ADVANTAGES OF USING THE HAUN SCALE TO DETERMINE CEREAL GROWTH STAGE

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INTRODUCTION

In today's high technology agriculture, ability to recognize and to predict plant growth stage is important. Knowing the growth stage at any point during the growing season will help us make sound management decision. Herbicide applications serve their purpose best when applied at the proper time. Timing applications of irrigation water and fertilizers can improve their efficient use. We need to accurately describe the phasic development of the plant if we are to accurately simulate its growth and yield. This is so because a specific weather event or weather condition may affect grain yield differently depending on the stage of growth at which it occurs.

The development and growth of cereal crops have been translated into several numeric sacles to facilitate quantification of development for scientific and management purposes. The most commonly used scales are Feekes (Large, 1954), Zadoks (Zadoks et al. 1974), Haun (1973) and Robertson (1968). Those scales differ in method of designation, in detail, and in sensitivity to changes in plant development rate.

In the past, comparisons between the research findings of different experiments have been confused by the different methods used in quantifying the growth stage and by imprecise reference to the growth stages of the cereal plants at the time of treatment or assessment. Among those commonly used scales, we agree with Bauer et al. (1984) that the Haun scale is more definitive and is more sensitive to changes in the plant morphology than others. In this paper, we will discuss some advantages of using the Haun scale in determining cereal growth stage in order to encourage its use by researchers, extension personnel and farmers.

HAUN SCALE IS MUCH SIMPLER, NO AMBIQUITY, AND MORE PRECISE

The Feeks scale is probably the best known and most widely used numerical staging scale in North America. Eleven development stages describe physical plant changes from the first-leaf stage through grain ripening. The heading and ripening stages are subdivided for greater detail. However, this scale does not provide adequate descriptions of the important tillering stage of cereal growth.

The Zadoks scale provides more detailed information during early development stages than the Feeks scale. The scale is based on ten principal development stages which are divided into secondary stages. A new leaf is counted as fully emerged when 50 percent of the leaf blade has unfolded.

Two or three decimal codes may be needed to describe a plant using the Zadoks scale. For example, wheat that has six leaves unfolded, three tillers and one node on the main stem would be staged as 16,23,31 in Zadoks scale. This scale looks very complicated and too detailed to commit to memory. It also is not sensitive to daily changes in plant morphology.

The Haun scale numerical designations are based on morphology of the main stem. A number, called a growth unit, is assigned to each leaf on the main stem as it develops. The leaves are numbered consecutively in the order in which they appear. Four growth units occur after the last leaf is developed. These correspond to flag leaf extension, booting, heading, and head extension. We believe that this system is an easy-to-use staging procedure for cereal grains.

In all instances the appearance of the ligule of a leaf and the emergence of the tip of the next leaf occur at about the same time. Thus, each growth unit in Haun scale which begins with its own appearance and end with the appearance of the next growth unit is more definitive and is capable of a better objective interpretation than with other scales. Each growth unit is visible and easily recognized; hence, there is no confusion and no ambiquity.

Designation of the development stage of each leaf and each of the four morphological units after the completion of flag-leaf emergence in the Haun scale is subdivided into decimal fractions to reflect difference over the range from its initial appearance until it is fully developed. These decimal fractions are determined by comparing the development entity to the most recent fully developed morphological unit. This method provides an accurate description and a continuous numerical expression of plant development from the appearance of the first leaf through to flowering. The Haun scale does not provide designations in as much detail during the grain filling stage as do other scales; however, this might not be a serious shortcoming since little can be done after flowering stage, from a management standpoint, to alter the yield potential.

Bauer et al. (1984) determined the number of main-stem leaves for sixteen hard red spring and three durum wheats grown at Mandan, North Dakota. They reported that all cultivars produced eight leaves on the main stem except one which produced seven. For a wheat variety which produces eight leaves on the main stem, the Haun growth-stage designation is 8.0 when the ligule of the eighth leaf is just visible. The four growth units identified in the Haun scale after the flag leaf is developed are numbered consecutively following the number assigned to the flag leaf. Thus, flag-leaf extension designations for 8-leaf varieties range from 8.1 to 9.0, and boot-stage from 9.1 to 10.0. The boot stage is completed when the head begins to emerge through the collar of the last (flag) leaf.

However, from our experiments at Swift Current, we found that the number of the main stem leaves for a given cultivar is not a constant. Neepawa produced either 7 or 8 leaves on the main stem and HY320 had 9 or 10 leaves when they were seeded in mid-May, 1987 (Cutforth et al., 1988). The majority of Neepawa plants had 7 leaves and HY320 had 9 leaves. Number of leaves produced on the main stem did not differ among moisture treatments. In 1988, plants were sampled from three seeding-date tests under dryland. When plants were seeded on April 27 Neepawa and HY320 produced 7 leaves on the main stem. Neepawa produced either 7 or 8 leaves and HY320 had 8 or 9 leaves when they were seeded on May 11. When seeding was delayed until June 10 the majority of Neepawa plants produced 8 leaves on the main stem and a few plants had 7 leaves; HY320 was more sensitive to the environmental condition and most plants produced 10 leaves on the main stem while 20 percent of plants had 11 leaves. We are presently trying to quantify the influence of environmental conditions on the number of main stem leaves. A knowledge of total number of main-stem leaves and its relationship to the environmental factors is important if we are to gain a better understanding of general growth and development of wheat cultivars.

COMBINED WITH KLEPPER'S SYSTEM OF NAMING LEAVES AND TILLERS, HAUN SCALE CAN BE USED TO ASSESS THE EFFECT OF ENVIRONMENTAL CONDITION ON PLANT DEVELOPMENT

Haun scale growth designations are based on morphology of the main stem. Tiller development is not described in this scale. However, the relationship between the development of the main stem and the developments of tillers can be easily constructed because the plant's parts and structures appear and develop in a consistent and orderly pattern. Klepper et al. (1982) have shown a relationship between main stem Haun stage and the development of the potential tillers on a plant.

A tiller is formed either from a bud located at the coleoptilar node (coleoptilar tiller) or from the bud in the axil of the leaf. In Klepper's system, leaves are numbered acropetally begining with the first foliar leaf (L1) on the main stem (Figure 1). Tillers borne on the main stem bear the number of the leaf that subtends them; thus T1 is produced from the bud in the axil of L1 and T2 from the axil of the second foliar leaf on the main stem (L2). The coleoptile is designated as L0; the coleoptilar tiller T0. Thus, the tillers on the main stem (primary tillers) have designations comprising the letter " T " and a single digit such as T0, T1, T2, T3..... etc.

Tillers are synchronous with the main stem but lag in the development stage. Each main stem tiller can produce subtillers from buds in the leaf axil on the tiller, including the bud in the axil of the prophyll at the base of the tiller. The leaves on the primary tillers and the subtillers associated with these leaves (secondary tillers) bear two-digit numbers. For example, the first leaf of T1 is L11, and the tiller in the axil of L11 is T11. The second leaf of T1 is L12, and the tiller associated with it is T12. Tillers arising from the axil of the prophyll have a zero as the second digit. Thus, T1 might have two subtillers, T10 and T11; the first would be produced from the bud in the axil of the prophyll of T1 and the second from the axil of the first leaf of T1.

In like manner, the secondary tillers can occasionally produce third-order tillers (tertiary tillers) from the buds in the axils of their leaves. Leaves on the secondary tillers and the tertiary tillers associated with them bear three-digit numbers. Thus, T100 comes from the axil of the prophyll on the subtiller borne in the axil of the prophyll of T10. The designation T110 would indicate that a tiller arises from the bud at the prophyll of the subtiller which is in the axil of the first leaf of T1.

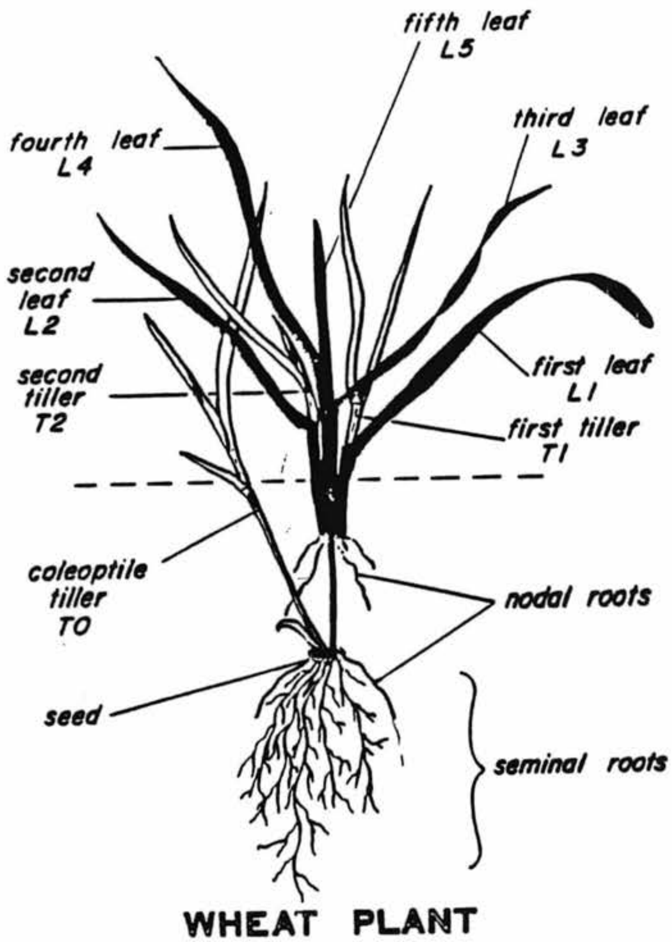

Figure 1. Klepper's System of naming leaves and tillers of wheat (Klepper et al. 1982).

The Klepper's system described above has been used in both field and growth room tests to describe leaf and tiller development for both Neepawa and HY320. We constructed plant maps indicating the time for the appearance of leaves and tillers for both cultivars grown both in the field and the growth chamber under optimal moisture and nutrient conditions (Figure 2). Figure 2 uses the "phyllochron" concept. A phyllochron is the developmental time between the elongation of successive main stem leaves, in this case the time interval between a Haun stage of X and X+1. In general, both cultivars revealed the same pattern of tiller productions. Regardless of whether the plant was grown in the field or in a growth chamber, the second tiller on the main stem (T2) was usually first observed during the time when the fourth leaf of the main stem was just about to finish (at a Haun stage of 3.6 to 3.8) and the third tiller (T3) at the time when the fifth leaf had nearly completed. T1 usually began to emerge when the plant had three leaves. However, in the growth room tests, T1 was generally first observed before the the third leaf had completed (at a Haun stage 2.7 to 2.8) while in the field, T1 was produced slightly later at a Haun

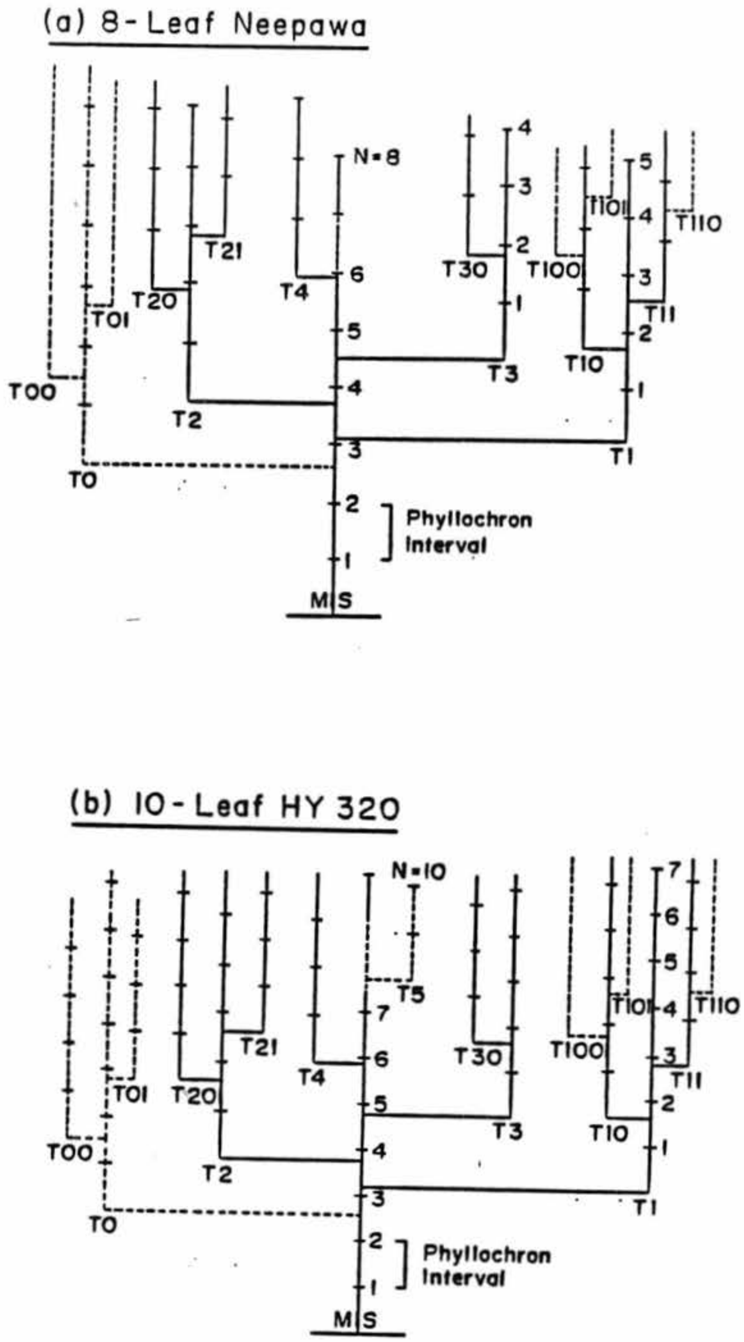

Figure 2. Plant maps showing relationship between main stem Haun stage and developments of potential tillers for Neepawa and HY320.

stage of 3.0 to 3.2. The coleoptilar tiller (T0) appeared to emerge at any time independent of the number of leaves on the main stem. In the growth room tests at a planting depth of 2.5 cm all plants had T0 which emerged at the main stem Haun stage of 2.4 to 2.5. In the field where the seeding depth was more than 5.0 cm, a very low percentage of plants formed T0 and these appeared at the Haun stage ranging from 3.0 to 4.5. This is consistent with reports of low production and vigor of T0 in both wheat and barley. T0 was most affected by the field conditions at seeding time.

Figure 2 shows the Haun stages of the main stem when each tiller begins to emerge. Once produced, tillers generally developed their own leaves at the same rates as the leaves on the main stem except under conditions where environmental stress was so great that the leaves were ready to abort. Environmental conditions could also cause delay in the production of a tiller relative to the Haun stage shown in Figure 2 or resulted in its abortion. Figure 3 shows tiller development of our 1987 field experiments. Soil moisture was generally favorable at seeding time. These results obtained for our optimal soil moisture treatment are typical plants which we might expect to observe in fields with minimal stress. The reason that HY320 had more later-formed tillers (namely T20, T11, T4, T30, T21, T5, T100, and T12) than Neepawa is because HY320 produced two more leaves on the main stem than did Neepawa. On the dryland plots, the plants were under severe moisture stress in later development stages. Thus, the number of plants having later-formed tillers were reduced substantially for both cultivars (Figure 3).

Spring of 1988 was very dry in Swift Current. Very little precipitation occurred in the months of April and May. Because plants were under moisture stress in their early development stages when they were seeded in late April, a majority of them did not produced T1 and T2 (Figure 4). From late May to early July, we received 120 mm of rainfall and soil moisture condition improved significantly. Consequently, most of the early seeded plants developed T3 and T4 tillers. The late-seeded plants (seeded on June 11) produced more T1 and T2 tillers than early-seeded plants due to improved soil moisture conditions (Figure 4). Because adverse environmental conditions can delay the production of a tiller or cause its abortion, analysis of plant development permit inferences to be made about their stress history. It is not unusual to find that wheat plants growing in dry, crusted, or otherwise unfavorable seedbeds produce neither a T0 nor a T1 and T2 is the first tiller produced in such cases. Likewise, if a plant has T1, T2, and T5 with T3 and T4 missing, we have a very good reason to suspect that a stress of some kind might have occurred during the periods of the fifth and sixth phyllochrons. Thus, combined with Klepper's system of naming leaves and tillers for cereal plants, the Haun scale can be used to assess the effect of environmental conditions on the plant development.

A GREATER DEGREE OF PRECISION CAN BE ACHIEVED WHEN HAUN SCALE IS USED IN QUANTIFYING PLANT GROWTH

The general availability and relatively low cost of modern computers is currently providing scientists with the opportunity to construct dynamic

Tillers Development - 1987 field experiments

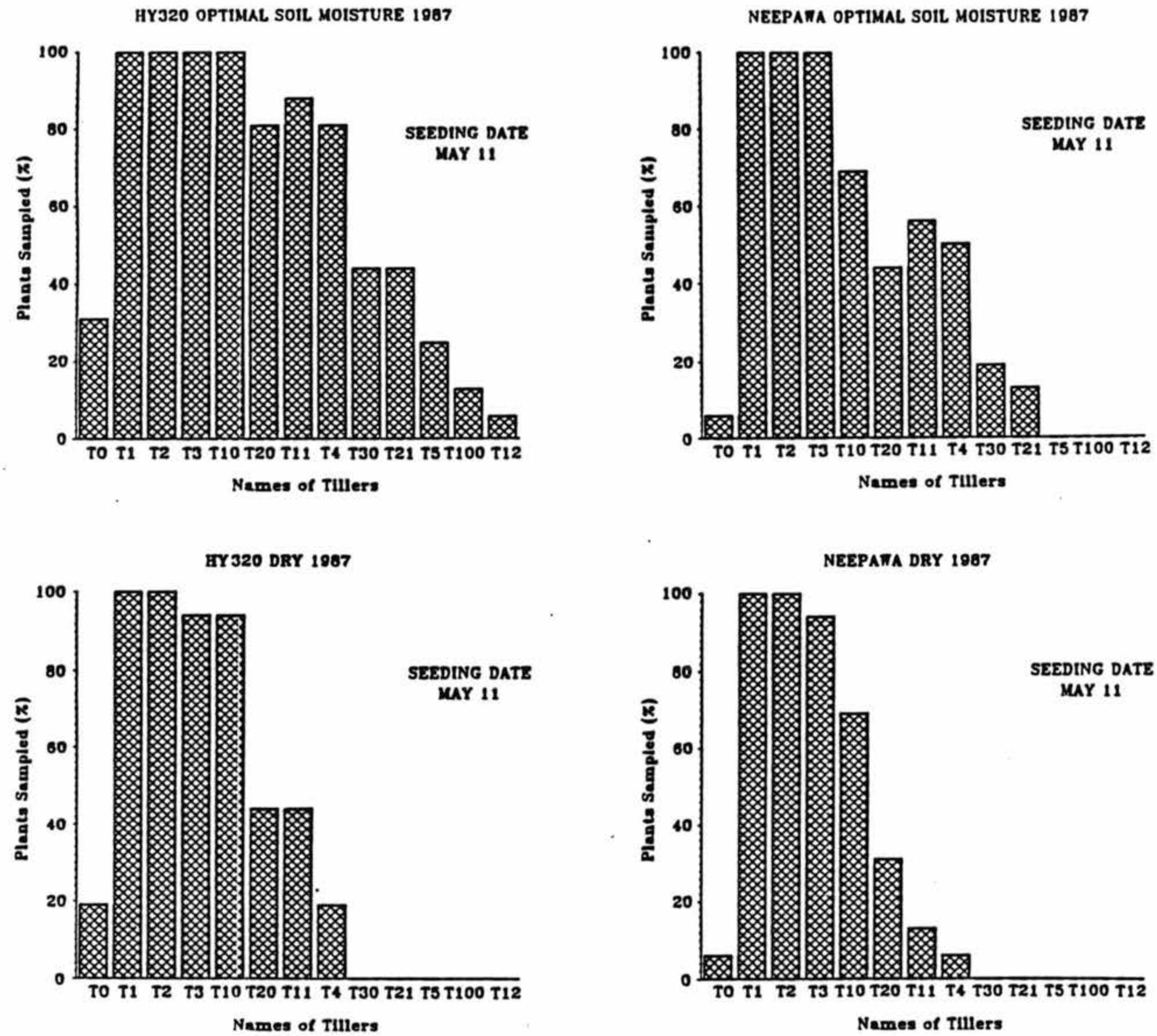

Figure 3. Tillers development - 1987 field experiments.

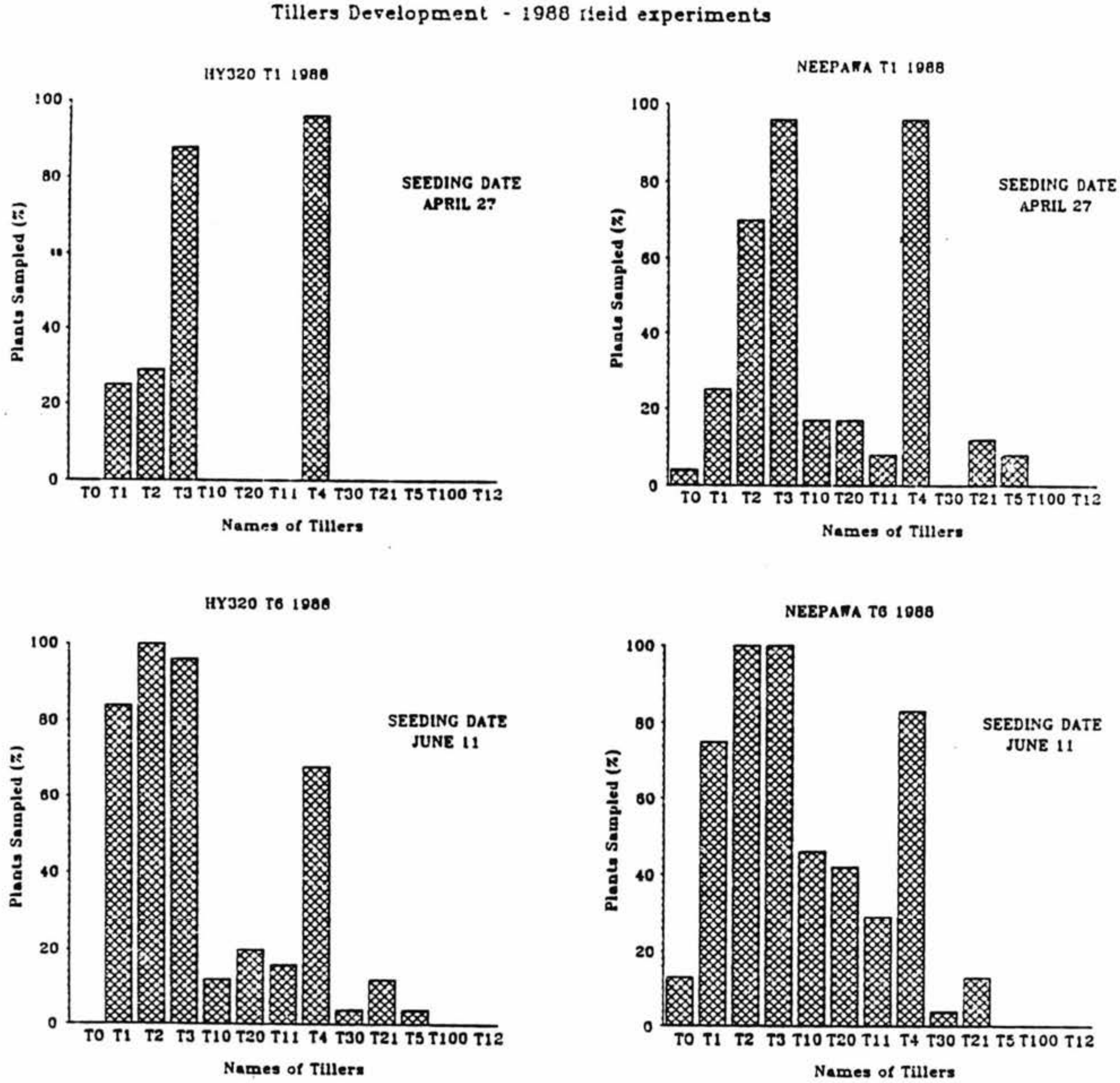

Figure 4. Tillers development - 1988 field experiments.

crop growth simulation models to study particular problems of crop production (Childs et al., 1977; Ritchie and Otter, 1985; Protopapas and Bras, 1987; Bernardo et al., 1988). Presently we are developing a wheat growth simulation model which will be used as a tool for providing insights into the behaviour of many aspects of cropping systems in our area.

In order to accurately simulate crop growth and yield of wheat, it is necessary to be able to accurately describe the phasic development of the plant. Numerous indexes based on calender days, accumulated growing degree-days, and photothermal units have been used to estimate growth rate and growth stage of a wheat plant. However, equations used are all empirical, derived mainly from regression analysis. To realistically simulate wheat growth, a phenologically based index that will accurately and reliably predict the growth stage is more desirable.

Among many environmental factors, temperature is considered to be the most important one influencing plant development rate. Growth chamber work (Klepper et al. 1982) as well as field experiments (Baker et al. 1986) have shown that each leaf on the wheat plant requires about the same number of thermal units to develop. The number of thermal units required for the production of each successive leaf is referred to as a phyllochron interval (PI). The linearity of PI was evidened when Haun growth units were plotted against the accumulated growing degree-days (GDD) (Figure 5). Bauer et al. (1984) also showed that the number of GDD required for each of the four growth units in Haun scale after the flag leaf is the same as that required for a leaf. Thus, the growth stages of a wheat plant can be determined with a high degree of accuracy from emergence through anthesis-complete by knowing the number of leaves on the main stem and PI of the wheat cultivar. The method is widely adopted in wheat simulation models for determing growth stages (Ritchie and Otter, 1985; Baker et al., 1985; Jame et al., 1988).

As we mentioned previously, the number of main stem leaves is not a genetic constant that depends solely on genotype. The value seemed to vary with environmental conditions. This also seemed to be true with PI. The effect of seeding date on PI was reported by Delecolle et al. (1985). They suggested the rate of daylength change at seedling emergence may affect the rate of leaf appearance. The effect of moisture stress in decreasing PI was also observed (Baker et al., 1986; Cutforth et al., 1988). The reduction in PI was thought to be the result of drought-stress plants accumulating thermal units faster because they were warmer than the well-watered plants. From our experiments, PI of Neepawa varies from a value of 85 to 95 under a wide range of environmental conditions; HY320 generally has a lower value of PI than Neepawa, ranging from 70 to 85.

The linearity of PI was challenged by several researchers. Bauer et al. (1984) found that temperatures ranging from 28 to 36^{o} C through Haun stage 2.0 introduced some nonlinearity in the regressions of Haun growth unit against GDD. Baker et al. (1986) reported that differences in PI between pre- and post-double ridge formation were large and highly significant for all spring wheat cultivars. However, there are reports of both increases and decreases in leaf appearance rate in other species as plants progress from vegetative to reproductive growth (Mauney et al., 1978; Vine, 1983; Wiegand et al., 1981; McMichael and Hesketh, 1982). More work is

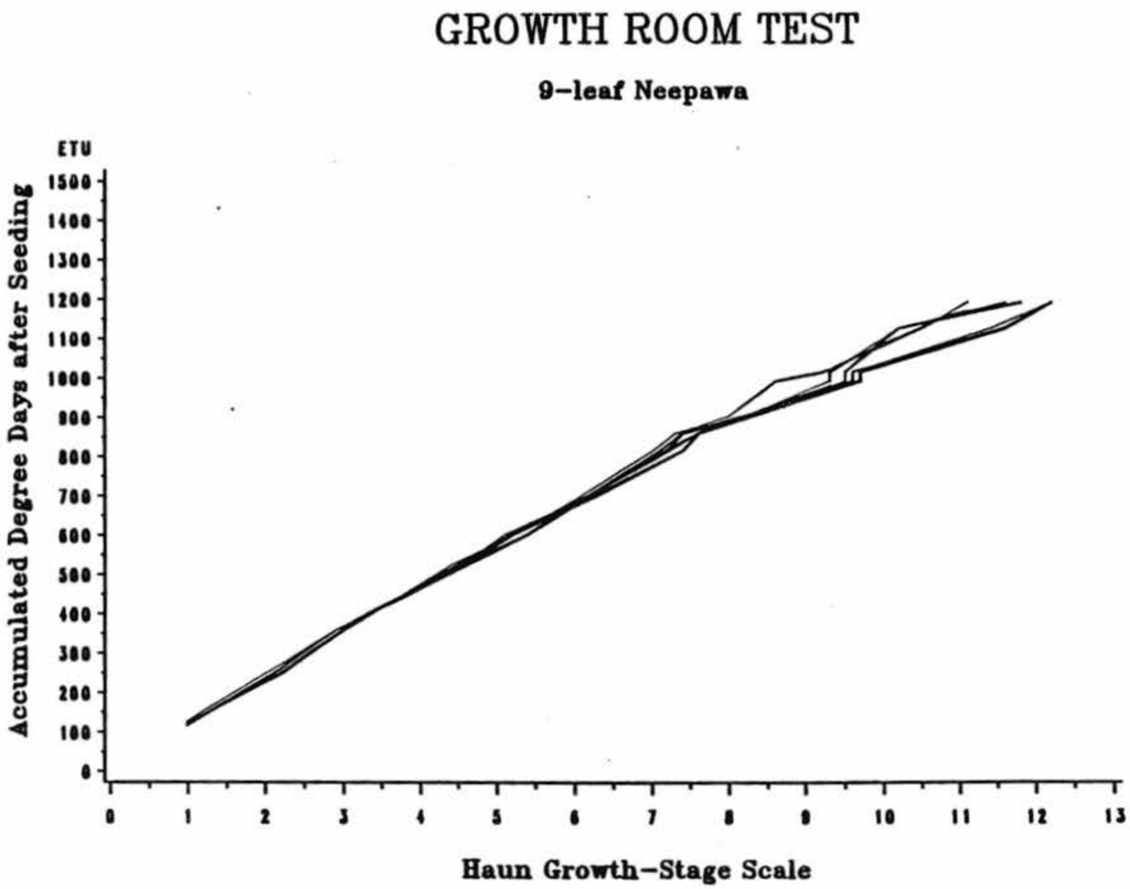

Figure 5. Haun growth stages vs accumulated growing degree days for Neepawa.

needed to determine how various environmental factors influence PI, and to quantify PI for specific varieties.

CONCLUSIONS

In this paper we have discussed several apparent advantages embodied in the Haun scale. We believe that this system is an easy-to-use staging procedure for cereals. Furthermore, when combined with Klepper's system of naming leaves and tillers, the Haun scale can be used to assess the effect of the environmental conditions on plant development. It is also possible that by adopting this system to quantify growth development, we can achieve a higher degree of precision than we do with other methods. Thus, we encourage researchers, extension personnel and farmers to adopt the use of the Haun scale in their experimental trials and in crop management. More work is needed to quantify the total number of main stem leaves and the phyllochron interval for specific varities. The information will be useful to breeders and agronomists in gaining a better understanding of plant development and in assessing varietal and yearly variations in crop yields.

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REFERENCES

BAKER, D.N., F.D. WHISLER, W.J. PARTON, E.L. KLEPPER, C.V. COLE, W.O. WILLIS, D.E. SMIKA, A.L. BLACK, and A. BAUER. 1985. The development of winter wheat: A physical physilogical process model. In ARS Wheat Yield Project. U.S. Dept. of Agriculture. ARS - 38: 176 - 187.

BAKER, J.T., P.J. PINTER, JR., R.J. REGINATO, and E.T. KANEMASU. 1986. Effects of temperature on leaf appearance in spring and winter wheat cultivars. Agron. J. 78: 603 - 613.

BAUER, A., A.B. FRANK, and A.L. BLACK. 1984. Estimation of spring wheat leaf growth rates and anthesis from air temperature. Agron. J. 76: 829 - 835.

BERNARDO, D.J., N.K. WHITTLESEY, K.E. SAXTON, and D.L. BASSETT. 1988. Irrigation optimization under limited water supply. Trans. ASAE Vol. 31 (3): 712 - 719.

DELECOLLE, R., F. COUVREUR, P. PLUCHARD, and C. VARLET-GRANCHER. 1984. About the leaf-daylength model under French conditions. In Wheat Growth and Modelling (Day, W. and R.K. Atkin edit.). NATO ASI Series A: Life Science Vol. 86: 25 - 31.

CHILDS, S.W., J.R. GILLEY, and W.E. SPLINTER. 1977. A simplified model of corn growth under moisture stress. Trans. ASAE Vol. 20 (5): 858 - 865.

CUTFORTH, H.W., Y.W. JAME, and C.A. CAMPBELL. 1988. Modeling growth stage of two spring wheat cultivars - Neepawa and HY320: I. Phenological development characteristics. Proceedings of the Soils and Crops Workshop. University of Saskatchewan, Saskatoon, Canada. Vol. 1: 93 - 105.

HAUN, J.R. 1973. Visual quantification of wheat development. Agron. J. 65: 116 - 119.

JAME, Y.W., H.W. CUTFORTH, and C.A. CAMPBELL. 1988. Modeling growth stage of two spring wheat cultivars - Neepawa and HY320: 2. Model development and performance. Proceeding of the Soils and Crops Workshop. University of Saskatchewan, Saskatoon, Canada. Vol. 1: 106 - 119.

KLEPPER, B., R.W. RICKMAN, and C.M. PETERSON. 1982. Quantitative characteristics of vegetative development in small grain cereals. Agron. J. 74: 789 - 792.

LARGE, E.C. 1954. Growth stages in cereals. Plant Pathol. 3: 128 - 129.

MAUNEY, J.R., K.E. FRY, and G. GUINN. 1978. Relationship of photosynthetic rate to growth and fruiting of cotton, soybean, sorghum, sunflower. Crop Sci. 18: 259 - 263.

MCMICHAEL, B.L. and J.D. HESKETH. 1982. Field investigations of the response of cotton to water deficits. Field Crops Res. 5: 319 - 333.

PROTOPAPAS, A.L. and R.L. BRAS. 1987. A model for water uptake and development of root systems. Soil Science. Vol. 4 (5): 352 - 366.

RITCHIE, J.T. and S. OTTER. 1985. Description and performance of CERES - wheat: A user-oriented wheat yield model. In ARS Wheat Yield Project. U.S. Dept. of Agriculture, ARS - 38: 159 - 175.

ROBERTSON, G.W. 1968. A biometeorological time scale for a cereal crop involving day and night temperatures and photo-period. Agron. J. 71: 391 - 397.

VINE, D.A. 1983. Sward structure changes within a perennial ryegrass sward: Leaf appearance and death. Grass Forage Sci. 38: 231 - 242.

WIEGAND, C.L., A.H. GERBERMANN, and J.A. CUELLAR. 1981. Development and yield of hard red winter wheats under semitropical conditions. Agron. J. 73: 29 - 37.

ZADOKS, J.D., T.T. CHANG, and C.F. KONZAK. 1974. A decimal code for the growth stages of cereals. Weed Res. 14: 415 - 421.