少、产量低。这与紫甘蓝覆盖麦秆在早春栽培中结果类似，而采用麦秆＋地膜覆盖甘蓝比单纯覆膜或覆麦秆的产量都高[17]。这充分说明地膜的增温作用对旱作水稻的生长有利。但本试验条件下覆麦秆处理还出现了水稻缺锰现象，在灌施锰肥(裂区)后缺锰症得到显著改善，水稻产量也恢复到正常淹水处理的水平。而同时除施锰裂区外，覆盖旱作与传统淹水处理间土壤有效锰的含量却没有明显差异(表 1)。这说明覆麦秆处理水稻生长不良在很大程度上是由于土壤前期低温(图 1)抑制了水稻根系对锰等营养元素的结果。由于试验地所属冲积性水稻土 pH 高、质地轻常出现小麦缺锰问题[14]，因此在旱作覆麦秆条件下也容易诱化水稻的缺锰现象。众所周知，在淹水后土壤氧化－还原电位降低，土壤有效锰增高。所以覆麦秆水稻旱作栽培可以通过在前期适当淹水来防治缺锰问题，但能否彻底解决麦秆降温所造成的不利影响，需要进一步试验验证。

从水稻传统淹水栽培到覆地膜、覆麦秆旱作栽培，尽管可以大大提高水分利用效率、减少总耗水量、节省灌溉水资源(表 4)，并获得与传统淹水相近或略高的产量(表 2)，但是也不能否认由此会对农田生态系统的微环境变化产生复杂而深远的影响，其中包括土壤理化性质、微生物区系和作物根系分布等等。如何评价水稻覆盖旱作条件下的经济、生态乃至环境效应，特别是将传统稻/麦轮作转变为覆盖条件下旱作稻/麦轮作后整个系统的稳定性，还需要进一步的研究加以定量化。

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