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Crop Physiology and Nutrition [and Discussion]

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INCREASING PRODUCTIVITY

Crop physiology and nutrition

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In the context of physiology and nutrition, many of the treatments which affect crop yields do so by influencing either the total photosynthesis per unit area of land or the partition of assimilates within the plant or both. Examples are given to illustrate the inter-relationships of nutrition, crop physiology, leaf growth and yields in cereals, grasses, potatoes and sugar beet which represent four very different models of crop growth. In each case limitations to yield are discussed but the main emphasis is on those points where there seems to be promise for future practical application to give improved yields, for example by changing models, the use of growth regulators, the time of supply and quantity of plant nutrients especially nitrogen and the timing of husbandry operations which these changes will permit and demand. With cereals the main aim should be to extend the interval between anthesis and time of ripening, with potatoes to break the apparent linkage between early tuber initiation and early leaf senescence to give a longer period of tuber bulking, with sugar beet to advance leaf growth earlier in the season and to control the partition of assimilates between leaves and storage roots and with grassland to replace inferior species with better ones.

Introduction

The objectives of those concerned in any way with crop production in the 1980s will be the same as they have been for generations, namely the improvement of crop yields and quality and the reduction of costs of production. The most spectacular developments since the war have been with cereals where in this country national average yields of grain have increased by 75 % and the credit for this must go to plant breeders who have provided new varieties and to chemists and plant physiologists who have paved the way for fertilizer use and weed control. Most of our techniques of crop production except perhaps some chemical treatments have resulted from empirical trials and the observations of astute practical men and often the agronomists have confirmed how right their predecessors were and in some cases they have been able to provide an explanation for the superiority of particular techniques evolved by trial and error and they have eliminated defects in methods of production. The major problems of crop production are probably too complicated for any individual to solve – they are over-simplified in this paper – but most crystal balls show some encouraging views of the future resulting from the work of teams where agronomists, plant breeders, chemists, physiologists, pathologists and others are working together to seek better understanding of how crop yields develop.

A study of crop physiology and nutrition aims to investigate the processes working within the crop in relation to the structure and morphology of crop plants, the development of leaves, the structure and photosynthetic efficiency of the leaf canopy in relation to light and CO_2 in the crop, the competition for and the distribution of assimilates, senescence and the internal biochemical and physiological factors involved in these processes. This paper aims to examine where such studies may well result in increased yields. It must be emphasized that any crop is filled with interactions and compensations which incidentally many are trying to unravel but because of interactions the study of an individual component of yield in isolation gets us very little further forward.

A number of estimates of potential photosynthesis indicate that the yields now being obtained from what we consider to be good crops are only a small fraction of the potential yield, for they represent less than 3 % conversion of visible radiation, whereas the theoretical maximum is probably 18 %. There are several reasons for this difference, but from this standpoint the problem of increasing yield is a problem of increasing the total annual photosynthesis per unit area of crop and of managing the crop to encourage the maximum accumulation of assimilates in the edible parts of the plant (economic yield). Sometimes a gain in total yield is offset by a reduction in economic yield and it is assumed that in years to come we shall have some control over sink-source relations and hence the partition of assimilates within the plant, so enabling us to avoid this reversible reaction of roundabouts and swings. Already it is evident that in some circumstances it is the capacity of the sink to store assimilates which limits yield, while in others the supply of assimilates is the limiting factor, but more frequently the situation may change during the development of a crop or even during a 24 h period and, to be sure, our techniques of production may have to cater for both an increased supply and an improved capacity to store assimilates.

There is a relation between leaf-area index (area of leaf laminae per unit area of land surface) and the rate of increase of dry mass per unit area of land, known as the crop growth rate. There is also a relation between leaf-area duration (the integral of leaf-area index over a growth period) and total yields of dry matter but neither relation is a simple one or, for that matter, completely understood for any crop for much depends on the number, size, shape and age of leaves, the manner in which they are distributed throughout the crop profile and their inclination or posture which has an effect on the penetration of light through the leaf canopy.

One key to influence what happens in a crop is the nitrogen supply. The main effects are to increase leaf growth and to delay senescence and within limits of levels of supply which are related to species and variety, soil and season, this results in increases in yields of dry matter. But with all crops as nitrogen levels increase beyond those currently in use on many farms there are secondary effects which in terms of economic yield often nullify the advantages of high nitrogen and in some cases, presumably by adversely affecting the partition of assimilates within the plant, bring about reductions in economic yields of grain, tubers or sugar – and these in cereals not necessarily related to lodging which in itself reduces yields. When we can secure the advantages of higher levels of nitrogen and at the same time avoid these adverse effects then we can look forward to higher yields still.

Each species of crop plant imposes different fundamental limitations to yield, and so each species has to be considered separately although most principles have common application. A consideration of cereals, potatoes and sugar beet will illustrate the different limitations and a comment on grassland will show that here entirely different factors are limiting production.

CEREALS

The time of anthesis conveniently divides the growth of wheat and barley into two stages. Events which precede anthesis and those which follow both have an effect on final grain yields but different principles operate in each stage. Accumulation of dry matter in the grain starts after anthesis, most of this dry matter being the product of photosynthesis which occurs as grain filling proceeds and in the main it is synthesized by the flag leaf and sheath, the peduncle and the ear itself including awns if present but the stem and upper leaves may contribute. The relative contribution of these organs varies between species and varieties and to some extent from crop to crop, but in both cereals grain yield is usually related to leaf area after ear emergence, but not before. Nevertheless, the leaf area at ear emergence and also the number of possible sites for grain filling are determined by the events which precede ear emergence.

The extent of tillering in spring depends on the supply of nutrients (nitrogen in particular), species, variety, time of sowing, plant density and several other factors, all of which also influence the proportion of tillers which survive to produce ears. Shoot numbers per plant or unit area vary from crop to crop and often from plant to plant within a crop, but invariably more shoots are produced than survive. With some of the older varieties of wheat (e.g. Yeoman) tiller abortion may account for about two-thirds of those present at the peak of tillering; with more recent varieties the proportion is much less being of the order of 40 % and with modern spring wheats, which tiller less to begin with, only about 20 % abort. The extent to which these abortive tillers compete with fertile tillers is not clear and no doubt the density of tillers is of considerable importance in this context and different densities may account for differences in the results of those who have tried to assess the effects of abortive tillers on yields of grain. Possibly the time of their death is important, but if they have an effect through competition they may influence the size of the surviving tillers and for a given variety the flag leaf area, the size of ear and the potential number of grains is closely related to the size of shoot bearing them. The possible transference of some nutrients and assimilates from the dying tillers to the survivors may counteract some of the competition. Nevertheless, there are many reports of field trials on the effect of time of application and level of nitrogenous fertilizer on winter wheat where, in the absence of lodging, reductions in grain yield have resulted from the higher levels of application, 200 (80) units N per hectare (acre) on some fertile sites, and in some cases this reduction has been attributed to excessive production of abortive tillers or the longer survival of abortive tillers. A degree of tillering will always be essential to compensate for unevenness of plant establishment, but it is better that the tiller population of a crop should be under our control rather than left in the haphazard situation which currently exists. More precise control of tiller population and shoot size will probably give improved yields and this will be possible with new varieties with reduced tillering capacity and the adjustments of seed rate and the time of application and quantities of nitrogenous fertilizer which the new varieties will permit and require. Foliar spraying of nitrogenous fertilizer may in part replace top dressing with solid fertilizer to ensure that the crop receives the nitrogen at the most effective time.

The size of shoot determines the size of the photosynthetic system for grain filling (the source) and also the number of potential sites for grain filling (the sink) but the final grain numbers may be less for other reasons. There seems little point in trying to establish that the activity of either the source or the sink invariably limits grain yield when the situation may change from crop to crop or at different stages in the development of a particular crop and appreciable increases in yield may require enhanced activity of both source and sink together. Once high values of leaf area index at anthesis have been achieved – including awns where appropriate – the supply of assimilates can be improved by delaying the senescence of the ear and flag leaf. Nitrogen exerts an important effect here but there are limits to its use, primarily because of lodging. The use of C.C.C. (chlormequat) with wheat may counteract this and there will be other and better growth regulators to control straw length but the really interesting contest will be between the plant physiologists and the plant breeders. The former may develop growth regulators to delay senescence for they already have limited success with the cytokinins, while the latter may produce varieties with both earlier ear emergence and late senescence. Striving for early crop maturity we have lost potential yield and delays of even 20 days with winter barley and up to 10 days with spring barley will not be serious on most farms and should give increased yields where quantity of assimilates is the limiting factor, provided that the delay is not the result of delayed ear emergence and anthesis. Those who specifically require early maturing crops will have to continue to forfeit yield on those crops, but this need not apply to the whole of the cereal area grown on a particular farm. Figure 1 shows the rate of dry-matter accumulation of winter and spring barleys seen against the potential rate – a compound of temperature, light intensity and daylength assuming a closed leaf canopy. The stark facts are that photosynthesis for grain filling takes only a matter of 4 or 5 weeks of the year and after the end of July no photosynthesis occurs on millions of hectares of this country – an argument for catch cropping as land resources dwindle. The advantage of extending the interval between anthesis and senescence in increasing yields of dry matter are clear and where the supply of assimilates is limiting grain yields then this is the way to remove this limitation.

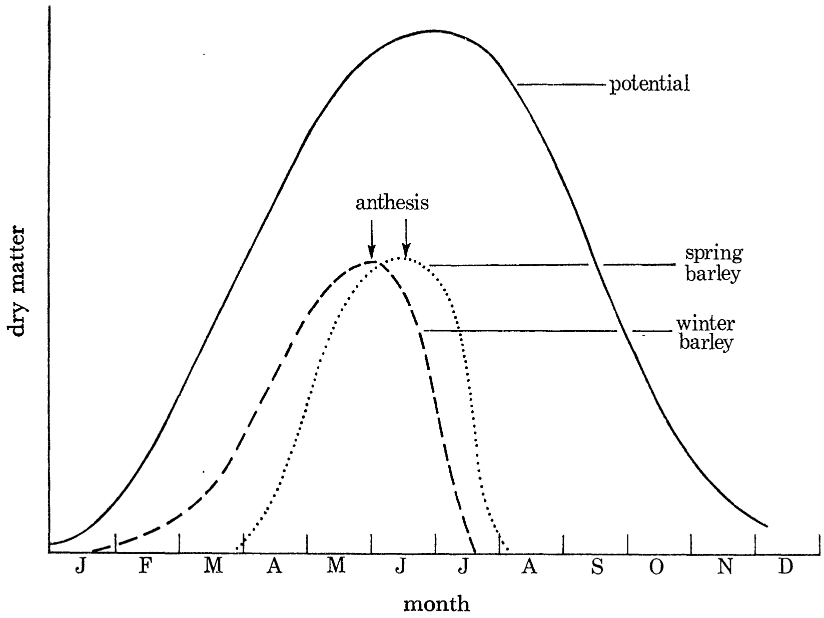

FIGURE 1. The rate of dry-matter accumulation in barley seen against the potential rate.

At present the leaves below the flag leaf of wheat supply very little to the grain and there is no anatomical reason why they should not for if the flag leaf is removed the penultimate leaf makes a bigger contribution. Does the answer lie in more erect leaves to allow better light penetration to the lower leaves or have they started to senesce too soon to be of benefit? We need to know the answer.

Awns have been mentioned. Photosynthesis by the ear of barley can account for around 35 % of the final mass of the whole crop and by far the majority of ear photosynthesis takes place in the awns. Their total surface area can equal the land surface and can exceed that of the flag leaves. They are favourably placed for light interception and CO_2 uptake, are close to the grain, develop later than the flag leaf and may longer maintain their photosynthetic activity during grain filling. Their function in barley is well established but so far with wheat they appear to be an asset only in dry climates. However, as sink capacity is increased then source activity may become limiting and their role could become more important. The high yielding Mexican wheats are strongly awned and in dwarf wheats the awns may replace the diminished contribution from stems.

Work is in progress to investigate the physiological processes involved in induction, initiation and development of the inflorescence in both cereals and grasses but the processes are complicated and not yet fully understood and it seems unlikely that they will be controllable by crop treatments in the next decade or so. The pattern of ear development is set very early in the growth of the crop and there are some clues. The more rapidly the ear develops before emergence the fewer the florets, but it would appear to be more profitable to increase the number of surviving florets than to increase the number initiated. In wheat only about half the florets which reach the stage of anther differentiation develop to set grain. Normally the later formed florets fail and Australian work suggests that this is the result of a hormone-controlled inhibitory effect of the first florets to set grain. Grain size is an important component of yield but does not appear in itself to be a limiting factor for the grain has elastic properties with some resistance to growth but no upper limit to size and this leads one to believe that they can be better filled if the supply of assimilates is there. Many farmers, seedsmen and maltsters maintain that cereal grain is less well filled than it used to be, even for well established varieties and N.I.A.B. data show that the traditional bushel mass of 28.5 kg (63 lb) is seldom obtained from trial samples of wheat even when these have been cleaned. Thin grain means loss of yield and it is probable that the poorer filled samples will incur penalties under E.E.C. intervention standards. Certainly weather and diseases such as rusts and mildew have an effect in some cases and in others high phosphate nutrition may hasten senescence and ripening, but it is not really surprising to find that some grain is not well filled when photosynthesis for grain filling occurs only for 4 or 5 weeks in the life of the crop. An extension of this period would also reduce the susceptibility of the crop to adverse weather conditions during this critical period of grain filling for the weather is less likely to be unfavourable for photosynthesis over a long period than a short one.

The number of grains per ear is equally important and we know that at least with spring sown cereals this can be influenced by time of sowing, later sowing (end of April) giving higher grain numbers than early sowing (early March) on some soils. One of the environmental factors involved is temperature but the relationship is not really clear. The late emerging ear in spring wheat has higher grain numbers, so the earlier emergence advocated a few moments ago will have little or no advantage if it takes place at the expense of grain numbers, illustrating the need to view all yield components simultaneously rather than in isolation.

Potatoes

In the potato crop, the time and extent of leaf growth is related to tuber yields and three situations are shown in figure 2, but there are others, mainly intermediate. A represents an early variety or one growing with a low supply of nitrogen. Tuber initiation takes place early, but leaf growth is limited and insufficient to maintain maximum crop growth rates and so the rate of tuber bulking is low. Early senescence of the leaves means a short period of tuber bulking and altogether this means low final yield of tubers. In B the crop attains a higher leaf area index and in consequence crop growth rate is higher and although the time of initiation of tubers is later than in A the final yield is higher because of the higher rate of bulking and the longer bulking period related to the greater leaf persistence. The extra leaf growth in C does not lead to an increase in the rate of bulking, compared with B, for several reasons, one being that the extra leaf is shading the lower leaves and so crop growth rate is not increased. Until the leaves of B start to senesce there is no difference in tuber yield between B and C but, absence of blight permitting, the extra leaf persistence in C giving a longer bulking period, will result in higher final yield.

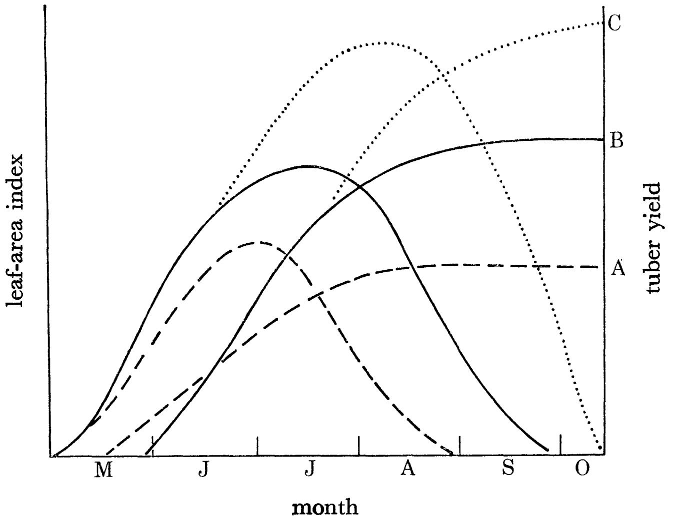

FIGURE 2. Examples of relation between leaf growth and tuber yields in the potato crop.

Through varieties, levels of nitrogenous fertilizers, seed treatments, irrigation, time of planting and other treatments we determine tuber yields at one or more of the following key phases: (i) Time of tuber initiation. (ii) Rate of bulking which is related to leaf area index (l.a.i.) up to values of about 3. This is imprecise and varies with the angles of leaves in the canopy which affect light interception and the age of leaves which affects their efficiency. Usually we have to produce higher l.a.i. values to ensure that there is a succession of new leaves, but there is a point beyond which extra l.a.i. is detrimental to tuber yield for then too great a proportion of the assimilates are going to leaf growth rather than to storage in the tubers. (iii) Leaf persistence which determines the length of the bulking period. Beyond a certain rate we have found it very difficult to increase the rate of bulking and this could be a limitation of the varieties we have used. We can manipulate the crop to give various combinations of (i), (ii) and (iii), but success in obtaining massive yields has so far eluded us. Some effects are linked to the extent that they may cancel out each other and almost invariably advancing the time of tuber initiation results in earlier leaf senescence. When we can break this linkage we shall achieve much higher yields. Chitting seed to advance early leaf growth and the time of tuber initiation is of vital importance for early crops but with maincrops it gives appreciable increases in yield only when the growing season is relatively short, e.g. because of blight or drought, and if the growing season is long unchitted seed of maincrops may outyield chitted seed because it does not suffer from the early senescence linked with early tuber initiation. Unwittingly we have almost certainly discarded useful varieties in the past, primarily because we categorize them as earlies, maincrops and late maincrops and we have never really sought material with both early tuber initiation and a long bulking period.

In the 1980s heavier yielding crops will be grown, using chitted seed to give the early emergence and early tuber initiation. Once leaf growth has reached optimum levels of l.a.i., between 3 and 4, further leaf growth will be controlled by growth regulators which influence the partition of assimilates within the crop and there are examples of limited success in this area already published, giving accounts of work in Holland and by my colleague Dr Scott. This control of leaf growth will enable us to use higher levels of nitrogen for the crop, levels which at present do little more than stimulate excessive leaf growth, but which in the presence of growth regulators will be directed to delay leaf senescence. Some of this additional nitrogen will be provided from slowly available sources in new fertilizers or will be applied as foliar sprays to avoid the delays in tuber initiation which result from very high levels of available nitrogen before tuber initiation. Current work on cytokinin-like substances suggests that further control will be available through the use of other growth regulators which specifically delay leaf senescence and the incorporation of a systemic fungicide in the anti-senescence spray will control blight so that the benefits of leaf persistence may be gained. Our control of the build up of potato yields could be so precise that in order to produce a sample attractive to the housewife without large and coarse tubers we shall be lifting many crops in August while waiting for the late ripening and heavy yielding cereal crops to mature – and this would be most beneficial to all but the lightest soils in a wet year.

Control of tuber numbers and size is another fascinating story and there are several different techniques for the production and storage of crops for different purposes such as canning, crisping, processing and the ware market. Here as the requirements become more specific so will the techniques of production.

Sugar beet

This crop represents a different model of growth where early leaf senescence is not a problem for there is an active leaf canopy until the time of harvesting, but there is a paucity of leaf in the first half of the growing season. Starting off with small reserves of capital in the seed, which is not sown until March or April, leaf growth is slow in the early stages and usually it is July before the crop meets in the rows. By the time an adequate l.a.i. is reached for maximum crop growth rate conditions for photosynthesis are declining – day length and light intensity at first and also temperature later (figure 3).

Early leaf growth can be advanced by raising seedlings under glass early in spring and transplanting in the field in April and this technique has given appreciably higher yields than direct drilled crops – an average of 68.4 (27.3) tonnes/ha (acre) over four consecutive years compared with 54.2 (21.6) tonnes/ha (acre) from direct drilling. However, the technique demands much labour and at present serves more to illustrate the relation between early leaf growth and yield than as a technique for commercial production. It is probably asking too much to expect a new cultivar which is winter hardy and which only initiates flowers for the benefit of the seedgrowers when sprayed with a specific hormone. More progress is likely in the selection of lines extremely resistant to bolting which may be sown in the autumn and treated with growth regulators to completely inhibit bolting. Either of these sown in the autumn would give l.a.i. of at least 3 or 4 in early May and the coincidence of high l.a.i. and optimum conditions for photosynthesis would result in phenomenal increases in yield.

Some progress in advancing early growth has been made by selecting large monogerm seed from a sample and over 4 years large seed has given increases in sugar yield of between 10 and

20 % compared with small seed, but the advantage is less in comparison with the whole mixture of sizes found in a normal sample of seed. Another approach to the problem is through seed treatments with growth regulators to stimulate early growth. Results so far can only be regarded as promising but no doubt such treatments will become common practice if the winter hardy lines are long delayed. Sowing at low soil temperatures will require highly effective chemicals for the protection of seed and seedling from bacterial and fungal attack.

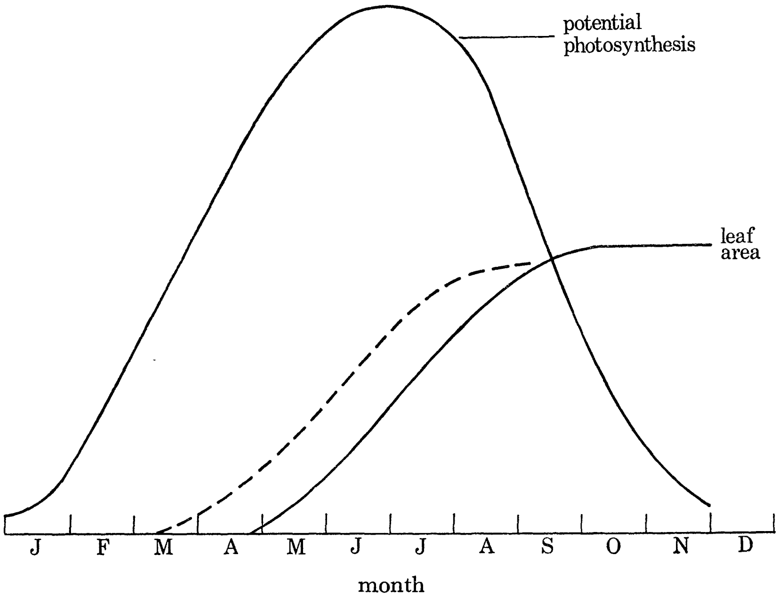

Figure 3. Leaf growth in sugar beet seen against the potential for photosynthesis. Dashed line indicates advantages of earlier leaf growth.

By the 1980s we shall have resolved the push or pull debate on whether the movement of assimilates to the roots is due to pressure by accumulation at the source (leaves) or by a pull from the site of storage in the root. The 'push' hypothesis implies that the rate of photosynthesis determines sugar yields while the 'pull' hypothesis is based on the assumption that the capacity of the root for storage is more important. It is conceivable that both hypotheses are correct within a period of 24 h where the situation may change from day to night depending on the stage of growth of the plant. Nevertheless, once the mechanism is understood we shall know where to work to control it.

Detailed studies now in progress on the water relations of the sugar-beet plant are indicating that by precise watering at critical times we may obtain economic responses to irrigation over a wide range of soil types but except on sandland with low moisture-holding capacity irrigation as we now practise it in most years gives no extra yield of sugar despite the fact that there is an increase in total yield of dry matter. Similarly, high levels of nitrogen supply give increased yields of total dry matter but again no extra sugar. Both treatments encourage additional leaf growth and this is where the extra dry matter is found. No doubt at the higher l.a.i. which result the extra leaf will shade other leaves but these are older and less efficient and there is some gain in crop growth rate, but the problem is to get the extra assimilate into the root in the form of sugar. This will be achieved by the use of growth regulators to influence the partition of assimilates within the plant and again limited success in this direction has been reported.

Where possibilities with growth regulators have been mentioned, frequently the term 'limited success' has also been used. Some chemicals are being used commercially, particularly in horticulture, to control growth and flowering and much research is in progress. It is now only a matter of time before more effective synthetic analogues of naturally occurring growth regulating hormones are available, cheap to use and with no undesirable side effects. There seems little point in discussing those now available for much better ones will be available in the 1980s and at present it seems best to point out the rôle which these growth regulators are required to fulfil.

GRASS

With grass for pasture and conservation – by far our most extensive crop – we are not concerned with the partition of assimilates but with total yields of dry matter. There are several ways of increasing yields of dry matter on most farms – less frequent defoliation for example – but in connexion with the attainment of high levels of animal production the digestibility of the dry matter is of paramount importance and frequently quantity and quality are in opposition.

Today well-established methods of grassland improvement still offer possibilities for vast increases in yields of digestible dry matter and it is possible that economic changes in the next decade will force us at last to use the techniques so ardently advocated by Stapledon in the 1930s and 1940s. Figure 4 shows the seasonal patterns of growth of perennial ryegrass and *Agrostis*. There are fundamental difficulties in measuring grassland productivity in terms of animal production and data are liable to misinterpretation for numerous factors influence the results, some of them virtually unconnected with the grassland. Nevertheless, an indication of the relative productivity of the two species is given by the fact that in 1970 on the same farm at Sutton Bonington using the same dairy herd, an *Agrostis* dominant sward gave 70 % of the output of a perennial ryegrass sward when measured in terms of milk yields, 76 % in terms of cow-days and 73 % in terms of utilized starch equivalent. Both swards received 500 (200) units N per ha (acre). The 1969 survey shows that *Agrostis* dominates virtually 60 % of our permanent grassland while perennial ryegrass dominates only about 20 % and the situation has changed very little in the past decade. Substitution of the former by the latter in lowland grassland, a task relatively easy, would accomplish far greater increases in production than anything else that can be imagined and this is likely to occur widely well before the 1980s due to the economic consequences of entry into the E.E.C. with increasing costs of cereals and concentrate feeds. Some farmers using the better varieties of Italian and perennial rye grasses, high levels of

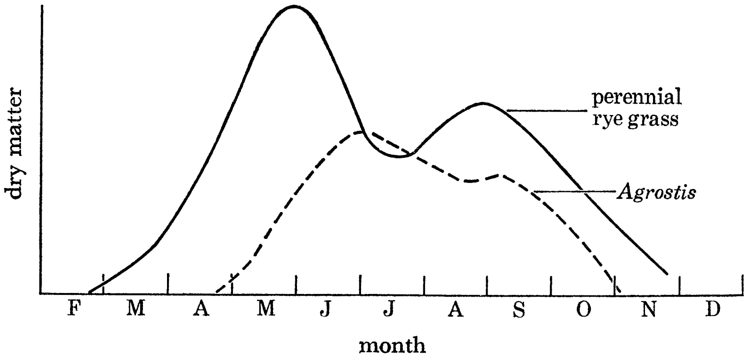

FIGURE 4. Seasonal production of perennial ryegrass and *Agrostis* compared.

nitrogenous fertilizers and a rotational grazing system are achieving very high levels of animal production, especially milk, from grass, but the products of the plant breeder currently affect only about one-third of the grassland area in the U.K. excluding the rough grazings.

One can imagine several ways in which an understanding of crop physiology and nutrition might be brought to bear. The elevation of the leaf canopy which occurs at the time of heading coincides with the maximum growth rates possibly via improved light interception and we could have methods of encouraging some perennial grasses to elevate their leaf canopies more than once per year; analogous to cereals a delay in senescence after heading conceivably could increase dry-matter yields and if simultaneously this effected a delay in the fall in digestibility which normally occurs after heading a double benefit would result. As grass production depends on the successive production of crops of tillers closer control of this process could be exploited to increase yields. These are possibilities, but detailed studies of animal physiology and nutrition appear to be more rewarding for the 1980s than work on crop physiology and nutrition. Although the importance of digestibility and the phenomenon of the rapid fall after heading has been known since 1889 we have only begun to pay attention to this on a practical scale in the last decade. At present our techniques of grass production are not based on the science of animal physiology and nutrition and we know very little about the precise requirements of different categories of grazing livestock and the effects of deviations from the ideal diet on their metabolism and production and one can be sure that when we do, this will have a big influence on our techniques of grass production – but this is another subject.

There will be important developments for the herbage seed grower. Our best varieties of perennial ryegrass have been bred for high yields of digestible organic matter, very high tillering capacity and persistency, but in seed crops they produce thick mats of vegetative and reproductive tillers which become tangled and lodged in a leaf profile which is far from ideal for photosynthesis. Many reproductive tillers die and others fail to produce seed either because of pollination failure or inadequate supplies of photosynthates to fill the grain – the latter aggravated by the never ending production of new vegetative tillers which are not self supporting for photosynthates in the early stages of their development. In field experiments at Sutton Bonington, seed crops of S 24 perennial ryegrass with a population of 2600 fertile tillers per square metre produced on average 126 florets per fertile tiller, but only an average of 27 viable seeds per fertile tiller. A reduction in levels of nitrogen to reduce lodging reduces the number of fertile tillers and seed yields are lessened but limited success with growth regulators chlormequat and maleic hydrazide which reduce straw length and lodging and improve the ratio of fertile to vegetative tillers suggests that this problem will be overcome by chemical manipulation on the part of the seedgrower, leaving the plant breeder to concentrate on the desirable agronomic characteristics of new varieties.

CONCLUSION

Several important aspects of crop physiology have not been considered here. At least 10% of the products of photosynthesis are lost by photorespiration and a break-through in controlling this rather wasteful process could result in increased yields of dry matter. We need much more information on root growth and its relationship with other functions of the plant before we can appreciate the picture as a whole. Studies on the effects of day length will probably enable us to understand more about the mechanisms involved in crop growth and work with anti-transpirants may improve our control of the water relationships of crops. In the 1980s we shall know more about the processes at work within the crop and armed with this knowledge we shall be able to manipulate and control the crops much more precisely for improved economic yields.

Discussion

J. L. Harper (*School of Plant Biology, University College of North Wales, Bangor*). Professor Ivins focuses attention on some weaknesses in present-day crops that prevent even the well-grown crop from realizing its potential yield of useful product. I imagine that the 1980s will see the methods of the best farming systems of 1973 spreading widely over the country – but by that time the top farmers will be doing something different. If the crops that they are growing at the end of the 1980s make better use of the light climate, spend a longer time filling their grains or tubers and convert a bigger fraction of their assimilates to useful harvestable product it will be largely due to the research effort and foresight of D. J. Watson and his colleagues at Rothamsted. The physiologists' insights have come increasingly to control the direction of crop improvement rather than the trial and error methods of the breeder.

My own view is more radical than that of Professor Ivins. I will be surprised if there have not been major changes in the form of many of the common crop plants before 1990. I find it extremely odd that the potato and the sugar beet, both of which fill below ground organs with storage carbohydrate, do it with such different foliar machinery. In the potato a stemmy structure with a canopy of leaflets provides the assimilatory system – in the sugar beet the same job is done with a rosette of large entire leaves. It is surprising if both systems are equally adapted to do the job – particularly as we know that in nature precise details of leaf architecture and form are under strong selective pressure. This is just one example of a question about crop form that seems to me likely to influence crop production in the 1980s. Agronomists are now questioning, at a level much more fundamental than ever before, whether the species nature has given us are more or less right, given a brushing up by the plant breeder. Suddenly we are daring to ask whether peas would yield better if they had no leaves, whether wheat plants have too many roots, whether the stem of a potato plant is really necessary. The answers to such questions can greatly affect cropping in the 1980s and changes can come quickly. A rapid change in the rate of change of cropping practice is made possible by the chemist – chemical modification of plant form and behaviour (as with C.C.C.) removes the period of waiting while the geneticist alters the genotype. The likely pattern of development seems to me that chemical manipulation of crop performance will precede, and set the path for later genetic achievement of the same ends.

The balance of crop species seems bound to change on the British scene; probably the seed legume with its potential as a meat substitute will become a more dominant crop type. If it does, the beans will surely not be the badly designed plants we know now – they will probably have ceased to bear an umbrella of superfluous foliage that shades the pods! Cereals are due for a profound change. Will they be high density uniculm plants, photosynthetically very efficient forms with nearly erect leaves, no tillers and a very high harvest index or will they be F1 hybrids with expensive seed sown at very low density but with very great tillering ability? Decision between these alternatives will surely be made early in the 1980s. Professor Ivins's target may be right for 1982–3, but I hope we have visions (or ideotypes!) of more profound changes that can be realized by 1989.