

微分光谱遥感及其在水稻农学参数测定上的应用研究

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摘要: 通过不同氮素营养水平的水稻田间试验, 解析了水稻冠层微分光谱对消除背景(湿土、水面)信息的影响, 证实微分光谱在消除背景信息的影响方面起到了很好的作用。用微分光谱确定出最优的波段宽度应小于 10 nm; 将微分光谱应用于农学参数测定, 存在红边位移现象, 在孕穗期之前, 红边随施氮量增加向长波方向移动“红移”; 孕穗期之后“红移”现象基本消失, 而发生“蓝移”。红边参数(红边、红边振幅、红边振幅与最小振幅的比值、红边峰值面积)与上层叶片的叶绿素含量 LAI 有着密切的关系, 而与叶片中的叶绿素 b、类胡萝卜素之间相关性不明显。一些红边参数可作为水稻叶绿素含量 LAI 测定的简捷方法, 从而证实了利用微分光谱测定一些农学参数的可行性。

关键词: 微分光谱; 水稻; 农学参数; 红边参数

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野外光谱仪在自然环境下测得的高光谱数据可用于不同的遥感领域。首先这些数据可供用来建立和测试描述表面方向性光谱反射和生物物理属性的关系。地表的辐射能抵达传感器是一个复杂过程, 受多种因素影响, 包括地面的生物物理性质、地表的宏观微观糙度、观测和光线照射的几何角度、大气状态等因素。因而利用高光谱数据对地表属性进行模拟是必要的。其次, 地面光谱测量用来描述表面反射特性, 可用于航空和航天传感器的定标。第三, 当有些应用不需要图像数据时, 光谱测定不失为成本低廉、灵活的数据获取方法^[1]。

有了光谱数据, 对这些数据求微分, 得到微分光谱, 这项技术在消除背景信息的影响和对混合光谱分解方面起到了很好的作用^[5], 为分析化学和遥感领域提供了应用前景。在化学分析中常用到吸收光谱技术, 有用的光谱信息常常与背景噪声和其它未知信号相伴, 在遥感技术中, 传感器接受的反射光谱用于估算地物特性时, 就受到背景信息和其它地物的干扰, 如各种不同地物反射率就影响到对作物生长和其条件的测定, 为减少误差, 化学分析中经典的方法归结于模糊矩阵, 即两个波段之比或之差。

Inada (1965) 利用叶片在 670 nm (叶绿素吸收波段) 与 800 nm (这个波段对叶子中分子结构不连续性敏感) 的透射率之比来测定内部叶子的叶绿素含量^[8]。同样的理由, 在遥感中比值和有关的光谱指

数比单个波段要有用得多。

然而, 如果这些信号是处于理想水平即以常数项出现(或从一个信号到另一个信号有一个常量斜率), 用不同波段的比值和差值能完全校正背景影响。实际上, 背景反射率从可见到近红外是逐渐增加, 且增加比值随不同土壤而不同, 背景信号时常发生其它变化, 例如大气中的瑞利散射与波长的 4 次方成正比。

在定量分析中, 微分技术与 RV I DV I 相比, 更具简捷性和有效性, 遥感中大多采用一阶微分来寻找关键波段如“红边”^[4], 而分析化学中采用一阶、二阶和高阶微分作为消除低频背景噪声和减少重叠光谱混淆的一项技术。

1 试验方法及数据获取

1.1 田间试验概况

田间试验于 1999、2000 年在浙江大学华家池校区的试验农场(30°14'N, 120°10'E) 内同一地块上进行。供试品种是秀水 63; 小区面积 20 m², 4 个重复, 随机排列; 5 个氮素水平处理, 分别施纯氮量 0、45、135、225、315 kg/ha, 使之表现为严重缺氮、缺氮、适量氮、过量氮、严重过量氮(用 N₁、N₂、N₃、N₄、N₅ 表示), 分别在返青期、拔节期和抽穗始期按 60%、30%、10% 施入, 钾肥在拔节期和抽穗始期分两次等量均匀施入各小区; 行、株距为 0.14 m × 0.17 m, 田间管理按大田管理方式进行。两年试验都是在 6 月 25 日播种, 移栽期: 1999 年 7 月 24 日; 2000 年 7 月 21 日。

1.2 叶片叶绿素测定

对不同氮素处理的稻株主茎自上而下选择 3 张完全展开的叶片, 分别记为上叶、中叶、下叶。采用

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4.5 4.5 1 的 $\text{CH}_3\text{CH}_2\text{OH}$ CH_3COCH_3 H_2O 混合提取液浸提 24 h, 再用 72-2 型分光光度计测定一定波长的光密度, 用下式求出叶绿素 a、叶绿素 b、类胡萝卜素含量及叶绿素总含量分别为

$$\text{Chla} = 9.784 \text{OD}_{662} - 0.990 \text{OD}_{644}$$

$$\text{Chlb} = 21.426 \text{OD}_{644} - 4.650 \text{OD}_{662}$$

$$\text{Car} = 4.695 \text{OD}_{440} - 0.268 (\text{Chla} + \text{Chlb})$$

$$\text{Chlt} = \text{Chla} + \text{Chlb}$$

式中 Chla 、 Chlb 、 Car 、 Chlt ——分别为叶绿素 a 含量、叶绿素 b 含量、类胡萝卜素含量和叶绿素总含量; OD_{440} 、 OD_{644} 、 OD_{662} ——为 440 nm、644 nm 和 662 nm 的光密度。

1.3 发育期观测和 LAI 测定

移栽后, 进行发育期观测, 在分蘖盛期、拔节期、孕穗期、抽穗普遍期、乳熟期, 进行 LAI, 叶片鲜、干重测定。LAI 测定采取干叶称重法, 即:

全部叶片的面积 (A) 与部分叶片叶面积 (a) 之比等于全部叶片的干质量 (W) 与部分叶片的干质量 (w) 之比。即:

$$A/a = W/w, A = a \times W/w$$

将部分叶片平铺, 固定在白纸上, 复印, 扫描入计算机, 在 GIS 软件支持下跟踪图斑轮廓, 计算面积 (a)。全部叶片的面积 (A) 与占地面积之比得到 LAI。

1.4 光谱反射率测定

冠层光谱是用光谱仪- FieldSpecR (美国 ASD 公司生产) 测定, 视场角 25° ; 光谱反射率经专用平面白板标准化, 该仪器测定 512 个光谱波段, 波段范围为 333.05~1056.06 nm, 光谱分辨率约为 3 nm。选择晴朗无风天气, 分别在水稻分蘖、拔节、孕穗、抽穗和乳熟期测定, 每次测定时间为北京时间 10:15~11:45 (太阳高度角大于 45°)。传感器探头垂直向下, 与冠层顶相距约 0.75 m 左右, 观测范围直径为 0.62 m。每个小区内不同点测定 10 次, 取平均值作为该小区的光谱反射值, 每个小区测定前、后都立即进行白板校正。光谱测定后, 取样待测农学参数。

2 数据处理与分析

将测定水稻不同发育期冠层的反射光谱, 用 ASD 公司提供的 PORTSPEC™ 和 VNIR™ 软件进行处理, 有了光谱数据, 对这些数据求微分, 得到微分光谱。

2.1 利用微分光谱消除背景噪声影响

图 1 所示是水稻冠层(抽穗期)、新翻湿地和水面 3 条反射光谱曲线, 新翻湿地和水面反射光谱曲线近似为直线, 假设 3 条多项式曲线方程为

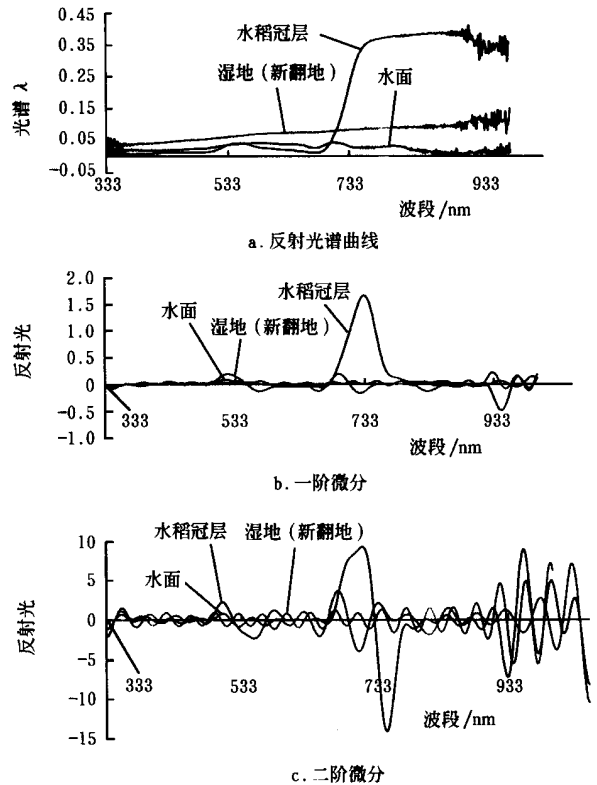


图 1 水稻冠层、湿土和水面的反射光谱曲线(a)、它们的一阶微分(b)和二阶微分(c)

Fig. 1 Spectral reflectance characteristics of rice canopy, wet soil and water(a) and their first differentiation(b) and second differentiation(c)

水稻冠层反射光谱曲线

曲线 1 信号 $y_1 = a_1 + b_1x + c_1x^2 + d_1x^3$ (1)

水面和新翻湿地反射光谱曲线

曲线 2 信号 $y_2 = a_2 + b_2x$ (2)

曲线 3 信号 $y_3 = a_3 + b_3x + c_3x^2$ (3)

对方程 1、2、3 加权求和

$$y = (1 - F_1 - F_2)y_1 + F_1y_2 + F_2y_3$$
 (4)

对(4)式求微分

$$\begin{aligned} dy/dx = & (1 - F_1 - F_2)dy_1/dx + F_1dy_2/dx + \\ & F_2dy_3/dx = (1 - F_1 - F_2)(b_1 + 2c_1x \\ & + 3d_1x^2) + F_1b_2 + F_2(b_3 + 2c_3x) \end{aligned}$$
 (5)

二次微分

$$\begin{aligned} d^2y/dx^2 = & (1 - F_1 - F_2)(2c_1 + 6d_1x) \\ & + F_22c_3x \end{aligned}$$
 (6)

可见, 式(2)中的 y_2 被消除, 尽管其值取决于加权系数, 但两次微分便独立于背景噪声 y_2 。而式(3)中的 y_3 被消除了一部分, 两次微分后还不能完全独立于背景噪声 y_3 。三次微分后才完全独立于背景噪声 y_3 。实际上, 背景信号的干扰比方程(2)、(3)复杂

得多,而高阶微分是可用的。例如,四阶微分可消除大气中的由瑞利散射造成的影响。随着微分阶数的增加,土壤背景的影响基本消除。为消除背景信号,比率(例如比值植被指数)也是非常有效的方法,但二阶微分的比值则不行,因为背景信号的二阶光谱不仅移向 y 轴上,而且存在不同的斜率,这在图 1c 中也能看到,背景信息为波长的线性函数,无论是否是斜率的函数,其二阶微分等于零,比值植被指数或其它比率都对不同斜率很敏感,对背景信号斜率变化的敏感性一般会影响到对叶片光谱特性微小变化的测定。相反,微分光谱指数在处理土壤光谱斜率变化上是较好的方法。

微分的另一个方面是在遥感中对重叠混合光谱的处理起着重要作用。如果几个光谱重叠,随着增加窄波段微分阶数,其相对振幅增加,这在图 1b、1c 中可清楚看出,这导致微分光谱比零阶光谱更易区分。

2.2 利用微分光谱确定最佳波段宽度

从不同氮肥处理的小区试验中获取叶片和冠层光谱,在同一小区上采集 10 次光谱,求其平均光谱,此光谱作为有用信号,对平均光谱作不同波段间隔的平滑处理,然后求微分,此微分值的绝对值作为噪声,信噪比与平滑波段宽度建立多元函数(图 2),最优的波段宽度小于 10nm。这与“识别植被的含氮量和纤维素所需的光谱分辨率应为 10nm”一致^[2]。

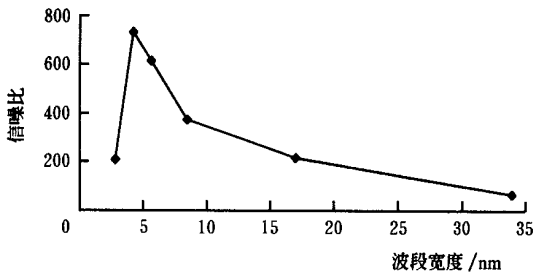


图 2 信噪比与波段宽度的关系曲线

Fig. 2 The relationship between the ratio of signal to noise and smoothing bandwidth

2.3 微分光谱与红边参数的关系

通过计算光谱反射率在 680~750 nm 之间的一阶微分来计算红边参数,这些参数包括:红边:当一阶微分值达最大时所对应的波长 (K_{ed}); 红边峰值:680~780 nm 之间的光谱一阶微分值; 红边振幅:当波长为红边时的一阶微分值 (dK_{ed}); 最小振幅:波长在 680~750 nm 之间的最小一阶微分值 (dK_{in}); 红边振幅与最小振幅的比值 (dK_{ed}/dK_{in}); 红边峰值面积:680~750 nm 之间的光谱一阶微分值包围的面积 ($2dK_{680-750}$)。有人认为有两个因素决定着红边位置和红边峰值形状^[3,7]。其中一个因素是叶绿素含量,它引起 700 nm 附近的光

谱变化,另一个因素是作物对近红外波段的散射特性。叶绿素含量增加时,叶绿素吸收波段带变宽,红边振幅、红边峰值面积随之增加,红边向长波方向移动^[6]。

2.3.1 红边位移

从图 3 可见,水稻冠层反射光谱的红边位于 700~740 nm 之间, N_1, N_2, N_3 3 个处理随施氮量增加,整个生育期的红边位置均向长波方向移动, N_4, N_5 处理在拔节期和孕穗期的红边位置随施氮量增加向长波方向移动,而分蘖、抽穗、乳熟期则相反。不同氮素处理随发育期推移而“红移”到孕穗期 (N_4 处理除外) 时达最大,抽穗期后出现“蓝移现象”;从图中曲线的曲率可知,5 种处理中 N_1 和 N_2 处理“红移”现象最明显,其次是 N_4, N_5 处理, N_3 处理“红移”最不明显。由于叶面积指数和叶绿素含量随施氮肥量增加而增加,因此,“红移”现象与前人研究结果一致。

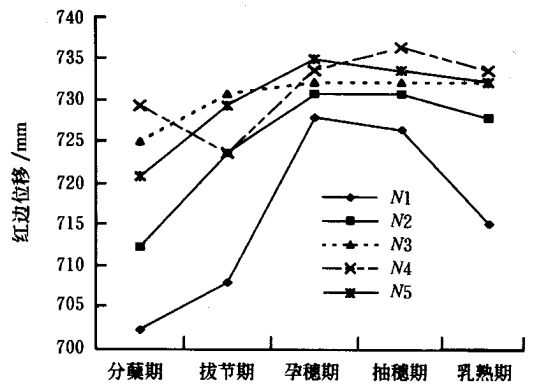


图 3 不同发育期、不同氮素处理的水稻冠层反射光谱的红边位移

Fig. 3 Displacement of red edge of canopy spectral reference of rice in different nitrogen and stage

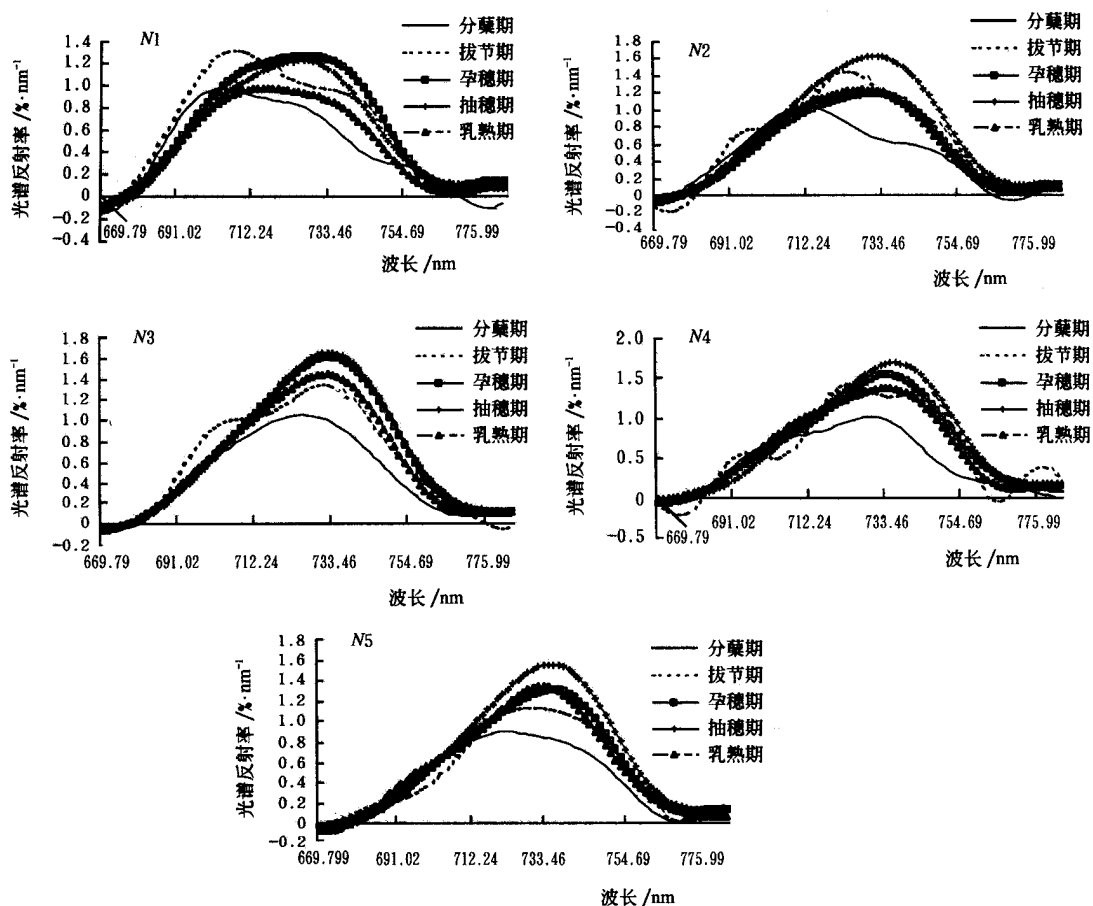
2.3.2 红边峰值形状

从图 4 可见, N_1, N_2, N_3, N_4 随氮素增加在分蘖与拔节期都出现“双峰”现象,“双峰”程度随氮素增加而减弱,拔节期之后变成单峰, N_5 处理在不同发育阶段都是单峰。说明不同氮素营养水平对红边峰值形状有影响;红边峰值随氮素增加而增加,同一氮素营养水平的红边峰值以分蘖期最低,抽穗期最高。

2.3.3 红边参数与叶片色素含量之间的关系

分别计算红边 (K_{ed})、红边最小值 (dK_{02})、红边振幅 (dK_{ed})、 dK_{ed} 与 dK_{02} 的比值、红边峰值面积 ($dK_{680-780}$) 与叶片叶绿素含量之间的关系,从表 1 可见,红边参数与上层叶片叶绿素 a 的含量之间有很好的相关性,与不同层位叶片叶绿素 b、类胡萝卜素的含量相关性不明显,其中 K_{ed} 、 dK_{ed} 、 $dK_{680-780}$ 、

$dK_{ed} \text{Öd} K_{02}$ 与上层叶片叶绿素 a 含量相关性达到了极显著检验水平。



(图中横轴为波长, 纵轴为光谱反射率的一阶微分: % · nm⁻¹)

图 4 水稻冠层反射光谱的红边峰值形状

Fig 4 The shape of red edge peak of canopy spectral reference of rice in different nitrogen and stages

表 1 稻株不同层位叶片色素和 LA I 与红边参数之间的相关系数 (n = 25)

Fig 1 A correlation between leaf pigment and LA I and the red parameters of different leaves mg · g⁻¹

	dK_{ed}	K_{ed}	dK_{02}	$dK_{ed} \text{Öd} K_{02}$	$dK_{680-780}$
上叶 <i>Chla</i>	0.072	0.601 ^{3 3}	-0.4616 ³	0.7050 ^{3 3}	0.5593 ^{3 3}
上叶 <i>Chlb</i>	-0.219	0.1620	-0.4328 ³	0.3962	0.0679
上叶 <i>l</i>	0.006	0.190	-0.1908	0.3898	0.3471
上叶 <i>Chlt</i>	-0.029	0.500 ³	-0.5093 ³	0.6705 ^{3 3}	0.4319 ³
中叶 <i>Chla</i>	0.198	0.430 ³	-0.6058 ^{3 3}	0.6375 ^{3 3}	0.1982
中叶 <i>Chlb</i>	-0.027	0.033	-0.2672	0.2810	0.0211
中叶 <i>l</i>	0.211	0.214	-0.1962	0.3821	0.1257
中叶 <i>Chlt</i>	0.129	0.312	-0.5206 ^{3 3}	0.5478 ³	0.1462
下叶 <i>Chla</i>	0.177	0.248	-0.1954	0.3409	0.0939
下叶 <i>Chlb</i>	-0.017	0.062	-0.2517	0.2179	-0.1211
下叶 <i>l</i>	0.183	0.158	-0.1289	0.2902	0.0916
下叶 <i>Chlt</i>	0.121	0.197	-0.2207	0.3127	0.0268
LA I	0.3088	0.7385 ^{3 3}	-0.4047 ³	0.7693 ^{3 3}	0.7672 ^{3 3}
dK_{ed}		0.6061 ^{3 3}	-0.1241	0.6779 ^{3 3}	0.9820 ^{3 3}
K_{ed}			-0.5768 ^{3 3}	0.6792 ^{3 3}	0.6322 ^{3 3}
dK_{02}				-0.7726 ^{3 3}	-0.0108
$dK_{ed} \text{Öd} K_{02}$					0.5917 ^{3 3}

3、3 3 分别表示通过 0.05、0.01 显著、极显著水平, 下同。

表中 *Chla*, *Chlb*, *l*, *Chlt* 分别代表叶绿素 a、叶绿素 b、类胡萝卜素和叶绿素的含量。

2.3.4 利用红边参数测定叶面积指数

分别计算红边 (K_{ed})、红边最小值 (dK_{02})、红边振幅 (dK_{ed})、 dK_{ed} 与 dK_{02} 的比值、红边峰值面积 ($dK_{680-780}$) 与叶面积指数之间的关系, 通过上、中、下层位上的叶片色素含量与叶面积指数之间的相关分析, 得出叶面积指数与上层叶片中叶绿素 a 之间存在极显著相关性, 相关系数达 0.7948, 与不同层位上叶片叶绿素 b 、类胡萝卜素之间的相关性不明显。

由于一些红边参数与上层叶片中叶绿素 a 之间存在极显著相关性, 上层叶片中叶绿素 a 与 LAI 之间存在极显著相关性, 因此用红边参数也能测定叶面积指数。另外, 许多研究结果表明, 植物冠层的近红外反射率与红光反射率的比值与叶面积指数或生物量之间有极显著相关性^[9], 那么, 光谱反射率一阶微分的红边峰值面积也应与叶面积指数有密切联系。用红边参数与 LAI 之间的相关系数, 除 dK_{02} 呈显著相关外, 其它参数都达到极显著水平。

3 结果与讨论

微分光谱用于解决分析化学问题, 无疑在遥感领域中有广阔的运用前景。用微分光谱确定出最优的波段宽度应小于 10 nm, 本试验采用的波段宽度为 1.41 nm。一些参数, 如叶绿素测定能用微分光谱获取, 这些参数是常用的宽波段光谱指数无法或是很困难获取的。微分光谱在消除土壤背景信息的影响和对混合光谱分解方面更加有效。在试验中, 通过微分光谱得到的一些变量, 用这些变量来估测农学参数, 达到了较好的结果, 应归结于微分光谱在减少或消除土壤背景信息和重叠光谱的影响。这为宽波段光谱指数所不及的。

在田间试验中, 通过人为控制施氮量, 可导致水稻 LAI 叶色和叶片物质组成等的显著差异, 这些差异必然导致不同氮素营养水平的冠层光谱差异。水稻在孕穗期之前, 红边随施氮量增加向长波方向移动, 即“红移”, 孕穗期之后“红移”现象基本消失, 抽穗期后发生“蓝移”。红边参数与上层叶片的叶绿素含量、LAI 累积施氮量有着密切的关系, 其中红边

位置与上层叶片的叶绿素含量相关性最大, 用它来描述上层叶片的叶绿素含量是可行的, 其中与上层叶片中的叶绿素 a 相关性极显著。但红边参数与叶片中的叶绿素 b 、类胡萝卜素之间的相关性不显著。故用遥感技术测定一些红边参数去推算水稻冠层的叶绿素含量和叶面积系数的方法是可行的。

无论是在可见光, 还是在近红外区, 还是在微波区, 低频背景噪声和其它光谱重叠信号的干扰在遥感中是普遍问题, 随着高光谱分辨率仪器的测试和发展, 微分光谱将用于测试解决这类问题。

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ABSTRACTS

· Specialization ·

General Strategy of Land Consolidation in China (1)

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Abstract: This paper presents the elementary concept and the developing history of land consolidation and stresses the significance of vigorously promoting land consolidation in China. Meanwhile, it outlines the overall strategy of land consolidation in China and clarifies the primary principles in the course of land consolidation. Some serious issues and problems faced in the current operation of land consolidation in China, which need to be solved in priority, are also stressed in this paper.

Key words: land consolidation; general strategy; management of land resources; farmland protection

Reflection on Developmental Trend & Emphases of Agricultural Mechanization Technology in China During the Period of the "Tenth-Five-Year" Plan (6)

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Abstract: During the period of the "Tenth Five-Year" Plan, agricultural mechanization technology in China faces the new situation of agricultural structural adjustment, western region development and China's entry to the WTO, the innovation and broadening the field of agricultural mechanization technology should be insisted on and encouraged, and the principle of different emphases in different types of regions and making breakthroughs of focal points should be implemented. The emphases are to research and develop bottleneck technologies in developing agricultural mechanization technologies, energy-saving and efficiency-increasing technologies, technologies for promoting agricultural sustainable development and to popularize "Ten Important Agricultural Mechanization Technologies", which will provide powerful equipment and technological support for increasing agricultural efficiencies, benefits and farmers' incomes, realizing agricultural modernization and sustainable development of agriculture.

Key words: agricultural mechanization technology; developmental trend; emphases; technological support; period of the "Tenth Five-Year" Plan

· Applied Technology and Fundamental Research ·

Derivative Spectrum Remote Sensing and Its Application in Measurement of Rice Agronomic Parameters of Rice (9)

Wang Xiuzhen, Wang Renchao, Huang Jingfeng (*Institute of Agricultural Remote Sensing & Information Application, Zhejiang University, Hangzhou 310029, China*)

Abstract: The objective of this paper is to analyze the elimination of background signals (such as wet soil, water and so on) using derivative canopy spectra of rice under different nitrogen status. Application of this technique for tackling analogous problems such as interference from soil background reflectance in remote sensing is proposed. Potential areas for the application of this technique in remote sensing are considered. The optimum spectral bandwidth for smoothing is less than 10 nm. When the derivatives are applied to determine the agronomic parameters, there is a shift phenomenon of the red edge. The red edge positions move to longer wave bands till booting stage and move to shorter bands after booting stage with nitrogen increasing. The red edge parameters in the first derivative reflectance curve (wavelength, amplitude and area of the red edge peak) were studied to evaluate rice leaf chlorophyll. LAI. A high correlation was found between chlorophyll content of top leaves and the wavelength of the red edge position and between

LA I and the red edge parameter. Then, the red edge was proved to be valuable for assessment of rice upper leaves chlorophyll contents. But a correlation was not found between chlorophyll content of leaves or carotenoid and the wavelength of the red parameters. Some red edge parameters are one of the best remote sensing descriptors. The feasibility of using derivative spectra to measure some agronomic parameters is verified.

Key words: derivative spectrum; rice; agronomic parameter; red edge parameters

Numerical Simulation for Collision on Safe Cab of Farm-Forestry Vehicles (14)

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Abstract: The model of collision on safe cab of farm-forestry vehicles has multi-nonlinear features on geometry and material. The large-scale deformation elastic and plastic and plastic theories are applied by setting up the mathematical model for cab, the strength feature of it is analysed. The relation of force and deformation when vehicle rolled is predicted. The safety of driver's space ingressed by deformation of components of the cab is estimated, and the deformation failure is assessed. The numerical simulation for collision on safe cab of vehicle is realized. Based on a type of farm-forestry vehicle, simulations based on theory and experiment are conducted. Both results are basically coincident. This simulation model is practical and feasible, which can provide reference for safety design of vehicle cab.

Key words: vehicle; safety; cab; numerical simulation

Determining Sediment Concentration in Runoff Flow with C Ray Attenuation and the Related Theoretical Algorithm (18)

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Abstract: An attempt was made to use gamma ray transmission method to measure sediment concentration in runoff. Two types of soils (silt loess and clay loess), three increments of sediment concentration (3%, 5% and 10%) and 3 sampling periods (6 s, 10 s, 20 s) were adopted for sediment measuring experiments, so as to validate the feasibilities of measuring sediment concentration with gamma ray method and to determine the response of measured sediment concentration to different conditions. The theoretical algorithm was derived for determining sediment concentration with gamma ray method. A simple relation of sediment concentration with gamma ray readings was statistically given. Experimental data were used to verify the correctness of the theoretical equation and to check the consistency of the theoretical results with those from experiments. Results showed very good linear relationship between sediment concentrations and gamma ray readings, as well as very good consistency between measured sediment concentrations and the theoretically computed values. The gamma ray method can be used to determine sediment concentrations steadily, reliably and precisely.

Key words: sediment concentration measurement; penetration method by gamma ray; runoff; penetration intensity; sampling period

Characteristics of Aquasorb and Its Application in Crop Production (22)

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Abstract: Aquasorb is a kind of sodium polymer with characteristic of absorbing and storing water. There are many types and varieties in commercial market. The purpose of this study is to determine the chemical features of sodium polymer and its effect on soil improving, and to analyze the influence on crop yield and fertilizer use efficiency in farming field. The result showed that $[Na^+]$ and electronic conductivity (EC)