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A decimal code for the growth stages of cereals

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Preface

An internationally acceptable scale for recording the growth stages of cereals is clearly desirable. Such a scale should be acceptable to agronomists, plant breeders, plant pathologists, plant physiologists, taxonomists and all others concerned with recording details of crop growth. The decimal code developed by Zadoks, Chang and Konzak has been widely recognized as the best scale available. It was considered in detail by a committee comprising experts in the disciplines concerned, who made a number of proposals which have been incorporated in the scheme which has been published in mimeographed form by Eucarpia (The European Association for Research in Plant Breeding) and is now published here. It is also hoped that it will be published in America in the Wheat, Oat and Barley Newsletters.

Users of the code should appreciate that it refers throughout to individual plants, or, where appropriate, to the main shoots of such plants, and that the growth stages described are not mutually exclusive. A plant may, for example, be equally well described in terms of the number of leaves unfolded on its main shoot or in terms of stem elongation. At the same time the number of tillers developed is more likely to be descriptive of plant spacing or agronomic treatment than of developmental stage.

An extension of the code is planned to cover, in the first instance, maize and sorghum, and, subsequently, forage grasses and dicotyledonous crops, and a full version, with illustrations, will be published elsewhere. It is very much hoped that the final version will not differ significantly from that published here, but any suggestion for minor amendments or for changes in phraseology would be welcomed.

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Introduction

The best known and most widely used scale for the recording of growth stages of cereals is probably the scale designed by Feekes (1941), as illustrated and amended by Large (Chiarappa, 1971; Large, 1954). The main morphological stages of cereals, easy to recognize, were numbered from 1 to 11 in ontogenetic order from seedling emergence until grain ripening. Some crucial growth stages were subdivided, and the subdivisions were indicated by numerals in one or two additional columns. The Feekes' scale is well suited to the small grain cereals in North West Europe, especially wheat, but it can also be applied to wheat, barley, rye, oats, and to rice (A. O. Klomp, unpublished) in other parts of the world. However, the relative importance attached to a growth stage may vary from area to area and from crop to crop, and therefore a scale designed for North West European conditions is not necessarily the most suitable scale elsewhere. The four-digit Feekes' scale is inefficient for data processing, and for computer storage and retrieval (Loegering, 1968).

General principles

A few general principles for the design of a scale for plant growth stages can be mentioned: (1) The growth stages distinguished must be easily recognizable under field conditions, even by an observer with little technical training, without specialized equipment. (2) The growth stages must be graded in the order of their ontogenetical appearance. (3) Most 'rough and ready' applications of the scale do not permit the use of more than nine or ten stages. These are the *principal growth stages.* (4) The principal growth stages should be identified by symbols, for example the numbers 0 to 9, which should correspond with the positions available in one column of a punch card, to be acceptable as a common denominator for all languages. (5) In order to provide for more detail, as needed in more refined studies, each principal growth stage should be subdivided into *secondary growth stages.* (6) The secondary growth stages also should be coded by means of symbols, e.g. the numbers 0 to 9, for the same reasons as given above. (7) Thus, the principal growth stages are indicated by a one-digit code, and the principal plus secondary stages are indicated by a two-digit code. (8) The scale should be applicable to most or, preferably, to all cereals (in principle to all Gramineae). (9) The scale should be applicable in all or most parts of the world. (10) Each coded stage should be illustrated to provide for universal intelligibility.

In the attempt to meet these requirements, which at times conflicted with each other, some liberties had to be taken with the original idea at the onset of the work: a decimal Feekes' scale.

Table 1. A decimal code for the growth stages of cereals. Principal growth stages

1-digit code	Description
0	Germination
1	Seedling growth
2	Tillering
3	Stem elongation
4	Booting
5	Inflorescence emergence
6	Anthesis
7	Milk development
8	Dough development
9	Ripening
T	Transplanting and recovery (rice only)

Principal growth stages (Table 1)

The principal growth stages are self-explanatory. The 'borderlines' between the growth stages mentioned may be established by means of the detailed classification of secondary growth stages (see below), but the reader should realize that plant growth is continuous without stopping at arbitrary 'borderlines'. In the scale of growth stages, the code 0 designates germination, including the period from the dry seed until the appearance of the coleoptile. Code number 1 designates seedling growth, up to tillering. Code 2 indicates tillering, and code 3 stem elongation including the appearance of the flag leaf. Code 4 covers the booting process. Inflorescence emergence and anthesis were placed in separate principal growth stages, codes 5 and 6, because both are processes which allow the assessment of small but distinct differences in growth rhythm between cultivars. The process of caryopsis development is divided into three stages: code 7—milk development, code 8—dough development, and code 9—ripening, because these stages are particularly important for yield prediction, quality, crop loss and other evaluation research.

Special conditions

Rice presents a special problem since most of the Asian rice cultivars are largely grown under the transplanting procedure. Transplanting often induces a stoppage of development followed by recovery. While not a growth stage, the recovery process may involve stages worthy of recording. This special problem has been met by a special solution, the use of the letter T. Neither in field work nor in computer programming does the use of one extra symbol beyond the 0 to 9 range cause insurmountable problems. In many areas of the world, direct seeding of rice is practised.

Secondary growth stages (Table 2)

The detailed classification of the secondary growth stages uses a second digit, coded from 0 to 9, for each principal growth stage. As it is unrealistic to attempt to define the latter too closely, not all positions are necessarily used. Usually, position 5 is reserved for the middle or medium value. Sometimes, positions have been reserved for intermediate notes, to be used when desired.

The detailed classification serves several purposes. First, it conserves the Feekes' scale stages which

Table 2 A decimal code for the growth stages. Secondary growth stages

2-digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Germination		
00	Dry seed		
01	Start of imbibition		
02	—		
03	Imbibition complete		
04	—		
05	Radicle emerged from caryopsis		
06	—		
07	Coleoptile emerged from caryopsis		
08	—		
09	Leaf just at coleoptile tip		
	Seedling growth		
10	First leaf through coleoptile	1 (10–11)	
11	First leaf unfolded*		Second leaf visible (< 1 cm)
12	2 leaves unfolded		50% of laminae unfolded (12–19)
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		
	Tillering		
20	Main shoot only		
21	Main shoot and 1 tiller	2	
22	Main shoot and 2 tillers		This section to be used to supplement records from other sections of the table: 'concurrent codes' (22–29)
23	Main shoot and 3 tillers		
24	Main shoot and 4 tillers		
25	Main shoot and 5 tillers		
26	Main shoot and 6 tillers	3	
27	Main shoot and 7 tillers		
28	Main shoot and 8 tillers		
29	Main shoot and 9 or more tillers		
	Stem elongation		
30	Pseudo stem erection†	4–5	In rice: vegetative lag phase
31	1st node detectable	6	Jointing stage (31–32)
32	2nd node detectable	7	
33	3rd node detectable	(31–36)	Above-crown nodes
34	4th node detectable		
35	5th node detectable		
36	6th node detectable		
37	Flag leaf just visible	8	
38	—		
39	Flag leaf ligule/collar just visible	9	Pre-boot stage In rice: opposite auricle stage
	Booting		
40	—		
41	Flag leaf sheath extending		Little enlargement of the inflorescence, early-boot stage
42	—		
43	Boots just visibly swollen		Mid-boot stage
44	—		
45	Boots swollen	10	Late-boot stage
46	—		
47	Flag leaf sheath opening		
48	—		
49	First awns visible		In awned forms only

Table 2 A decimal code for the growth stages. Secondary growth stages (*contd.*)

2-digit code	General description		Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Inflorescence emergence			
50	First spikelet of inflorescence just visible	N	10·1	
51		S		N = non-synchronous crops; S = synchronous crops (see text)
52	$\frac{1}{4}$ of inflorescence emerged	N	10·2	
53		S		
54	$\frac{1}{2}$ of inflorescence emerged	N	10·3	
55		S		
56	$\frac{3}{4}$ of inflorescence emerged	N	10·4	
57		S		
58	Emergence of inflorescence completed	N	10·5	
59		S		
	Anthesis			
60	Beginning of anthesis	N	10·51	Not easily detectable in barley.
61		S		In rice: usually immediately following heading
62	—			
63	—			
64	Anthesis half-way	N		
65		S		
66	—			
67	—			
68	Anthesis complete	N		
69		S		
	Milk development			
70	—			
71	Caryopsis water ripe		10·54	
72	—			
73	Early milk		11·1	Increase in solids of liquid endosperm notable when crushing the caryopsis between fingers
74	—			
75	Medium milk			
76	—			
77	Late milk			
78	—			
79	—			
	Dough development			
80	—			
81	—			
82	—			
83	Early dough		11·2	
84	—			
85	Soft dough			Finger nail impression not held
86	—			
87	Hard dough			Finger nail impression held, inflorescence loosing chlorophyl
88	—			
89	—			
	Ripening			
90	—			In rice: terminal spikelets ripened
91	Caryopsis hard (difficult to divide by thumb-nail)‡		11·3	In rice: 50 per cent of spikelets ripened
92	Caryopsis hard (can no longer be dented by thumb-nail)§		11·4	In rice: over 90 per cent of spikelets ripened**
93	Caryopsis loosening in daytime			
94	Over-ripe, straw dead and collapsing			
95	Seed dormant			
96	Viable seed giving 50% germination			
97	Seed not dormant			
98	Secondary dormancy induced			
99	Secondary dormancy lost			

Table 2 A decimal code for the growth stages. Secondary growth stages (*contd.*)

2-digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Transplanting and recovery (rice only)		
T1	Uprooting of seedlings		
T2	—		
T3	Rooting		
T4	—		
T5	—		
T6	—		
T7	Recovery of shoot		
T8	—		
T9	Resumption of vegetative growth		

* Stage of seedling inoculation with rust in the greenhouse.
† Only applicable to cereals with a prostrate or semi-prostrate early growth habit.
‡ Ripeness for binder (*c.* 16% water content). Chlorophyll of inflorescence largely lost.
§ Ripeness for combine harvester (< 16% water content).
** Optimum harvest time.

have shown merit. Second, the two-digit scale permits the introduction of particular details needed, on occasion, for specific purposes. For instance, the number of leaves (codes 11 to 19) and the number of tillers per plant (codes 21 to 29) have been included as an addition to the Feekes' scale to serve for studies on the epidemiology of cereal diseases and on herbicide applications. An assessment of tillering patterns in relation to other growth processes is essential in many rice research projects. Furthermore, the booting stages have been distinguished especially to meet the needs of gametocide application. Finally, a third purpose of the detailed classification is to give the scale some adaptability to various crops, crop management uses, and special interests (see below).

The germination stage, code 0, received much attention for several reasons. A sub-division of this stage can be useful in weed control, seed pathology, radiobiology, seed laboratory work, and it is important to determine the right moment to sow pre-soaked rice seed in direct seeding by aircraft. The seedling stages, codes 10 to 19, are important in glasshouse procedures for disease resistance testing, and have been used extensively in weed control studies and epidemiological field work. The tillering and stem elongation stages, codes 20 through 39, are important in many aspects of agronomic research. In wheat, barley and rye, some cultivars have a prostrate or semi-prostrate habit (as is common with many winter wheat cultivars). In these cultivars the early prostrate growth is followed by 'pseudostem (leaf sheath) erection' (code 30). Code 30 can also be used for pseudostem elongation in rice, a process distinct from shooting or internode elongation (codes 31 to 39) (Milthorpe & Ivins, 1966). In some rice cultivars with a long vegetation period there is seemingly a stand-still in the development of the crop just at the stage of leaf sheath elongation. Code 39, 'flag leaf ligule just visible', is equivalent to the 'opposite auricle stage' in rice, the stage when the auricles of the flag leaf are at the same height as the auricles of the penultimate leaf. This growth stage is important in rice because it practically coincides with meiosis (Chang & Bardenas, 1965).

In barley, meiosis takes place at about the same stage as in rice, when the flag leaf ligule is just visible (code 39). In wheat and rye, meiosis coincides with the early booting stages (code 41 for wheat and code 43 for rye). In barley, wheat and rye, meiosis begins just above the middle of the ear, and proceeds upwards and downwards. The whole process of meiosis, however, can strongly be influenced by the environment, which means that the stages should not be taken too strictly (W. Lange, personal communication).

It seemed appropriate to allocate a great number of positions (up to 20) to the processes of inflorescence emergence and anthesis (codes 50 through 69) for the estimation of slight but sometimes agronomically important developmental differences. Estimates of differences during inflorescence emergence and anthesis may both be needed for a precise description. Inflorescence emergence may be practically synchronous (S) all over the crop, so that nearly all stems have simultaneously completed $\frac{1}{4}$, $\frac{1}{2}$ or $\frac{3}{4}$ of their inflorescence emergence. Alternatively, inflorescence emergence may vary in time between, as well as within, plants, such that the lack of synchronization (N) within the crop is conspicuous. In the former case, the odd numbered codes of stages 5 and 6 are more suitable, in the latter case the even numbered codes are more descriptive. For example, for a synchronous wheat crop with half of each of the ears emerged one could use code 55, but for a non-synchronous wheat crop code 54 could be used to indicate the stage at which 50% of the stems in the population had their ears extruded at least half-way. A synchronous oat crop with all plumes fully emerged could be described by code 59, but a non-synchronous oat crop with 50% of the plumes fully emerged might be characterized by code 58.

In wheat and rye, anthesis usually occurs after heading; it begins just above the middle of the ear, and proceeds upwards and downwards. In some barley cultivars, the flowers open little if at all; the anthesis stages (codes 60 to 69) can be omitted, though with the advent of F1 hybrid barley the situation may change. In rice, flowering proceeds from the top of the panicle downwards, and in tropical areas immediately follows heading. However, inflorescence emergence and anthesis can be separated by a few days at higher latitudes or in case of adverse weather conditions.

The early dough stage (code 83) of wheat is a crucial stage in the Netherlands, Northern Germany and Australia, because from that stage onwards observations have to be made for the prediction of sprouting in the ear (Belderok, 1968).

Concurrent use of codes

In synchronous crops, different codes can be used concurrently. For example, in a seedling with three leaves the first tiller may have appeared, so that codes both for leaf number (code 13) and for tiller number (code 21) are applicable. For ordinary use, it is advised to utilize the highest ranking code, i.e. code 21. For more precise description, as might be desirable for herbicide application, the two codes could be used concurrently, i.e. 13, 21. A similar situation may occur at inflorescence emergence and anthesis, e.g. 57, 61.

In asynchronous crops, it is again advisable to use the highest ranking code number for the description of the growth stage. For more precise description, one might indicate the range of growth stage, e.g. 57–61.

Discussion

An internationally acceptable scale for the recording of growth stages in cereals is obviously needed. But this statement has previously marked the end of the agreement. There is nearly complete disagreement about how to implement the agreed principles. This is logical, because a scale which does not arouse objections will, by that very reason, satisfy nobody. Furthermore, there exist many local or regional considerations that are sound and acceptable. In addition, it seems presumptuous to expect that one scale will cover all possible circumstances. Two typical examples of regional argument will be given. The Feekes' scale, developed under North-west European conditions, uses four principal positions (Feekes' codes 2 to 5) for a group of growth stages taking only two principal positions (codes 2 and 3) in the new scale. Feekes' pre-occupation was with winter wheat, autumn-sown and with good winter hardiness, and therefore he rightly emphasized the winter growth stages. His scale is somewhat ambiguous for the early stages of spring wheat and of the erect South European short cycle winter wheats (with little or no need of vernalization by low temperature). In this proposed scale, some of Feekes' stages have been transferred from the principal to the secondary group of growth stages. The Feekes' scale lacks detail in the post-anthesis stages, a definite weakness for use in North America. The typical North American interest in these stages has to do with matters such as quality control, prediction of harvest time and yield, etc. Here, the new scale uses three principal stages after anthesis where the Feekes' scale has only one..

The numerical codes proposed for each growth stage are not entirely arbitrary, but are based on written tradition. A scale developed in Switzerland (Keller & Baggiolini, 1954) is an extended Feekes' scale in which growth stages have been coded by letters. Another, recent proposal is a recoded Feekes' scale using the numbers 1 to 22 (Brouwer, 1972). Such letter or number codes share all the disadvantages of the Feekes' scale mentioned above, without the positive advantage of adaptability. Therefore, the risk of some arbitrariness is acceptable in the knowledge that there are many ways to allot the ten available principal positions to more than ten definable growth stages (Kilpatrick, 1970). In this context, it is encouraging that the European Brewery Convention, with its network of barley field trials covering fifteen nations, accepted a first draft of Broekhuizen & Zadoks' decimal Feekes' scale, and utilized it from 1967 onwards for all its data processing by means of a computer. A temporary decimal growth stage scale was used for FAO/IAEA co-operative rice and durum mutant trials from 1966 (Anon., 1968; Bogyo *et al.*, 1969; Chang, 1968; Tessi *et al.*, 1968), for a regional cereal testing program in the Western United States (McNeal *et al.*, 1971) and for the International Yellow Nurseries (R. W. Stubbs, personal communication).

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