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Mohamed Hazem Kalaji, Stefan Pietkiewicz

Department of Plant Physiology, Warsaw Agricultural University SGGW, Nowoursynowska 159, 02-776, Warszawa, Poland

REVIEW: SOME PHYSIOLOGICAL INDICES TO BE EXPLOITED AS A CRUCIAL TOOL IN PLANT BREEDING

ABSTRACT

This article is mainly addressed to plant physiologists and breeders. Nowadays, the cooperation between these two groups seems to be more important than ever before. Plant physiology offers better understanding of mechanisms and factors responsible for plant yielding. Thus, it might help to find proper traits for plant selection. Plant breeding proposes highly differentiated material for testing.

Key words: chlorophyll fluorescence, gas exchange, growth analysis, plant breeding, physiological indices, salt stress, selection criteria, yielding.

INTRODUCTION

A substantial progress in biology has been recently achieved thus, assuring the development of modern agriculture (Nalborczyk 1998). This is illustrated in Table 1, which shows the impact of the principal factors affecting crop productivity. The use of fertilization was the main factor affecting crop productivity during the years 1951-1970 while the use of biological progress has been responsible for productivity increase through the years 1971-1998. Nevertheless, better use of available modern methods, techniques and cooperation between different agricultural disciplines might accelerate this progress.

The plant breeder has -for a long time- been the one who works under field conditions using skilled hands and experienced eyes to obtain mainly one goal - the achievement of higher final yield, while its quality being treated as a secondary one. In addition, he has been always using a large scale selection and crossing methods what means, that he has not enough time for analysis of the necessary biochemical and physiological parameters. Looking for the characteristics of crop ideotypes he narrowed his interest only to the ones directly related to yield like num-

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ber of ears per plant, number of grains per ear, thousand corn weights etc. Such approach leads to a loss in the crops' quality and narrowed crop diversity to a small number of the highest yielding cultivars.

Table 1

The impact of the principal factors affecting crop productivity within the years 1951-1998 (Nalborczyk 1998)

Factor	Productivity increase [%]	
	1951-1970	1971-1998
Biological progress	18	52
Fertilization	47	24
Plant production	22	14
Agrotechnology	9	7
Others	4	3
Total	100	100

The plant physiologist analyses the individual life processes and develops an understanding of the plant's response to fluctuations in environmental conditions. In other words, the plant physiologist aims to answer the following questions: How is it functioning? Why does it function in this way? Thus, he occupies the branch of plant sciences, which could help others to interpret and explain their obtained data. Therefore, the plant physiologist should become a vital partner of the experienced breeder in the process of developing and evaluation of new promising cultivars. For example, Polish breeders effectively exploited interrelationship between leaf area and yielding of cereals offered by a plant physiologist (Nalborczyk and Czembor 1990, Nalborczyk *et al.* 1986).

Generally, so far, the cooperation between breeders and plant physiologists is still poor, not fully explored and should be substantially improved. Probably, its weakness stems -among other things- from a lack of awareness amongst breeders concerning current advances in plant physiology. Recently, a considerable development in plant physiology was observed, resulting in important advances of "agrophysiology". This was achieved due to the availability of modern computerized portable devices and instruments, which enable the plant physiologist not only to work in the laboratory but also in the field and get thousand of measurements in short period of time. Such devices allow monitoring nearly complete chain of plant life processes i.e. starting with e.g. GMO (Genetically Modified Organism), physiological analysis through experiments in the laboratory and finally followed by field verification (Starck and Niemyska 1998) on the canopy scale (Pietkiewicz *et al.* 2002,Wyszynski *et al.* 2002).

In this article, the authors -as plant physiologists familiar with many plant breeding programs- would like to share with plant breeders, few concepts related to physiological issues which seems to be crucial to the mutual cooperation between plant physiology and plant breeding.

SELECTION CRITERIA AND PLANT PHYSIOLOGY

While reviewing the worldwide literature we found that, the number of registered tolerant or resistant cultivars obtained by plant breeders is relatively poor as compared to their documented researches. The most commonly selected (popular) traits to be used as criteria in plant selection programs were those of a morphological or a simple physiological nature related to the yield (final outcome) but not to the yielding (process of yield formation) ones. Our search in ISI Science Citation Index within 1993-2000 years for the literature related to “selection criterion” or “selection criteria” (Table 2) revealed that, some of criteria were established upon the recommendation of certain common classical methods used in plant breeding (Fernandez and Kuo 1993, Chilagane 1994, Piepho 1995, Preciado Ortiz *et al.* 1995, Bokyeong *et al.* 1995, Wisniewski and Zagdanska 1998, Jamjod and rerkasem 1999*,* Voltas *et al.* 1999*,* Kamali and Boyd 2000). Very few positions that directly related to plant physiology were found (Wu and Tao 1995, Srinivasan *et al.* 1996, Akazawa *et al.* 1997). The rest of the cited criteria were related to traits of common growth parameters estimation e.g. mean lesion length within taproots (Salter *et al.* 1994).

To analyze more thoroughly the contribution of various agricultural disciplines for plant breeding we have chosen the case of International Center for Agricultural Research in the Dry Areas (ICARDA) as an example. According to SCI, data related to ICARDA output, in the view of newly registered cultivars should be considered as satisfactory one. Table 3 reveals their success in registration of many new germplasm lines between 1994 and 1999. Nevertheless, nearly all of these cultivars were developed without substantial use of progress in plant physiology (Table 4).

Moreover, it was surprising when we found that, the most of the realized by plant breeders works in the frames of selection criteria establishment had been undertaken in stress conditions. It is in disagreement with what plant breeders were practicing i.e. selection for yield should be conducted under non stressed conditions (Ceccarelli *et al.* 1996).

Recently, plant physiology offers some new methods to characterize physiological and biochemical traits to be looked for through plant breeding programs. We assume, that in the past, many valuable plant physiology researches did not leave the laboratory because scientists did not know how to make better use of their obtained valuable results. On the other hand, the breeders have not been convinced enough by the form of data presentation adopted by plant physiologists. In the following part of this article we will survey some of the physiological parameters that we believe are noteworthy, deserve more investigation and should attract plant breeders' interest and concern. Below, we are going to underline some of issues, which we believe that exemplify useful selection criteria.

Table 2

Selection criteria found in the World-wide appraisal of plant breeding programs (ISI Science Citation Index).

Year	Author	Trait or criterion of plant selection/breeding	Plant
1993	Fernandez G., Kuo C.	Stress tolerance index (STI) = (potential yield × stress yield) × (mean potential yield)	Mung bean
1994	Salter R. *et al.*	Mean lesion length (vertical discoloration) within taproots (resistance to root rot caused by *Fusarium* species)	Alfalfa
1994	Okamoto M	Leaf color as indicator for chemical components of grain (N content)	Rice
1994	Chilagane A.	Farmers' criteria for evaluating: plant height, drought tolerance, threshability, milling qualities and cooking qualities	Rice
1995	Piepho H.	Desirability index	Various plants
1995	Worku T	Water-retention capability (flag leaf)	Wheat
1995	Wu P., Tao Q. N.	Physiological nitrogen use efficiency: efficiency in transferring nitrogen from terminal parts for grain production, HI and N content	Rice
1995	Yagbasanlar T. *et al*.	Biomass yield and harvest index (selection for improving seed yield)	Wheat
1995	Jackson P. *et al*.	Sugar yield or net merit grade	Sugar cane
1995	Preciado-Ortiz R. *et al.*	Growth and yield modeling as methods (shorter vegetative and longer reproductive periods has greater predicted yield)	Maize
1995	Johnson R.C. *et al.*	Shoot weight and HI have better correlation to yield than WUE and it relation to photosynthesis	Lentil
1995	Jafari S. *et al.*	High grain yield under salinity stress is better selection criterion for tolerance than biomass yield, harvest index	Wheat
1995	Pyl'nev V.	Number of fertile tillers/unit area	Wheat
1995	Kertikova D., Georgiev Z.	Regrowth rate: tolerance to intensive harvesting	Lucerne
1995	Bokyeong K. *et al.*	Chained ring weight (CRW) to select lodging resistant genotypes	Rice

Table 2

Continued

Year	Author	Trait or criterion of plant selection/breeding	Plant
1995	Petcu E. and Terbea M.	ree proline content indicating membranes injury of primary leaves (drought stress)	Soybean
1995	Ambawatia G. T. *et al.*	Synchronous tillering percentage: drought tolerance	Wheat
1995	Romer W.	Root length of young plants as a selection criterion for P efficiency in low phosphate P level areas	Maize and Barley
1996	Srinivasan A. *et al.*	The damage to cell membranes (as reflected by an increased leakage of electrolytes) and PS II (as reflected by a decrease in the ratio of variable to maximum fluorescence) as screening procedures for breeding heat-tolerant	Legumes
1997	Foolad M.R.	Tissue ion concentration under salt stress (high tissue Ca levels and to exclude Na from the shoot) at the level of F and F	Tomato
1997	Board J. *et al.*	Pod per reproductive node	Soybean
1997	Kharkwal M. C., Chaudhary H. B.	Grain density (tolerance during grain filling, under adverse abiotic conditions such as late planting, temperature, moisture stress.	Chickpea
1997	Russi L.	Early flowering and large leaf areas	Clover
1997	Singh D. *et al.*	HI, biological yield per plant, 100-seed weight and number of pods per plant	Chickpea
1997	Akazawa T. *et al.*	Water-soluble N may be a simple indicator for free amino acids (asparagine, alanine, glutamic acid, arginine, serine, histidine and valine) in seeds	Soybean
1998	Blum A.	Selection for better stem reserve supported grain filling under drought stress	Wheat
1998	Wisniewski K.., Zagdańska B.	Chemical desiccation of plants maybe used for indirect evaluation of drought tolerance	Wheat and Triticale
1999	Jamjod S. and Rerkasem B.	Boron efficiency	Barley
1999	Atanassov P. *et al.*	Yield, yield components, morphological traits and earliness	Barley
1999	Voltas J. *et al.*	Carbon isotope discrimination (DELTA)	Barley
1999	Gahoonia T. S. *et al.*	Root hair length	Barley, Wheat
2000	Kamali M. R. J., Boyd W. J. R.	The timing of awn appearance (heading)	Barley

Table 3

ICARDA registration of new germplasm lines 1994-2000 (Information are collected from ISI Science Citation Index)

Year	Plant	Tolerance or resistance
1994	Chickpea: eight germplasm	*Ascochyta* blight resistance, early maturing, and large seed
1995	Barley: 'Giza 125' and 'Giza 125'	Moderate tolerance for high stress environments and diseases
1996	Chickpea: Ladiz ILWC 292	Chickpea cyst nematode
1996	Chickpea: (three germplasm lines)	Leafminer
1996	Lentil: ILL 5582	Seed yield
1996	Lentil: ILL 5588	Vascular wilt and *Ascochyta* blight
1996	Chickpea: FLIP 87-59C	Drought
1996	Chickpea	*Fusarium* wilt
1997	Chickpea: FLIP 91-178C, FLIP 93-53C, FLIP 93-98C	*Ascochyta* blight, *Fusarium* wilt, and cold
1997	Chickpea	*Callosobruchus chinensis*
1999	Lentil: 'Barimasur-2'	*Uromyces fabae* [*U. viciae-fabae*]
1999	Lentil: 'Barimasur-3'	*Uromyces viciae-fabae* and *Stemphylium botryosum* [*Pleospora herbarum*]
1999	Lentil: 'Barimasur-4'	*Uromyces fabae* [*U. viciae-fabae*]) and *Stemphylium botryosum* [*Pleospora herbarum*]
1999	Faba bean: `Fiesta VF'	Disease resistance (moderately susceptible to *Botrytis fabae* and moderately resistant to *Ascochyta fabae*).

Table 4

ICARDA selection criteria for plant breeding (ISI Science Citation Index)

Year	Author	Trait or criterion of plant selection/breeding	Plant
1993	Bharati M. P. *et al.*	15 characters (mainly related to yield and plant morphology)	Lentil
1993	Khattab A. M. *et al.*	Seed yield, number of pods and number of double seeds/pod	Chickpea
1994	Ortiz F. *et al.*	Empirical and analytical criteria of genetic variability for heat tolerance	Wheat
1994	Mosaad M. G. *et al*.	Biological yield, grains/spike, main stem grain yield and water use efficiency	Wheat
1994	Ratinam M. *et al.*	Chlorophyll fluorescence (response to frost)	Ochrus chickling

Table 4

Continued

Year	Author	Trait or criterion of plant selection/breeding	Plant
1994	Ratinam M. *et al.*	Morphological, morpho-physiological and biochemical (sugar content) characters, root-shoot ratio, number of primary branches per plant	Forage legume species
1994	Dakheel A. J. *et al.*	Carbon isotope discrimination (DELTA) and water use efficiency/ Transpiration efficiency, photosynthetic rates	Barley, Wheat
1994	Erskine W. *et al.*	Appropriate phenology and increased water use efficiency (biotic and abiotic stresses)	Lentil
1995	Mosaad M. G. *et al.*	Tiller dynamics under water stress in breeding for drought tolerance	Wheat
1995	Pecetti L., Annicchiarico P.	Visual assessment for drought tolerance	Wheat
1995	Annicchiarico P., Pecetti L.	Morpho-physiological traits: grain yield, heading, maturity, grain filling duration, stature, plant glaucousness, number of kernels per spike, early vigor	Wheat
1995	Watanabe N. *et al.*	The feature of light green leaves may confer the ability to adapt to high levels of irradiance under drought conditions (by analysis of variation in thylakoid proteins, photosynthesis, chlorophyll content and chlorophyll a:b ratios)	Barley
1995	Sayre K. D. *et al.*	Carbon isotope discrimination (DELTA) used to augment selection for high yield, early maturity and minimal reduction in plant height	Wheat
1996	Ceccarelli S. *et al.*	Farmers' participation in genotype X environment selection and breeding for specific adaptation	Barley
1997	Yau S. K.	The efficiency of alpha-lattice designs	Barley, Wheat
1997	Goodchild A. V.	Genetic selection of crops with better straw feeding value	Barley
1997	Ferrara G. O. *et al.*	Vernalization requirements and photoperiod response	Wheat
1997	Nachit M. M. *et al.*	Biotic stresses resistance, the complex nature of the traits, and also and boron toxicity	Wheat
1997	Singh K. B. *et al.*	Increased plant height, which can produce higher biomass yields leading to greater seed yields	Chickpea
1997	Al Hakimi A. *et al.*	Morphophysiological traits (root volume and relative water content) under water stress	Wheat
1998	Pecetti L., Annicchiarico P.	Yield potential and morphophysiological features: plant height, grain filling duration and earleness of heading	Wheat

GAS EXCHANGE OF PLANT

Photosynthesis is the process by which energy is harvested from the sun and converted into plant biomass. The leader work of Nichiporovich *et al.* (1961 and 1967) established that, the main photosynthetic indices of plant productivity are: photosynthetic rate, photosynthetic area, leaf area duration, coefficient of photosynthetic plant efficiency and harvest index (Nichiporovich, 1997; Nichiporovich *et al.* 1961).

Estimation of gas exchange parameters allows some comparisons of leaf gas exchange between different genotypes (Choluj *et al.* 1997, Brestic *et al.* 1996, Choluj and Kalaji 1995). Also, it helps to study the effect of various unfavorable growth conditions, as e.g. effects of CO_2 enrichment on field crops, seasonal trends in photosynthesis rates, effect of insecticides, and assessment of herbivore impact on field crops as well as photosynthetic response to nutrient variation (Climate Stress Lab 1997). There is no doubt that it is a very simple and proper tool to underline crop fidelity and/or reliability through breeding programs.

The set of gas exchange parameters involving: photosynthetic rate (P_N), transpiration (E), their ratio (WUE - water use efficiency), intracellular CO2 concentration (C_i or g_m), stomatal conductivity (g_s) and dark respiration (R_D) could be a very suitable selection criteria since they may reveal the potential of plant growth capacity (Kalaji and Nalborczyk 1991, Łoboda *et al.* 2000). Estimation of dark respiration (R_D) as well as photorespiration (R_l) is also important since these processes consume a big part of the photosynthesis products creating yield (e.g. legumes 30%, Nalborczyk *et al.* 1986). There are several commercially available systems for measurement of gas exchange parameters. The use of such computerized portable instruments enables us to realize proper measurements and get high throughput of recordings in both laboratory and field conditions.

It is important to underline here that, plant gas exchange parameters are very important tool to explore the level of the hidden photosynthetic potential of plants. Cereal breeders started to be interested in such traits for high and stabilized yield e.g. triticale yield which was increased by one of the most famous world wide triticale breeders- Prof. Wolski (Nalborczyk and Czembor 1990). Taking into account the possibility of producing by biotechnology a triticale plant with resistance to the herbicide BAAS (Dobrzanska *et al.* 1997), this crop possesses an opportunity to prevail in some aspects above other cereals in yielding. Indeed, recently triticale plant proved to show better performance on field till now occupied by other cereals.

CHLOROPHYLL *a* FLUORESCENCE

The performance of photosynthesizing plants might be an indicator for biological yield prediction (Donald 1962). It is well established that plants can usually exploit only about 5% of the solar energy, and produce assimilates by the absorption of visible light in the 400-700 nm waveband (Photosynthetically Active Radiation PAR). Excess energy must be dissipated mainly as heat and small part as an optical reemission, which is called "chlorophyll *a* fluorescence". Measurement of chlorophyll *a* fluorescence seems to be one of the best indicators of photosynthetic efficiency. This procedure satisfies the demand for rapid, non-invasive screening tests, and can be easily applied to assay the influence of environmental effects on physiological state of plants (Govindjee 1995, Strasser *et al.* 2000).

Available chlorophyll fluorimeters are based on two different measurement techniques. The first one is referred to as continuous excitation whereby a high intensity beam of excitation light induces chlorophyll *a* fluorescence emission from the sample and is immediately detected by special detector. The advantage of this technique is the rapidity of measurement at high time resolution. A typical measurement of one-second duration provides a lot of information related to the transient fluorescence induction curve, which is observed when a plant is strongly illuminated after at least 30 min. of darkness. This allows large scale screening of crops at throughput rates of many hundreds of samples per hour (Strasser *et al.* 2000).

The second type of chlorophyll fluorimeter uses a technique called Pulse Modulation to discriminate fluorescence emissions even in ambient light (natural conditions). Measurements with such instruments are generally performed over longer time periods and at a range of light levels. They can be used in combination with gas-exchange measurements to simultaneous monitoring both effect of CO_2 assimilation and chlorophyll *a* fluorescence in different conditions (Schreiber *et al.* 1986).

In stress conditions, the ability of a plant to use solar energy for photochemistry is reduced and hence an increase in dissipation of energy via chlorophyll *a* fluorescence is observed. Stress conditions will strongly influence the kinetics of this fluorescence signal in susceptible plants allowing the plant physiologist to quantify stress even before visible symptoms are observed. It is therefore not surprising that chlorophyll fluorimeters are often marketed under names such as "'Plant Efficiency Analyzer" or "Plant Stress Meter" as these devices are ideal for the rapid determination of stresses. The use of such parameters by plant breeders will allow them to get a rapid snapshot of the changes in plant photochemical efficiency experienced by the plants growing under different growth conditions in the field.

TOPOGRAPHY OF PHOTOSYNTHESIS

Some well known methods or techniques such as the use of isotopes, which enable not only the estimation of plant gas exchange but also the distribution of the assimilates in different parts of the plant have also been intensively used. Carbon isotope ^{14}C methods enable estimation of the photosynthetic activity of shoots, shoot radioactivity decrease (respiration) and distribution of ^{14}C -labeled assimilates both in the shoot and root (Nalborczyk *et al.* 1981, Starck 2003, Gawrońska 1998, Dzierżyńska 1990).

In the 1981's a team led by Nalborczyk showed that, the exposition by isotope ^{14}C of five cereals (barley, oat, rye, triticale, and wheat) gives the opportunity to establish the photosynthetic topography of these genotypes and identified three types (models) of plant photosynthetic potential (Fig. 1): Leaf (barley, triticale and wheat), leaf-spike (barley and oat) and culm (rye). These models allow plant breeders to improve the efficiency of solar radiation energy captured by plant under field conditions (Nalborczyk and Czembor 1990). It was one of the best classical works of how plant physiology may help in plant breeding (Nalborczyk et al. 1981, Nalborczyk and Sowa 2001).

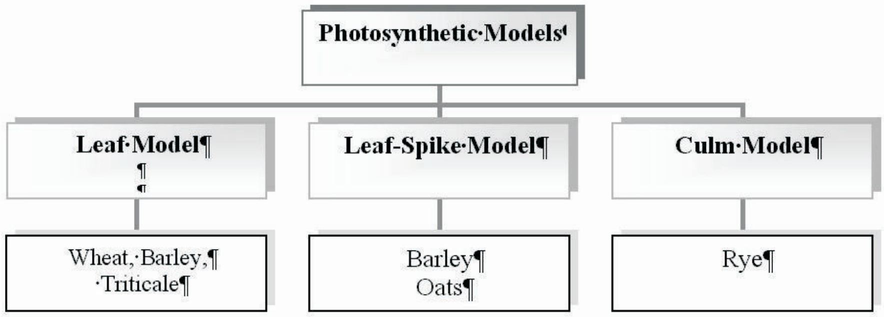

Fig 1 Main photosynthetic models affecting productivity of cereals (Nalborczyk 1998)

TRANSLOCATION OF ASSIMILATES

Translocation is the transport of the products of photosynthesis from leaves (source) to areas of growth and storage (sink). It involves phloem loading and unloading, assimilates allocation and partitioning (Niemyska 1986). If we understood different strategies of plants growing under various conditions it would be essentially advantageous for plant breeding (Starck *et al.* 1994, Starck 1995, 1996, 1997, Weems *et al.* 1999, Reynolds *et al.* 2001, Sowinski 2001, De Costa and Shanmugathasan 2002). Translocation of assimilates is the factor that should be considered as an important criterion for plant selection which determines yield by controlling how and where the products of the photosynthesis will be shared (Choluj *et al.* 2001). Furthermore, the relation between source and sink could offer better understanding of the plant growth strategy. Many factors are involved in this process e.g. source and sink activity, their size, and strength (Warren-Wilson 1986).

Knowledge of nutritional relations and hormonal balance of plants, could also add some important information to be used during the establishment of useful criteria for plant selection.

PLANT GROWTH ANALYSIS

Using combined parameters involving plant assimilatory surface and/or whole plant mass can enable to estimate the processes of growth and production of dry matter and its partitioning. The most used indices in the case of single plant analysis are: Relative Growth Rate (RGR), Unit Leaf Rate (ULR), Leaf Area Ratio (LAR), while the most used ones in the case of crops analyses are: Crop Growth Rate (CGR), Net Assimilation Rate (NARc), Leaf Area Index (LAI) and Leaf Area Duration (LAD) (Watson 1952, Radford 1967, Evans 1972, Pietkiewicz 1985, Hunt 1990, Pala and Pietkiewicz 2002).

The strategies of growth and yielding revealed with this method were described for nearly all important crops *e.g.* triticale (Czerednik and Nalborczyk 2000), wheat (Kornatowska and Pietkiewicz 1991), barley (Kalaji and Pietkiewicz 1993), rye (Nalborczyk and Sowa 2001), amaranth (Chwedorzewska and Nalborczyk 1994, Gontarczyk 1996), potato (Czerwinska *et al.* 1996, Olszewski *et al.* 1999, Pietkiewicz 1984, 1990, 2000) and rape (Zawadzki *et al.* 2000).

On the crop scale, LAI seems to be a crucial parameter characterizing the size of the plants (Watson 1947, 1952, Pietkiewicz 1985). One can find it in both simple analytical investigations as well as in mathematical modeling of growth, development and yielding of crops (see the pleiad of models CROPGRO, SUBGRO, DSSAT and their relatives in Bonhomme *et al.* 1996). Quite recently developed LAI meters enable systematic and massive recording of LAI for various plant species and canopy architecture analysis (McPherson and Peper 1998). Many scientific comparison works (Wilhelm *et al.* 2000) proved that, these instruments are useful for both plant physiology and breeding.

INTERRELATIONSHIPS BETWEEN MEASURED PHYSIOLOGICAL PARAMETERS

The application of correlation tests on some previous mentioned traits enables us to understand plant growth strategies under various growth conditions (Brestic *et al.* 1996). During an experiments conducted by Kalaji (1993), investigation realized with 8 barley cultivars of different geographical proveniences revealed that, when plants were subjected to stress condition caused by an excess NaCl salt (Figs. 2-3) plant growth strategies were shifted in different manners.

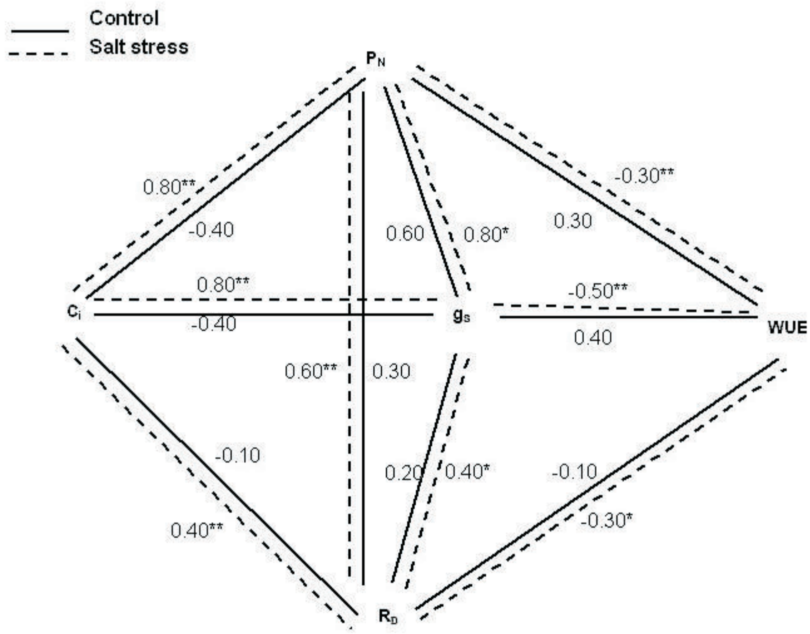

Fig. 2 The relationships between gas exchange parameters (photosynthetic rate P, water use efficiency WUE, intracellular CO2 concentration C, stomatal conductivity g and dark respiration R) of barley seedlings under control (solid line) and saline condition (dashed line). Stars indicate significance level of correlation coefficients (* =0.95, **=0.99)

It can be observed (Fig. 2), that most of relations between gas exchange parameters were shifted and the tolerant barley cultivars' reactions were toward assuring new strategy, which is considered to be more economic in the view of water using (compare WUE values for control and stress conditions). Under control conditions, the relation between photosynthesis (P_N) and intracellular CO^2 concentration (C_i) was inversely proportional, but under salt stress it became directly proportional. This indicated how the photosynthetic apparatus was partly blocked to minimize the growth rate (survival rate), which is under normal conditions allied with more opened stomata and more loss of transpired water (see the values between stomatal conductance g_s – Water Use Efficiency WUE and P_N – WUE). The relationships between gas exchange parameters and growth indices of barley seedlings grown under saline conditions showed how the photosynthesis and respiration processes became more crucial for plant growth especially to that of shoot dry matter (Fig. 3). Generally, the relation of the above mentioned parameters, were either not shifted, strengthened, or inverted (Figs. 2-3).

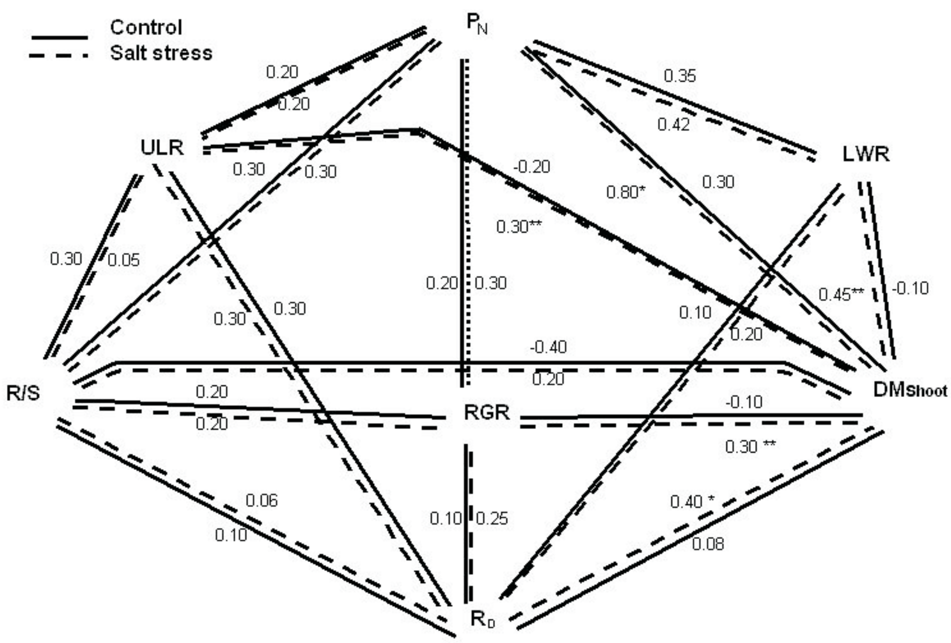

Fig. 3 The relationships between some gas exchange parameters (photosynthetic rate P and respiration R) and growth indices (Relative Growth Rate RGR, Unit Leaf Rate ULR, Leaf Weight Ratio LWR, Shoot Dry Matter DM and Root/Shoot Ratio R/S) of barley seedlings under control (solid line) and saline (dashed line) condition. Stars indicate significance level of correlation coefficients (* =0.95, **=0.99)

Basing on found relationships, Kalaji (1993) proposed the following conclusions related to some traits that could be used as criteria of selection and determination of plant tolerance on salt stress:

1. The economy of plant growing without salinization is characterized by wide opening of stomata, builds up an excess of assimilatory organs which consumes a lot of photoassimilates for maintenance, gathering of K^+ ions in the shoot, and even influences distribution of mono and bivalent ions.
2. This economy is changed under saline conditions into an efficient state which characterizes with: partially closed stomata, counterbalanced nutrient absorption demands, shifted water status, gas exchange processes and osmotic stress increase to prevent injury caused by absorption of toxic ions. It is achieved by maintaining only the size of assimilatory organs required to sustain limited growth of the whole organism. Besides, shifting the general investment of dry matter for root build up, using the available pool of non-toxic ions (K^+, Ca^{2+}) for osmoregulation and strengthening the embedded in cell membranes protective barriers against unfavorable influx of toxic ions (Na^+, Cl^-) as well their further penetration. The timing of initial reactions is very important.

3. The screening for plant tolerance to salinity should be based on the following characteristics: growth pattern (using growth analysis), gas exchange, calculated water use efficiency, ion relationships and their accumulation in different plant organs. Then, there should be done the evaluation of selected physiological characters .

PLANTS STRESS AND YIELDING

In the context of plant breeding, from the point of view of plant physiology it is very important to discuss some items, which we think are invaluable to understand and establish our concepts of criteria selection.

Very important is the understanding of "yield fidelity", which is strictly related to the concept of sustainable agriculture. Looking for the stability of the yield means the ability to pay the cost of survival in the field. We should not look only for the high yielding plants but also the ones, which would pay less cost when harsher growth conditions are experienced. Plant breeders should be aware that plants growing under field conditions never experience the optimum (control) conditions. Usually, plants undergo moderate multi-stress (Starck 1997). Furthermore, we have to remember that the optimum for plants is not necessary to be similar to that of human beings. In most cases, plants shift all the physiological processes which can make their further existence possible what means that yield is not important in such a case (Kalaji and Nalborczyk 2000, Pietkiewicz 2000).

Yield stability mechanisms fall into four categories: genetic heterogeneity, yield component composition, stress tolerance and capacity to recover rapidly from stress. In the context of stress tolerance, it has often been found that ecological adaptation and agronomic objectives are different and can be mutually exclusive. However, if the yield is our interest, of plant tolerance should be estimated at all levels of plant organization from organelles to crop.

When plant is stressed, the results of acclimation, adaptation changes or damage will appear. This will be depended on duration of stress and its strength. It is very important to distinguish between what are the results or the reasons and to identify the "stress sequences cascade". Information about resistance can be easily received by screening of genetically diverted material (e.g. landraces and breeding lines) as a result of cooperation between physiologists and breeders (Flowers and Yeo 1995). They suggested that it would be performed as follow:

- Expose a range of genotypes to a specific stress and choose the ones that perform best as a crop under those conditions (plant physiologists).
- Beyond evaluation of existing genotypes, screening could be carried from within a composite cross-aimed at increasing the recombination between resistance and agronomic traits (plant breeders).

- Selection should be first for tolerance/resistance, then agronomic characters. This sequence is very important because our reliance on “agronomic-first” selection is strongly against potentially tolerant genotypes before they are fixed.

BREEDING METHODS AND PLANT PHYSIOLOGY

The earlier example of Prof. Nalborczyk’s team cooperation (Nalborczyk and Czembor 1990) is really good evidence as to how plant physiology is able to indicate and underline some unseen new features to be looked for by the plant breeders. The results of Prof.Wolski’s team works are one of the main selection bases of today used in the cooperation program between the Department of Plant Physiology – Warsaw Agriculture University and DANKO (well known Polish Breeding Center as donor of triticale to the whole world). The main goal of this cooperation is study on crop physiology of conventional and half-dwarfed winter triticale plants. Generally works dealing with plant breeding and traits selection should depend on: crop ability to turn solar energy into biomass production, canopy spatial structure (LAI), changes in Red/Far Red ratio, and chlorophyll fluorescence under various stresses. This will allow achieving better characterizing of modern plant physiological ideotypes (Donald 1968).

The work of Łoboda and co-workers (Łoboda *et al.* 2000) in order to evaluate maximum potential of dry matter yield for the leading brewing barley forms is noteworthy. Measure of parameters describing the rate of physiological processes involved in crop yielding (photosynthetic rate, dark respiration, LAI, PAR absorption, and many others) and considering them jointly allowed to characterize the “ideotype” of the crop production capacity of nearly 100 t of dry matter × ha^{-1}. Obviously such a form, the same as the Donald’s ideotype (Donald 1962, 1968) will never be get, because of the influence of some factors (fluctuation in PAR incoming during vegetation period, self-shedding of the leaves and other constraints) nevertheless it allowed to specify some important physiological traits affecting the yield.

We believe that plant physiology can play an important role in both conventional (Mendelian) plant breeding (pure line, mass selection, pedigree, bulk, back crossing etc.) and in the case of “genomic” revolution (tissue culture, protoplast fusion, and recombinant DNA and genetic engineering methods). Surely, “molecular” plant physiology will contribute to “molecular breeding” progress since it is also functioning already carefully at the cellular level (Ondrej 1997, Bohnert and Jensen 1996). Independently of which object “Plant” or “DNA” should undergo breeding processes, it also can help to understand the whole organism homeostasis (Yeo 1998). The use of the methods outlined above to check the physiological trait fixation allowed plant physiologists to take part in evaluation of performance of GMOs multiplied in the field.

Concluding the previously mentioned facts, concepts, and results, we would like to underline some remarks related to the cooperation of plant physiology and breeding:

- Plant physiologists are well prepared to meet the needs of development of plant breeding due to adequate methods and devices used for screening the proposed selection criteria.
- Plant geneticists, breeders, and physiologists may work in concerted action. This would enable them to better understand the physiological- biochemical processes and their interactions, which determine the tolerance and the produced yield.
- Gas exchange measurements, chlorophyll *a* fluorescence screening, classical growth estimation, and isotopic exposure can help to reveal the hidden yield potential of crop genotypes.
- The preliminary selection of plants should be individual for yield, quality, or stress tolerance since its combination is elusive and selection for one magnitude is still at the cost of the others. Furthermore, we should distinguish where the crop is for trade or for subsistence.

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REFERENCES

Akazawa T., Yanagisawa Y., Sasahara T. 1997. Concentrations of water-soluble nitrogen and amino acids as criteria for discriminating vegeTable-type and grain-type soybean cultivars. Breeding Sci. 47: 39-44.

Al Hakimi A., Monneveaux P., Nachit M. M., Braun H. J., Altay F., Kronstad W. E., Beniwal S. P. S., McNab A. 1997. Direct and indirect selection for drought tolerance in alien tetraploid wheat X durum wheat crosses. Wheat: prospects for global improvement. Proc. 5th International Wheat Conference, Ankara, Turkey, 10-14 June 1996. 353-360., Developments in Plant Breeding Volume 6.

Ambawatia G. T., Sahu T. R., Garg D. C., Dubey A. K. 1995. Synchronous tillering - a new selection score in rainfed wheat. Crop Res. Hisar 10: 18-20.

Annicchiarico P., Pecetti L. 1995. Morpho-physiological traits to complement grain yield selection under semi-arid Mediterranean conditions in each of the durum wheat types mediterraneum typicum and syriacum. Euphytica 86: 191-198.

Atanassov P., Zaharieva M., Merah O., Monneveux P. 1999. Genetic and environmental variation of useful traits in a collection of naked barley I. Yield components and water use efficiency. Cereal Res. Comm. 27: 315-322.

Bharati M. P., Neupane R. K., Erskine W., Saxena M. C.1993. Genetic resources and breeding of lentil in Nepal. Lentil in South Asia. Proc. Seminar on lentil in South Asia, 11-15 March 1991, New Delhi, India., 82-93.

Blum A. 1998. Improving wheat grain filling under stress by stem reserve mobilisation. Euphytica 100: 77-83.

Board J. E., Kang M. S., Harville B. G. 1997. Path analyses identify indirect selection criteria for yield of late planted soybean. Crop Sci. 37: 879-884.

Bohnert H. J., Jensen R. G. 1996. Metabolic engineering for increased salt tolerance- The next step. Aust. J. Plant Physiol. 23: 661-667.

Bokyeong K., Choung J. I., Shin H. T., Lee S. Y. 1995. Lodging resistance of direct seeded rice on flooded soil surface. RDA J. Agric. Sci., Rice, 37: 13-19.

Bonhomme R., Drouet J-L., Ameglio T. 1996. Introduction a la modelisation du fonctionnement physiologique d'un couvert. Actes de l'Ecole-Chercheurs INRA en bioclimatologie. Le Crosis, 3-7 Avril 1995. T.1. De la plante au couvert vegetal, 647-669.

Brestic M., Olsovska K., Kalaji M. H. 1996. Physiological criteria of barley tolerance to water stress and production ecostability. In Progress In Plant Sciences: From Plant Breeding To Growth Regulation. Ordog V., Szigeti J., Pulz O. Pannon eds. Univ. Agric. Sci.. Mosonmagyarovar – Hungary, 47-52.

Ceccarelli S., Cooper M., Hammer G. L. 1996. Positive interpretation of genotype by environment interactions in relation to sustainability and biodiversity. In Plant Adaptation and Crop Improvement. M Cooper and G. L. Hammer eds., 467-486.

Chilagane A. 1994. Farmers' criteria for evaluating rice varieties. Research and Training Newsletter Dar es Salaam. 9: 13-15.

Choluj D., Kalaji M. H. 1995: Some chosen parameters of gas exchange of tomato plant after chilling. In "Polish Plants Under Modification Processes" Conference material and symposium of The 50th Meeting of PTB, Kraków, Poland. Mirek Z. and Wojcicki J., eds., 53.

Choluj D., Kalaji M. H., Niemyska B. 1997. Analysis of the gas exchange components in chilled tomato plants. Photosynthetica 34: 583-589.

Choluj D., Karwowska R, Jasińska M., Haber G., Podlaski S., Pietkiewicz S., Kalaji H. 2001. Drought effects on dry matter portioning and growth of sugar beet. 37th Croatian Symposium on Agriculture –CSA, 19-23.

Chwedorzewska K., Nalborczyk E. 1994. Growth analysis of *Amaranthus cruentus*. IInd Int. Conf. Amaranth, Olomouc: 5.

Climate Stress Lab 1997. Carbon dioxide, the greenhouse effect, and agriculture. Internet Home Page: http://hydrolab.arsusda.gov/csl/info.html.

Czerednik A., Nalborczyk E. 2000. Radiation use efficiency (RUE) – the new coefficient of photosynthetic productivity of plants in stand. Bull. IHAR 215:13-22 (in Polish).

Czerwińska A., Pietkiewicz S., Kołpak R., Tataj A. 1996. Growth analysis of the potato plants in dependence on minitubers planting depth and kind of ridges.13th Trien. Conf. EAPR, 14-19.07.1996, Veldhoven, The Netherlands:182-183.

Dakheel A. J., Peacock J. M., Naji I., Acevedo E. 1994. Carbon isotope discrimination and water use efficiency in barley under field conditions. Efficiency of water use in crop systems, Reading, UK, 6-8 July. Aspects of Applied Biology. 38: 173-183.

Costa W. A. J. M. de, Shanmugathasan K. N. 2002. Physiology of yield determination of soybean (*Glycine max* L. Merr.) under different irrigation regimes in the sub-humid zone of Sri Lanka. Field Crops Res., 75: 23-35.

Dobrzanska M., Krysiak C. Kraszewska E. 1997 Transient and sTable transformation of wheat with DNA preparations delivered by a biolistic method. Acta Physiol. Plant. 19: 277-284.

Donald C.M. 1962. In search of yield. J. Aust. Agric. Res. 28:171-178.

Donald C.M. 1968.The breeding of crop ideotypes. Euphytica. 17:385-403.

Dzierżyńska A. 1990. Comparative study of net photosynthesis in foliar mutants of *Pisum sativum* L. Acta Physiol. Plant. 12:15-23.

Erskine W., Tufail M., Russell A., Tyagi M. C., Rahman M. M., Saxena M. C., Muehlbauer F. J., Kaiser W. J. 1994. Current and future strategies in breeding lentil for resistance to biotic and abiotic stresses. Expanding the production and use of cool season food legumes. Proc. IInd Int. Food Legume Res. Conf. on Pea, Lentil, Faba bean, Chickpea, and Grasspea, Cairo, Egypt, 12-16 April 1992. 559-571.

Evans, G. C. 1972. The quantitative analysis of plant growth. Blackwell Sci. Publ. Oxford, UK.

Fernandez G. C. J., Kuo C. G. 1993. Effective selection criteria for assessing plant stress tolerance. Adaptation of food crops to temperature and water stress: proceedings of an international symposium, Taiwan, 13-18 August 1992, 257-270.

Ferrara G. O., Mosaad M. G., Mahalakshmi V., Rajaram S., Braun H. J., Altay F., Kronstad W. E., Beniwal S. P. S., McNab A. 1997. Photoperiod and vernalization response of Mediterranean wheats, and implications for adaptation. Wheat: prospects for global improvement. Proc. 5th Int. Wheat Conf. Ankara, Turkey, 10-14 June 1996, Developments in Plant Breeding Vol. 6: 509-516.

Flowers T. J., Yeo A. R. 1995. Breeding for salinity resistance in crop plants: Where next? (Viewpoint). Aust. J. Plant Physiol. 22: 875-84.

Foolad M. R. 1997. Genetic basis of physiological traits related to salt tolerance in tomato, *Lycopersicon esculentum* Mill. Plant Breeding. 116: 53-58.

Gahoonia T. S., Nielsen N. E., Lyshede O. B. 1999. Phosphorus (P) acquisition of cereal cultivars in the field at three levels of P fertilization. Plant and Soil. 211: 269-281.

Gawrońska H. 1998. Biomass production and distribution under different growth conditions in potato. Fund. Rozwój SGGW. Warszawa. 95 pp (In Polish)

Gontarczyk M. 1996. Photosynthesis and transpiration of C4 plants under drought conditions. Plant Physiol. Biochem. Special Issue; 328-329

Govindjee. 1995. Sixty-three years since Kautsky: chlorophyll a fluorescence. Aust. J. PlantPhysiol. 22: 131 –160.

Goodchild A. V. 1997. Effects of rainfall and temperature on the feeding value of barley straw in a semi-arid Mediterranean environment. J. Agric. Sci. 129: 353-366.

Hunt R. 1990. Basic Growth Analysis. Unwin Hyman Ltd., London, UK.

Jackson P., McRae T., Hogarth M. 1995. Selection of sugarcane families across variable environments. I. Sources of variation and an optimal selection index. Field Crops Res. 43: 109-118.

Jafari S. J., Corke H., Qualset C. O. 1995. Field evaluation of salinity stress in Iranian hexaploid wheat landrace accessions. Gen. Res. Crop Evolution 42: 147-156.

Jamjod S., Rerkasem B., 1999. Genotypic variation in response of barley to boron deficiency. Plant and Soil. 215: 65-72.

Johnson R. C., Muehlbauer F. J., Simon C. J., 1995. Genetic variation in water use efficiency and its relation to photosynthesis and productivity in lentil germplasm. Crop Sci. 35: 457-463.

Kamali M. R. J., Boyd W. J. R 2000. Quantifying the growth and development of commercial barley cultivars over two contrasting growing seasons in Western Australia. Aust. J. Agric. Res. 51: 487-501.

Kalaji M. H. 1993. Salnity effects of NaCl on growthand gas exchange of barley (*Hordeum vulgare* L.) seedlings. Ph.D. Thesis. Warsaw Agricultural University, Faculty of Agriculture.

Kalaji M. H., Nalborczyk E. 1991. Gas exchange of barley seedlings growing under salinity stress. Photosynthetica 25 (2): 197-202.

Kalaji M. H., Nalborczyk E. 2000. Triticale, wheat or rye? Crop of the next millennium. 4th IC Ecophysiology of Plant Production Processes in Stress Conditions (Rackova Dolina, Slovakia 12-14 Sept.).

Kalaji M. H., Pietkiewicz S. 1993. Salinity effects on plant growth and other physiological rocesses. Acta Physiol. Plant.15: 89-124.

Kertikova D., Georgiev Z. 1995. Possibility of using some traits as criteria in selecting for resistance to intensive harvesting in lucerne. Rasteniev"dni Nauki 32:28-29.

Kharkwal M. C., Chaudhary H. B. 1997. Grain density as selection criterion in chickpea and wheat. Indian J. Gen. Plant Breeding. 57: 415-423.

Khattab A. M., El Sherbeeny M. H., Rabeia B. M., Hassan M. W., El Warraky M. K., Shalaby F. H. 1993. 531 and 195, new chickpea promising lines developed by Food Legumes Program, FCRI, ARC. Bull. Faculty Agricult. Univ. Cairo 44:827-841.

Kornatowska B., Pietkiewicz S. 1991. The photosynthesis, transpiration and growth in winter wheat during feeding of aphids.In: Aphids, their bionomy, harmfulness and natural enemies(Cichocka E. and Goszczyński W. eds).PAN:53-60 (in Polish).

Łoboda T., Pietkiewicz S., Czembor H.J., Wiewióra J. 2000. Determination of yield potential of selected spring brewer's varietuies. Bull. IHAR. 215, 141-152 (in Polish).

McPherson E. G., Peper J. P. 1998. Comparison of five methods for estimating Leaf Area Index of open-grown deciduous trees. J. Arboriculture 24:98-111.

Mosaad M. G., Ortiz F. G., Mahalakshmi V., 1995. Tiller development and contribution to yield under different moisture regimes in two Triticum species. J. Agron. Crop Sci. 174: 173-180.

Mosaad M. G., Ortiz F. G., Nachit M. M., Saunders D. A., Hettel G. P. 1994. Role of photoperiod and vernalization in the adaptation of wheat under heat and moisture stresses. Wheat in heat-stressed environments: irrigated, dry areas and rice-wheat farming systems. Proc. Int. Conf. Wad Medani, Sudan, 1-4 February, 1993 and Dinajpur, Bangladesh, 13-15 February 1993., 146-152.

Nachit M. M., Braun H. J., Altay F., Kronstad W. E., Beniwal S. P. S., McNab A. 1997. Network for integrated research to improve durum wheat productivity in the Mediterranean region. Wheat: prospects for global improvement. Proc. 5th Int. Wheat Conf. Ankara, Turkey, 10-14 June 1996, Developments in Plant Breeding. 6: 561-570.

Nalborczyk E. 1998. Professor Anatol Listowski's main ideas of plant agrophysiology and their influence on the biological progress in agriculture. Acta Physiol. Plant.20 (1, supplement):S-5-S-6.

Nalborczyk E., Czembor H.J. 1990. Small grain cereal and root crop system in central Europe. In: Field Crop Ecosystems. Elsevier Sci. Publs Ltd. London, England.

Nalborczyk E., Dzierżyńska A., Krajewski W. 1986. Contribution of various assimilatory organs to yield forming of *Fabaceae* and their changes in ontogeny. IFR AN SSSR, Puszczino: 49-61 (in Russian).
Nalborczyk E., Nalborczyk T., Wawrzonowska B. 1981. Models of photosynthetic activity in cereals. Photosynthesis and productivity. Balaban Int. Sci. Services, Philadelphia, 97-106.
Nalborczyk E., Sowa A. 2001. Physiology of Rye. In Rye: Production, Chemistry and Technology. II Ed. W. Bushuk. Amer ed. Assoc. Cereal Chemists, Inc. St. Paul, Minnesota, USA. Chapter 4:53-65.
Nichiporovich A. A. 1967. Aims of research on the photosynthesis of plants as a factor of productivity. In: Nichiporovich, A. A. ed. Photosynthesis of Productive Systems. Israel program for sci. Translations. Jerusalem. 3-36.
Nichiporovich A. A, Strogonova L.E., Chmora S.N., Vlasova M. P. 1961. Photosynthetic Activity of Plants in Crops- Izdat. Akad. Nauk. SSSR, Moskva. (in Russian)
Niemyska B. 1986. Transportation and accumulation of photoassimilates in lant. Wiad. Bot. 30: 163-176. (in Polish)
Okamoto M. 1994. Studies on effect of chemical components on stickiness of cooked rice and their selection methods for breeding. Bull. Chugoku Nat. Agricult. Exp. Station.14: 1-68.
Olszewski T., Skonecka M., Kołpak R., Pietkiewicz S., Drosio A. 1999.Strategies of dry matter accumulation by potato plants grown from minitubers.14th Trienn. EAPR Conf. Sorrento,2-7.05.1999, Italy:716-717.
Ondrej M. 1997. Effect of transgenic plants on the natural environment. Zahradnictvi 24: 145-152.
Ortiz F. G., Rajaram S., Mosaad M. G., Saunders D. A., Hettel G. P. 1994. Breeding strategies for improving wheat in heat-stressed environments. Wheat in heat-stressed environments: irrigated, dry areas and rice-wheat farming systems. Proc. Int. Conf. Wad Medani, Sudan, 1-4 February, 1993 and Dinajpur, Bangladesh 13-15 February 1993., 24-32.
Pala J., Pietkiewicz S. 2002. Theory and Practice of Yield Prediction in Crops. In: Crop Physiology (R.J. Górecki and S. Grzesiuk eds). UWM Olsztyn, 523-570. (in Polish)
Pecetti L., Annicchiarico P. 1998. Agronomic value and plant type of Italian durum wheat cultivars from different eras of breeding. Euphytica 99: 9-15.
Pecetti L., Annicchiarico P., 1995. Efficacy of a visual assessment for drought tolerance in durum wheat improvement under dryland conditions. Cereal Res. Comm. 23:95-101.
Petcu E., Terbea M., 1995. Physiological criteria for estimating winter hardiness in winter wheat. Analele Institutului de Cercetari pentru Cereale si Plante Tehnice, Fundulea 62: 325-332.
Piepho H. P. 1995. Remark on a desirability index for selecting genotypes. Crop Sci. 35:1498-1500.
Pietkiewicz S. 1984. The growth of the potato plant at sufficient and insufficient water supply. 9th Trien. Conf. EAPR, 1-6.07. 1984 Interlaken, Switzerland:36-37.
Pietkiewicz S. 1985. Experimental and calculation techniques in growth analysis of plants. Wiad. Bot. 29: 111-126. (in Polish)
Pietkiewicz S. 1990. An impact of the density on the growth and photosynthetic rate of the potato plant.11th Trienn. EAPR Conf. 21-26.07, 1990, Edinburgh, England. 224-225.
Pietkiewicz S. 2000. Dry matter accumulation in potato Solanum tuberosum L. in the view of growth analysis use. SGGW.140 pp.
Pietkiewicz S., Wyszyński Z., Łoboda T., Gozdowski D. 2002. Time course of growth analytical indices of brewer's barley grown under different nitrogen fertilization. Annals WAU.-SGGW, Agriculture 43. 25-32.
Preciado Ortiz R., Weiss A., Johnson B. E. 1995. Developing prototype maize (*Zea mays* L.) hybrids by crop modeling for specific rainfed regions. Maydica 40:191-197.
Pyl' nev V. V. 1995. Adaptive potential of winter wheat in the course of breeding for increased grain yield in the steppe zone. Sel'skokhoz. Biol. 1: 41-50.
Radford, P. J. 1967. Growth analysis formulae-their use and abuse. Crop Sci. 7:171-175.
Ratinam M., Abd El Moneim A. M., Saxena M. C. 1994. Assessment of sensitivity to frost in ochrus chickling (*Lathyrus ochrus* L. D.C.) by chlorophyll fluorescence analyses. J. Agron. Crop Sci. 173: 338-344.
Ratinam M., Abd El Moneim A. M., Saxena M. C. 1994. Variations in sugar content and dry matter distribution in roots and their associations with frost tolerance in certain forage legume species. J. of Agron. Crop Sci. 173: 345-353.
Reynolds M. P., Calderini D. F., Condon A. G., Rajaram S. 2001. Physiological basis of yield gains in wheat associated with the LR19 translocation from *Agropyron elongatum*. Euphytica. 119:139-144.
Romer W., Schenk H., Daetz F., Schmidt L., Romer A. 1995. Genotypic differences in phosphate extraction and phosphate utilization in *Zea mays* L. and *Hordeum distichon* L. Kuhn Archiv 89:164-177.

Russi L., Torricelli R., Negri V. 1997. Characterization of annual clover landraces from central Italy. Current situation and future prospects for forage cultivation in grasslands and pastures, Lodi, Italy, 22-24 May 1996. Rivista di Agronomia., 31:237-240.

Salter R., Miller Garvin J. E., Viands D. R. 1994. Breeding for resistance to alfalfa root rot caused by *Fusarium* species. Crop Sci. 34:1213-1217.

Sayre K. D., Acevedo E., Austin R. B. 1995. Carbon isotope discrimination and grain yield for three bread wheat germplasm groups grown at different levels of water stress. Field Crops Res. 41: 45-54.

Schreiber, U., Schliwa, W., Bilger U. 1986. Continuous recording of photochemical and non-photochemical chlorophyll fluorescence quenching with a new type of modulation fluorimeter. Photosynthesis Res., 10, 51- 62.

Singh D., Sharma P. C., Kumar R. 1997. Correlation and path coefficient analysis in chickpea. Crop Res. Hisar 13:625 629.

Sowinski P. 2001. Assimilate transportation and tolerance to chilling in maize. IHAR. Monographs and Treatises, 9 (in Polish).

Srinivasan A., Takeda H., Senboku T., Srinivasan A. 1996. Heat tolerance in food legumes as evaluated by cell membrane thermostability and chlorophyll fluorescence techniques. Euphytica 88: 35-45.

Starck Z. 1995. An interaction between photosynthesis, assimilates distribution and plant tolerance to unfavorable growth conditions. Post. Nauk Roln. 3/95: 19-35 (in Polish).

Starck Z. 1996. The mechanisms of plants responses to stresses on the basis of experiments conducted on different level of organization: facts and artifacts. Polish Sci. Acad. Publ. Ecophysiological Aspects of Plant Reactios to Abiotoc Stress Factors. Grzesiak S. and Miszalski Z. eds. 85-96 (in Polish).

Starck Z. 1997. Response of plants to multiply stresses in aspect of source-sink relations. Proc. Int. Sci. Meeting Ecophysiological Aspects of Plant Responses to stress factors. Krakow 12-14 June 1997 (in Polish).

Starck Z. 2003. Transportation and Distribution of Nutrients in Plants. SGGW. 359 pp (In Polish)

Starck Z., Choluj D., Kalaji M. H. 1994. Photosynthesis and biomass allocation as response to chilling in tomato plants. In Crop Adaptation To Cool Climates, Dorfling K., Brettschneider B., Tantau H., and Pithan K eds. European Commission - COST 814, Pages: 125-132.

Starck Z., Niemyska B. 1998. Plant physiology: yesterday, today and tomorrow. Wiad. Bot. 42: 27-36 (in Polish).

Strasser R. J., Srivastava A., Tsimilli-Michael M. 2000. The fluorescence transient as a tool to characterize and screen photosynthetic samples. Printed in Probing Photosynthesis. Yunus M., Pathre U. and Mohanty P. eds. Taylor & Francis Group, Chapter 25: 445-484.

Voltas J., Romagosa I., Lafarga A., Armesto A. P., Sombrero A., Araus J. L. 1999. Genotype by environment interaction for grain yield and carbon isotope discrimination of barley in Mediterranean Spain. Aust. J. Agric. Res. 50:1263-1271.

Warren-Wilson J. 1986.Control of crop processes. In:Crop Processes in Controlled Environments (eds. R.A. Rees, K.E.Cockshul,D.W.Hand, R.C. Hurd).Academic Press, London.

Watanabe N., Naruse J., Austin R. B., Morgan C. L. 1995. Variation in thylakoid proteins and photosynthesis in Syrian landraces of barley. Euphytica 82:213-220.

Watson D. J. 1952. The physiological basis of variation in yield. Adv. Agron. 4:101-145.

Watson D. J. 1947. Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. Ann. Bot. NS. 11:41-76

Weems Y. S., Bridges P. J., LeaMaster B. R., Vincent D. L., Weems C. W., Sultana N., Ikeda T., Itoh R. 1999. Effect of NaCl salinity on photosynthesis and dry matter accumulation in developing rice grains. Environ. Exp. Bot. Vol. 42:211-220.

Wilhelm W., Ruwe K., Schlumer R. R. 2000. Comparison of three Leaf Area Index meters in corn canopy. Crop Sci. 40: 1179-1183.

Wisniewski K., Zagdanska B. 1998. Field methods of drought resistance evaluation of spring wheat and triticale. Bull. IHAR. 208:67-72.

Wu P., Tao Q. N. 1995. Selection index for screening physiological nitrogen use efficiency in rice. Chinese J. Rice Sci. 9:179-184.

Worku T., 1995. Water retention capability as a selection criteria for drought resistance in wheat. J. Plant Nutrition 18:2105-2109.

Wyszyński Z. Gozdowski D., Łoboda T., Pietkiewicz S., Wołejko E. 2002. Reaction of spring brewer's barley grown under different nitrogen fertilization in two vegetation seasons differing in precipitation. Zesz. Probl. PNR.481:349-355 (In Polish).

Yagbasanlar T., Ozkan H., Genc I. 1995. Relationships of growth periods, harvest index and grain yield in common wheat under Mediterranean climatic conditions. Cereal Res. Comm. 23: 59-62.

Yau S. K., 1997. Efficiency of alpha-lattice designs in international variety yield trials of barley and wheat. J. Agric. Sci. 128: 5-9.

Yeo A. 1998. Molecular biology of salt tolerance in context of whole-plant physiology. J. Exp. Bot. 49: 915-929.

Zawadzki J., Roszak W., Łęgowiak Z., Pietkiewicz S. 2000: Effect of triapenthenol (Baronet) and herbicides on growth, weed control and yield of winter oil seed rape. Part. I. Influence of triapenthenol (Baronet) on growth and yield of winter oil rape.Roczn. Nauk Roln. Ser. A. t. 114, 3-4: 53-60 (in Polish).