Near infrared estimation of crop age

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Introduction

Near infrared (NIR) reflectance spectroscopy is now used to determine the concentrations of nitrogen, starch, sulphur, phosphorus, potassium and moisture in samples of rice crops collected from about 40% of the rice farms in Australia.[1] Nitrogen fertiliser recommendations are calculated using this NIR data and information supplied by farmers.[2] The most important information provided by farmers to allow this recommendation to be made includes the cultivar and the growth stage at which the rice was collected.

Many farmers, and for that matter rice researchers, have difficulty estimating the growth stage as accurately as required for the NIR Tissue Testing laboratory to make a reliable fertiliser recommendation. In an earlier paper we reported that a filter NIR instrument could be used to determine the physiological age of wheat and rice but with limited accuracy.[3] The aim of this study was to examine the ability of a scanning NIR instrument and more sophisticated data manipulation treatments to determine plant age.

Materials and methods

Samples

Rice plants were collected weekly from commercial crops grown in southern NSW in the 1991–92 season. The plants were sorted according to the physiological growth stage scale of Zadoks *et al.*[4] (Table 1). Roots were removed and the samples dried in a microwave oven before being ground to pass a 0.5 mm screen in a cyclone mill (Cyclotec, Tecator model 1093, Höganäs Sweden). Figure 1 shows the correlation between time of sampling and plant growth stage. Even with the widely used growth stage scale of Zadoks *et al.*[4] it is difficult to define accurately the physiological age of a crop as not all plants in a crop are at the same growth stage on one day.

NIR calibrations

The reflectance spectrum of each sample was recorded as log(l/*R*) between 400 and 2500 nm with a scanning NIR spectrometer (NIRSystems Inc., model 6500, Silver Spring, MD). Calibrations were developed using sample sets which were selected with a uniform distribution of days after sowing or physiological growth stage.

Data were processed using NSAS (NIRSystems Inc.), Pirouette (Infometrics Inc., Seattle) or CSAS (Carolina State University, Raleigh) software.

Results and discussion

Calibration equations for days after sowing and physiological growth stage are shown in Figures 2 and 3. For these calibrations the log(l/*R*) spectra were mean centred, transformed to the second derivative and computed using partial least squares with cross-validation on 10 samples. The optimum number of factors to minimise the standard error of prediction was five for days

after sowing and 7 for growth stage (Figures 4 and 5). The R^2, *SEC* and *SEP* values for these models were 0.98, 5.3 and 6.1 for time (days) after sowing, and 0.98, 3.4 and 4.7 for growth stages, respectively. These are more accurate calibrations than obtained previously using a filter instrument.

One can ask what are we measuring? During this stage of cereal crop growth, gross morphological changes are occurring and these can be related to changes in the relative proportions of

Table 1. The descriptions of the principal and secondary growth stages of cereals by Zadoks *et al.*[4]

0	**Germination**
00	Dry seed
01	Start of imbibition (water absorption)
02	—
03	Imbibition complete
04	—
05	Radicle (root) emerged from caryopsis (seed)
06	—
07	Coleoptile (shoot) emerged from caryopsis
08	—
09	Leaf just at coleoptile tip
1	**Seedling growth**
10	First leaf through coleoptile
11	First leaf unfold
12	2 leaves unfolded
13	3 leaves unfolded
14	4 leaves unfolded
15	5 leaves unfolded
16	6 leaves unfolded
17	7 leaves unfolded
18	8 leaves unfolded
19	9 or more leaves unfolded
2	**Tillering**
20	Main shoot only
21	Main shoot and 1 tiller
22	Main shoot and 2 tillers
23	Main shoot and 3 tillers
24	Main shoot and 4 tillers
25	Main shoot and 5 tillers
26	Main shoot and 6 tillers
27	Main shoot and 7 tillers
28	Main shoot and 8 tillers
29	Main shoot and 9 or more tillers
3	**Stem elongation**
30	Ear at 1 cm (pseudostem erect)
31	First node detectable
32	2nd node detectable
33	3rd node detectable
34	4th node detectable
35	5th node detectable
36	6th node detectable
37	—
38	Flag leaf just visible
39	Flag leaf ligule just visible
4	**Booting**
40	—
41	Flag leaf sheath extending
42	—
43	Boots just visibly swollen
44	—
45	Boots swollen
46	—
47	Flag leath sheath opening
48	—
49	First awns visible
5	**Inflorescence (Ear/Panicle) emergence**
50	—
51	First spikelets of inflorescence just visible
52	—
53	1/4 of inflorescence emerged
54	—
55	1/2 of inflorescence emerged
56	—
57	3/4 of inflorescence emerged
58	—
59	Emergence of inflorescence completed

Table 1. The descriptions of the principal and secondary growth stages of cereals by Zadoks *et al.*[4] (continued).

6	Anthesis (flowering)	8	Dough development
60	—	80	—
61	Beginning of anthesis	81	—
62	—	82	—
63	—	83	Early dough
64	—	84	—
65	Anthesis half-way	85	Soft dough
66	—	86	—
67	—	87	Hard dough
68	—	88	—
69	Anthesis complete	89	—
7	**Milk development**	**9**	**Ripening**
70	—	90	—
71	Caryopsis (kernel) water ripe	91	Caryopsis hard (difficult to divide)
72	—	92	Caryopsis hard (not dented by thumbnail)
73	Early milk	93	Caryopsis loosening in daytime
74	—	94	Over-ripe, straw dead and collapsing
75	Medium milk	95	Seed dormant
76	—	96	Viable seed giving 50% germination
77	Late milk	97	Seed not dormant
78	—	98	Second dormancy induced
79	—	99	Second dormancy lost

cell types that in turn can be related to the biochemical constituents of these cells. Examination of the 2D spectra indicated strong correlations between time after sowing and growth stage at many wavelengths. Generally the correlations were slightly stronger for the variable time than for growth stage. Some of the functional groups suggested from the correlelogram (Figures 6 and 7) as having an influence on the calibrations include protein, cellulose, starch, CH, CH_2, CH_3, C=C and amino acids. This suggests that the actual stage of crop development is the integration of many constituents.

Conclusions

In the most evenly developing crops it in not uncommon to find plants with up to five different growth stages (Figure 1) and it is difficult to determine the mean growth stage. This study indicates that NIR analysis could be used to assign a growth stage to a plant sample submitted to an NIR-based tissue testing service. There would be no extra cost to the service to determine the plant growth stage and this would reduce the chance of making erroneous fertilizer recommendations to rice growers. The calibrations reported here are another example of the capacity of NIR to predict functional, as opposed to constituent, information on plant samples.

Acknowledgements

We were assisted in this study by Sue Ciavarella and Anne Sheldrick. Funding was provided by the Rural Industries Research and Development Corporation.

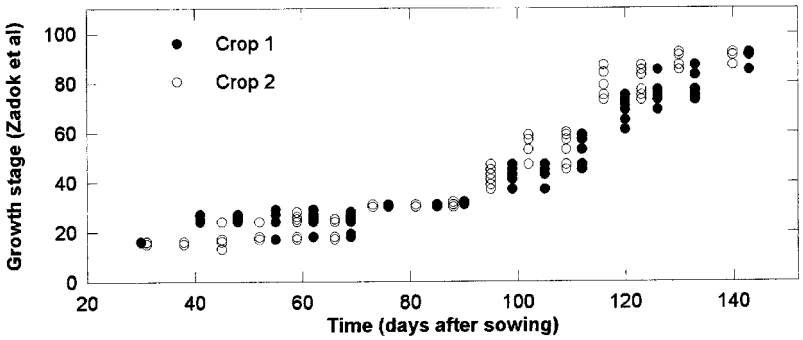

Figure 1. Relation between time after sowing and the growth stage of individual plants in a rice crop.

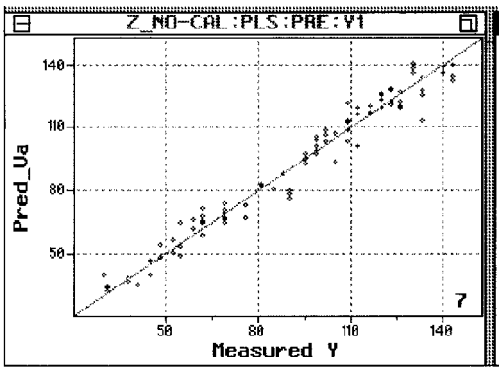

Figure 2. Calibration equation for age of rice plants (days after sowing).

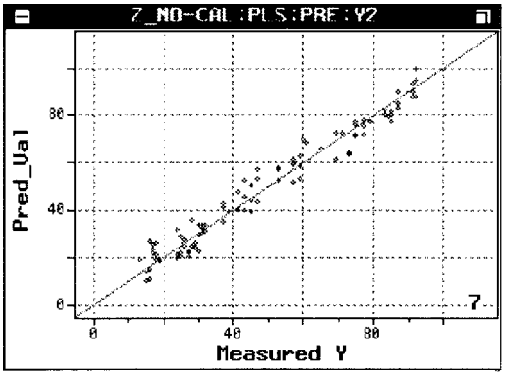

Figure 3. Calibration equation for physiological age of rice plants (Zadoks *et al.* scale)

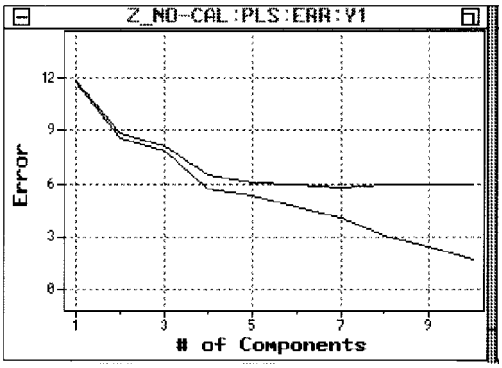

Figure 4. Comparison of number of PLS factors on the *SEC* and *SEP* values plant age (days after sowing).

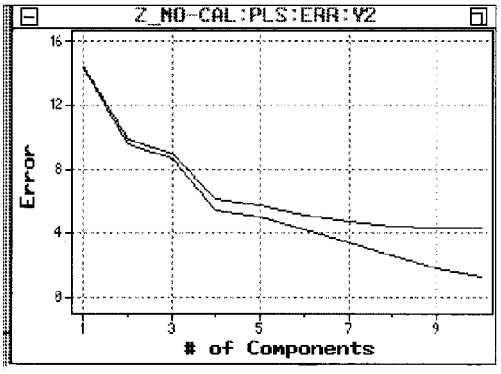

Figure 5. Comparison of number of PLS factors on the *SEC* and *SEP* values for physiological plant age (Zadoks *et al.* scale).

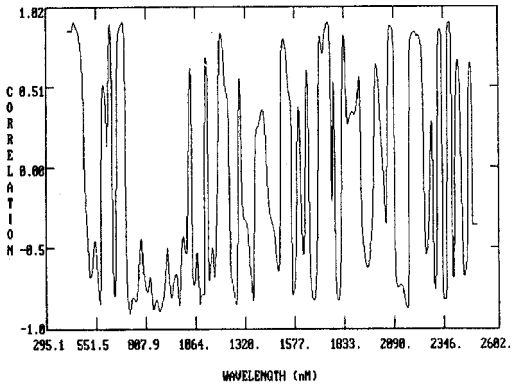

Figure 6. Correlelogram for plant age (days after sowing).

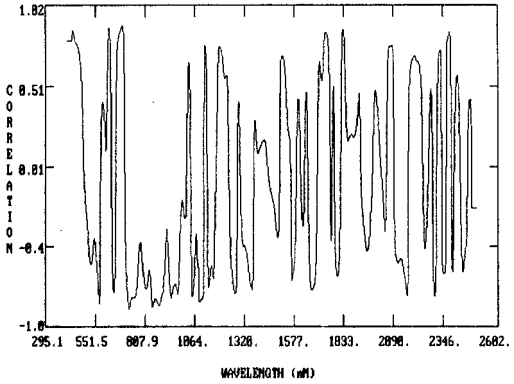

Figure 7. Correlelogram for physiological plant age (Zadoks *et al.* scale).

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4. J.C. Zadoks, T.T. Chang and C.F. Konzak, *Weeds Research* **14,** 415 (1974).