SESSION 1. BIOLOGICAL MECHANISMS OF WATER-SAVING AGRICULTURE

NO:1–001

Improving plant water use efficiency by physiological measures

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Approximately 70% of world-wide water use is committed to agriculture. Despite this, water shortages limit food production in many regions and if crop production is to be sustained and even increased in a changing environment then water must be used more efficiently. This is even the case in the UK where irrigation is required in most regions in most years to ensure reasonable crop yields of the required quality. The predicted impact of climate change on weather patterns will increase this reliance on irrigation and is focussing attention on irrigation techniques that allow more efficient use of water. Increasingly, higher value horticultural crops are grown in the UK under protected cropping. This increases yield quality but also provides opportunities both to save water and nutrient resources and to use modified supplies of these variables as regulators of growth and development. This type of 'natural' growth regulation can replace the widespread use of growth regulating chemicals, an expensive and undesirable component of crop production. Deficit- or nutrient-induced growth regulation can also reduce labour costs for the industry.

Novel deficit irrigation techniques allow enhanced water use efficiency in crop production by exploiting the plant's long-distance signalling mechanisms that modify plant growth, development and functioning as the soil dries. The novel science behind these mechanisms has been revealed in the last 15 years or so. This paper will discuss the opportunities for exploitation of increased understanding of plant drought stress physiology and show how this approach has already delivered substantial water savings into agricultural systems around the world and has also resulted in significant added value in terms of increased yield quality, labour saving and crop scheduling.

Key words: deficit irrigation, water use efficiency, plant physiology, long distance signalling

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NO:1–002

Biologic water-saving approaches and future perspectives

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Increasing the efficiency of water use by crops continues to escalate as a topic of concern because drought is a restrictive environmental factor for crop productivity worldwide. Greater yield per unit rainfall is one of the most important challenges in water-limited agriculture. Besides water-saving by irrigation engineering and conservation tillage, a good understanding of factors limiting and/or regulating yield now provides us with an opportunity to identify and then precisely select for physiological and breeding traits that increase the efficiency of water use and drought tolerance under water-limited conditions, biologic water-saving is one means of achieving this goal. A definition of biological water-saving measures is proposed which embraces improvements in water-use efficiency (WUE) and drought tolerance, by genetic improvement and physiological regulation. The preponderance of biological water-saving measures is discussed and strategies identified for working within natural resource constraints. The technology and future perspectives of biological water-saving could provide not only new water-saving techniques but also a scientific base for application of water-saving irrigation and conservation tillage.

Key words: biologic water-saving, water-use efficiency, drought tolerance, physiological regulation, water-saving breeding.

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NO:1–003

Carbon assimilation and water deficits: regulations and manipulation to optimize plant production

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Limitation by water deficits of plants carbon assimilation is becoming increasingly important in many areas of the globe. It may be caused either by a seasonal decline in soil water availability, developing in the long term, or by the increased evaporative demand of the atmosphere, occurring mostly on a daily basis and affecting even well-watered plants. In crop plants, the compromise between carbon uptake and water loss that has naturally evolved in nature to allow survival has been manipulated through plant breeding to optimize production. Today we are concerned with improving crops for drought-prone areas, by increasing the water-use efficiency and the drought-resistance traits. The various types of constraints to photosynthesis caused by water deficits, acting in isolation or in conjunction with other stresses, will be reviewed. In particular we will discuss the timing and relative importance of the limitations imposed by stomata, mesophyll diffusion, photosynthetic biochemistry and photochemistry on carbon assimilation. The feedback effects of decreased sink activity caused by water deficits on photosynthesis will also be raised. Novel management techniques for an improved plant trade-off between water used and carbon assimilated are now being exploited, and proved to have a positive impact on the quality of crop products. We will also discuss the promising advances in molecular biology that may allow engineering for a higher capacity for photosynthesis under stress conditions.

Key words: water deficits, photosynthesis, crops, genetic engineering, WUE.

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NO:1–004
Puddling depth and intensity effects in rice–wheat systems on water use and crop performance in a sandy loam soil

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A 3 year field experiment was conducted on a sandy loam soil to study the effect of puddling intensity and puddling depth on irrigation water use in rice (*Oryza sativa*) and the performance of rice and wheat (*Triticum aestivum*) crops. The treatments in main plots included: (i) unpuddled plots; (ii) and (iii) medium puddling–2 passes of a tractor-drawn cultivator followed by levelling with a wooden plank; and (iv) and (v) intensive puddling–4 passes of a tractor-drawn cultivator followed by levelling with a wooden plank, each at shallow (5–6 cm) and normal (10–12 cm) depths. Percolation losses decreased by 14–16% with increase in puddling intensity from medium to high, whereas irrigation water applied decreased by 10–25%. Intensive puddling intensity resulted in higher root mass density in 0–5 cm and 5–10 cm soil layers. Root mass density in shallow-puddled plots was 17% more in the 0–5 cm soil layer than in normal-puddled plots. Puddling treatments had no effect on total dry matter and grain yield of rice during all 3 years of study. Root mass density of wheat in the 0–15 cm soil layer increased from 301.9 μg cm^{-3} in 1994–95 to 318.7 μg cm^{-3} in 1996–97, whereas in the 15–30 cm soil layer it decreased from 85.1 to 47.1 μg cm^{-3}. High puddling increased the canopy temperature of wheat by 0.5–1.7 °C and decreased xylem water potential by 4–7%. Total dry matter and grain yield of wheat was 19 and 8% more, respectively, in shallow-puddled plots than in normal-puddled plots during 1996–97.

Key words: puddling intensity, depth, water use, rice–wheat cropping system, root mass density.

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NO:1–005
Effect of growing media and partial root zone drying on dry matter partitioning, yield, carbohydrate accumulation and water-use efficiency of tomatoes grown in protected environment

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A study at University Putra Malaysia examined the effect of two growing media, in combination with partial root zone drying (PRD), on dry matter partitioning, yield, carbohydrate accumulation and water-use efficiency of tomatoes grown in a protected environment. The media included mixed coconut coir dust and peat, in equal proportions, and standard greenhouse soil, amended with rice straw compost. The greenhouse soil contained top-soil, sand and peat in the proportions 2:1:2. A completely randomized two-by-two factorial design was used with three replicates. The two water factors included a well- watered control and a partially irrigated treatment with half tomato roots alternately receiving 50% of the control amount of water. Results showed that PRD significantly reduced leaf expansion, plant leaf area and stomatal conductance for both media, but severely so with standard greenhouse soil. At the same time, proline and sugars were dramatically increased in the leaf, especially with standard greenhouse soil. Dry matter partitioning showed a significant reduction in total dry matter, plant dry shoot weight and shoot to root ratio with PRD, but a significant increase in root to shoot ratio with no significant difference in plant dry root weight. Results suggested that PRD application could be effective with soilless media where high total carbon is provided.

Key words: partial rootzone drying, water-use efficiency, stomatal conductance, dry matter.

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NO:1–006
Modeling the root sink term under variable water stress

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The influence of water shortage on the water extraction pattern has been quantified for periods of water stress. A macroscopic water extraction model combined with the Richards equation was inserted in the numerical simulation model HYSWASOR, to test four different water stress functions. Input parameters were obtained from the literature and derived from extensive measurements under well-controlled conditions in the greenhouse with alfalfa. The results indicated that a linear reduction function could not fit the experimental data range satisfactorily. Most of the existing non-linear reduction functions could only fit a part of the data range, while best agreement was obtained with the non-linear two-threshold reduction function. The parameter values obtained by calibration differed only slightly from those of the experiments. The heterogeneity of matric potential over the root zone did not play a significant role in water uptake. The roots appeared to take up water from relatively wetter parts of the root zone to compensate for water deficit in drier parts. While the simulated transpiration agrees closely with the experimental data, the main reason for the discrepancy between the simulated and actual water contents appears to be water uptake during darkness over the stress period.

Key words: water stress, water extraction model, simulation.

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NO:1–007
Water-use efficiency of oil seed rape (*Brassica campestris*) under even or patchy water supply

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Investigations were conducted into optimal water supply regimes, which encourage full use of the water provided. These were undertaken in a greenhouse experiment at the University of Nijmegen. The aim was to improve understanding of how root foraging characteristics respond to different water application patterns. Measurements were made for oil seed rape (*Brassica campestris*), which is already widely cultivated in China.

Key words: water-use efficiency, water supply regime, oil seed rape (*Brassica campestris*).

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NO:1–008
Water uptake by plant roots

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A sufficient balance in the supply and loss of water is an important prerequisite for the occurrence, growth and productivity of plants. Often, the water balance is the crucial factor which limits the yield of crops. For a higher plant, the water balance is given by the difference between water uptake across the root and water losses by transpiration in the shoot which are unavoidable during the assimilation of carbon dioxide. Depending on the meteorological conditions, the amounts of water flowing through a plant, a canopy, or an ecosystem can be substantial. Much is known about the mechanisms used by plants to minimise water losses across stomata. For technical reasons, much less is known about the input side of the balance, i.e. about the regulation of water uptake from the soil. In the talk, methods and results are presented which have been used to study water uptake in great detail (cell, tissue, organ, and whole plant levels). Experimental findings result in models of the water and solute transport across roots which incorporate molecular mechanisms such as the gating of water channels or aquaporins. Depending on conditions, different pathways within plant roots may be switched on or off. This results in a variable capabality of roots to take up and to conduct water. The phenomenon has been interpreted in terms of a 'composite transport model of the root'. In terms of the model, regulation of water uptake is performed at different levels. It involves changes in root anatomy as well as physical and molecular adjustments. The flexibility of roots will be exemplified using recent results on corn and rice. The role of aquaporins in root water will be stressed using results obtained from isolated cells. Aquaporins form the molecular basis of an understanding of plant water which is of some importance when considering water savings in agriculture.

Key words: aquaporins, apoplast, cell-to-cell transport, composite transport, corn, exodermis, gating, hydraulic conductivity, rice, root, water transport.

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NO:1–009
Water deficits and yield in maize

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After reproduction is initiated in plants, subsequent reproductive development is sometimes interrupted by water deficits that decrease the final yield. We are working with maize (*Zea mays* L.) at low water potentials (low Ψ_w) to identify the factors that cause this kind of reproductive failure, especially losses in kernel number. In order to identify possible regulatory steps, we conducted field experiments to evaluate dry matter partitioning, the water status of reproductive tissues and water use. These indicated that kernel size was related to amounts of photosynthetic reserves at the time of low Ψ_w, but kernel number was controlled by additional factors occurring around the time of pollination. In the laboratory, low Ψ_w imposed for 5 days around pollination allowed embryos to form, but development ceased and the embryos aborted, causing kernel number to decrease markedly. We investigated starch, metabolite pools, enzyme activities and mRNA abundance in the developing ovaries while we manipulated the sugar stream by feeding sucrose to the stems. The results indicated that young embryos cease growing when the sugar stream is interrupted sufficiently to deplete starch during early ovary development. Maintaining the sugar stream partially overcomes this interruption, but invertase regulates ovary starch synthesis and forms a partial carbon block, which so far has prevented full recovery. Enzymes of senescence may then cause irreversible developmental arrest that results in kernel abortion and thus controls kernel number. Several of the genes coding for the sugar processing and senescence enzymes appear to be sugar responsive.

Key words: water potential, photosynthesis, kernel abortion, sugar-responsive genes, ovary starch, *Zea mays* L.

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NO:1–010
Improving water-use efficiency based on comparative sensitivity of soybean stomatal conductance and photosynthesis to soil drying

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The sensitivity of stomatal conductance and photosynthesis to stress was examined for soybean (*Glycine max* L. Merr.), during progressive soil drying, to suggest improvements to water-use efficiency. Soybeans were grown in pots in a climate-controlled greenhouse. Stomatal conductance (g_s), photosynthesis (A_{max}), photosynthetic water-use efficiency ($WUE_{Amax/gs}$), root water potential (φ_r), xylem sap [ABA] ($[ABA]_{xylem}$) and leaf turgor (φ_{pl}) were determined in well-watered and droughted plants. Measures of these biophysical parameters for droughted plants were expressed relative to those of the fully watered controls. As soil dried, relative g_s, relative A_{max} and relative φ_{pl} were about 1.0 until the fraction of transpirable soil water (FTSW) decreased to 0.64 ± 0.04, 0.51 ± 0.03 and 0.25 ± 0.03, respectively. Relative $[ABA]_{xylem}$ started to increase at FTSW = 0.65 and increased linearly with decreasing φ_r. Relative g_s decreased linearly from 1.0 to about 0.30 with increasing relative $[ABA]_{xylem}$. For drier conditions, it decreased further to about 0.10 and was linearly correlated with decreasing relative φ_{pl}. The relationship between relative g_s and relative A_{max} was well represented by a logarithmic function ($r^2 = 0.98$). Relative $WUE_{Amax/gs}$ was around 1.0 for FTSW > 0.60–0.65, then increased exponentially and reached a peak at FTSW = 0.25–0.30. As FTSW approached zero, $WUE_{Amax/gs}$ declined linearly to <1.0. These results indicate that at mild soil water deficits, g_s was controlled primarily by root-originated ABA and φ_{pl} significantly affected g_s only at severe soil water deficits. As a result of greater maintenance of A_{max} than g_s during soil drying, $WUE_{Amax/gs}$ was improved in a range of soil water deficits (FTSW from 0.64 to 0.10).

Key words: soybean, soil water deficits, stomatal conductance, photosynthesis, water-use efficiency.

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NO:1–011
Sunflower response to soil water and salt stress in Hetao area, China

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The relative effects of simultaneous water and salt stress were determined for growth of sunflowers. Sunflowers (American G101) were grown at Shahaoqu experimental station in Inner Mongolia Hetao Irrigation District, China. A field experiment was combined with the pot experiments during the seedling period. The height of the plant, area of the leaves, leaf water potential, dry matter accumulation and net photosynthetic rate were measured regularly. The effects of water stress, salt stress and water–salt stress on crop growth, physiological processes, yield formation and crop water-use efficiency (WUE) were studied.

Key words: saline soil, water–salt stress, water-saving irrigation, sunflower.

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NO:1–012
Leaf gas exchange in *Coffea canephora* clones in response to water deficit and rate of recovery after drought

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Twelve-month-old seedlings of Robusta coffee (*Coffea canephora*) were subjected to soil drying by withholding water under a rain-shelter in West Malaysia for 3 weeks, to screen varieties for drought tolerance. The six clones used were IC-2, IC-3, IC-4, IC-6, IC-8 and R-4. The plants were then re-watered and the rate of recovery was measured. Leaf water potential, stomatal conductance and rate of net photosynthesis declined significantly for all clones, as the period of soil drying/drought was prolonged. A decrease in these parameters was more obvious and greater after a week, compared with the conditions during the early stages of treatment. On re-watering, the difference between the clones was significant for leaf fall and rate of recovery from drought. The rate of leaf fall was higher for the IC-2, IC-4, IC-8 and R-4 clones, which had exhibited a lower rate of recovery after re-watering. On the other hand, varieties IC-3 and IC-6 had lower rates of leaf fall but showed higher rates of recovery. These observations suggest that it is possible to detect the level of drought tolerance in Robusta coffee varieties, based on such growth and physiological parameters.

Key words: Robusta coffee (*C. canephora*), drought tolerance, stomatal conductance.

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NO:1–013
Water-saving and high-yielding irrigation techniques for paddy rice

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Techniques for irrigation water saving are suggested which avoid any sacrifice of rice grain yield. Data were collected from paddy fields at 10 sites in Southeast China over a period of 8 years. Limiting values of soil water potential are proposed as irrigation indices for water-saving and high yield. These values are related to specific growth stages, namely –5 kPa to –10 kPa from recovery to critical leaf age of productive tillering, –20 kPa to –30 kPa from critical leaf age of productive tillering to secondary branch-differentiating stage, –10 kPa to –15 kPa from secondary branch-differentiating stage to 20 days after heading, and –15 kPa to –20 kPa from 21 to 45 days after heading. Irrigation is recommended as soon as critical soil water potential is reached. The upper limit of each index applies to freely drained or sandy soil and to semi-dwarf japonica cultivars, while the lower limit relates to clay or soil with a high groundwater table and to hybrid rice. Water-saving techniques were also established for seed production, field preparation before transplanting and crop management. The techniques were demonstrated and applied in six provinces of Southeast China. Compared with conventional drainage in mid-season and flooding at other times, the water-saving irrigation technique reduced water needs by 21–34% and increased rice grain yield by 7–13%.

Key words: rice (*Oryza sativa* L), water-saving irrigation, indices, soil water potential, high yielding.

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NO:1–014
Improving water-use efficiency of field grown soybean (*Glycine max* L. cv. Bromo) by partial zone irrigation

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Related biomass production and water-use efficiency (WUE) effects were investigated during partial irrigation of the root system of field-grown soybean, cv. Bromo. The experiment was designed as a randomized complete block design with four replications and a 4 m × 3 m plot size. Partial irrigation was compared with full irrigation over a period of 14 days from the late vegetative until the early flowering growth stage. Partial irrigation of the root system (PIRS) was obtained by irrigation of alternate furrows between rows of plants. In fully irrigated plots, the whole root system was kept close to field capacity. The results showed that the PIRS treatment largely maintained biomass production and relative leaf water content at the level of the fully irrigated treatment. However, water use was reduced by about 50% in the PIRS treatment, creating a significant increase in WUE. Partial irrigation of the root system appeared to be an effective and water-saving method in the field-grown soybean, in water-limited areas and under dry land conditions.

Key words: irrigation, soil drying, soybean, water content, water-use efficiency.

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NO:1–015
Irrigation scheduling: the advantages and pitfalls of plant-based methods

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This paper reviews the various methods available for irrigation scheduling, contrasting traditional water-balance and soil moisture-based approaches with those based on sensing of the plant response to water deficits. The main plant-based methods for irrigation scheduling, including those based on dendrometry, fruit gauges and other tissue water content sensors, those based on growth measurement and especially those such as infrared thermometry and thermography that depend on fluctuations in stomatal conductance, will be outlined, and recent advances highlighted. In addition to these more conventional approaches, the potential of satellite and airborne remote-sensing techniques for irrigation management will be discussed. The relative suitability of different approaches for specific crop and climatic situations will be discussed, with the aim of indicating the strengths and weaknesses of different approaches, and highlighting their suitability over different spatial and temporal scales. The potential of soil- and plant-based systems for automated irrigation control using various scheduling techniques will be evaluated and recommendations made.

Key words: dendrometry, infrared thermometry, irrigation control, plant stress, soil moisture balance, stomatal conductance, thermography.

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NO:1–016
A review on controlled alternate partial rootzone irrigation: its physiological consequences and impact on water-use efficiency

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There are two thoughts as a theoretical basis for using partial root zone irrigation to increase water-use efficiency. First, fully irrigated plants usually have wide-open stomata and a small narrowing of the opening may substantially reduce water loss with little effect on photosynthesis. Secondly, plants can respond to soil drying, even though only in part of their root system, by regulating stomatal opening. However, the saving of water may not be fully achieved under field conditions because stomatal control is only part of transpirational resistance. Stomatal opening may control transpiration of densely populated field crops, such as wheat and maize, less well than for fruit trees, which are established more sparsely. Also, it is not known for how long stomata remain 'partially' closed when a prolonged 'partial' soil drying is applied. More work is needed to investigate physiological consequences and plant water-use efficiency when this practice is applied to field crops and fruit trees. Our recent results have shown that, at least with field crops, substantial amounts of water can be saved with rather less than the expected reduction in grain yield.

Key words: partial root zone irrigation (PRI), water-use efficiency (WUE), soil drying, stomata, abscisic acid (ABA).

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NO:1–017
Genetic and agronomic options for increased crop water productivity in semi-arid environments

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Water scarcity and drought are the major factors limiting global crop production in arid and semi-arid zones. Both genetic and agronomic management strategies are required to tackle impacts of water scarcity in agriculture, with focus on maximum extraction of available soil moisture and its most efficient use in crop establishment, maximum crop growth and for increasing seed yield. Breeding and selection of drought-tolerant genotypes offer the best long-term solution to this constraint. A good physiological understanding of factors regulating crop growth and water use opens the possibility to identify physiological and morphological traits that increase the efficiency of water use and yield under rain-fed conditions. The incorporation and pyramiding of these traits into breeders' populations, using biotechnology tools, should also broaden their genetic base and lead to efficient selection methods.

Three major parameters have been generally considered to describe crop water-use efficiency: transpiration (T), transpiration efficiency (TE) and harvest index (HI), which are all closely related to crop yield. Dry-down experiments were recently carried out under a controlled environment for the physiological analysis of (TE), its genotypic variability and its relationship with stomatal regulation under water deficits in pearl millet, chickpea and groundnut. The data confirmed the genotypic variation observed previously in the field for total amount of water transpired, and TE. Importantly, the soil moisture threshold at which transpiration starts falling down during soil drying also showed substantial genetic variability, which was negatively correlated to TE. In addition, TE was also correlated with specific leaf area (SLA), nodulation and nitrogen status in groundnut. Work is currently in progress for the development of genetic linkage maps, which will facilitate the characterization of quantitative trait loci (QTL) and offer practical means for precisely manipulating the underlying traits for drought tolerance and crop water productivity in breeding programs.

Partial root zone drying (PRD) is a new irrigation technique in which half of a plant root system is exposed to drying soil, whereas the other half is kept in wet soil. Field and greenhouse experiments were recently conducted on several crop species to compare the effects of PRD with those of regulated deficit irrigation (RDI) on plant water relationships and crop yield. It is concluded that the PRD irrigation technique may reveal crops suitable for horticulture under water scarcity scenarios. However, more experimental testing is required before recommending its application on a wider scale.

The recent progress made in deciphering the complexity of drought and water use problems at crop level will be reviewed and future perspectives for the improvement of drought adaptation and crop water productivity in semi-arid areas will be discussed.

Key words: crop water productivity, partial rootzone drying, genetic and agronomic, semi-arid areas.

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NO:1–018
Remotely-sensed canopy temperatures used for irrigation timing linked to crop water stress index (CWSI)

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Measurements of canopy temperature by remote sensing have been used to determine values of the crop water stress index (CWSI) at Keszthely, Hungary (46°46'N, 17°14'E, altitude 116 m above msl) over the past decade. Ways of incorporating related field trial data were investigated for the water regimes of lysimeters, non-irrigated controls and irrigated treatments. Field study work and collection of meteorological data were conducted at the same place. Both leaf area index (LAI) and yield were measured. Effects of fertilization level and tassel removal were examined to determine their influence on the variability of canopy temperature and CWSI determinations. The amount of applied nitrogen seemed to be a basic determinant of canopy temperature. Tassel removal only caused changes in canopy temperature during dry and warm growing seasons. In humid seasons, removal of tassels had no significant influence on either canopy temperature or CWSI.

Key words: CWSI, maize, canopy temperatures.

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NO:1–019
Effects of deficit irrigation on yield, yield components and water-use efficiency of winter wheat

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Winter wheat is the main irrigated crop in the North China Plain. High demand and limited water sources result in deficit irrigation. The influence of the extent of deficit irrigation on yield and yield components of wheat was examined for different growing stages. Pot experiments showed that medium water deficits during crop revival and small water deficits during the grain-filling stage improved grain production. From jointing to anthesis, water deficits reduced grain production, but slightly improved seed weight. Medium to serious water deficit during jointing and booting significantly reduced spike numbers and seed numbers per spike. Three years of field experiments also showed that control of irrigation during crop revival and the late grain-filling stages not only improved grain production but also water-use efficiency. For the three seasons, irrigation twice, at jointing and at booting to anthesis, produced the maximum grain production in comparison with other arrangements. Jointing, booting and grain filling were the best time for irrigation, when applying water three times. Reducing the normal number of four irrigations to either three or even two is an option for reducing irrigation water use in the region. Irrigation scheduling should improve water-use efficiency and grain production of winter wheat.

Key words: deficit irrigation, grain yield, water-use efficiency, winter wheat.

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NO:1–020
Nutrient dynamics under drip irrigation

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Various doses of water-soluble fertilizers were applied through a drip system, for comparison with ordinary fertilizer application combined with a conventional irrigation method. For fertigation treatments of broccoli, it was observed that the ammonium form of nitrogen was dominant in the upper soil layers and almost the entire amount of applied nitrogen remained confined to the root zone. For irrigation by check basin, the nitrate form of nitrogen dominated the root zone concentrations and a significant amount was leached beyond the root zone. Some leaching losses were also observed when fertilizer was applied to soil, with accompanying watering by drip. In a second experiment with radish, it was observed that in fertigation treatments, potassium was confined to the root zone of the radish crop, while it moved beyond the root zone in significant quantities for the conventional furrow irrigation. Movement beyond the root zone was also observed in the soil-based fertilizer application with water provided by drip, but to a lesser degree. These experiments have shown that at least 40% of fertilizer use could be saved through fertigation with similar or higher yield in addition to water savings.

Key words: fertigation, drip, nutrient dynamics.

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NO:1–021
Fertigation of arecanut (*Areca catechu* L.)

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A study of fertigation effects on arecanut growth and related soil nutrient status began in December 1996, in a 2-year-old garden of the Central Plantation Crops Research Institute, Regional Station, Vittal. The laterite soil had a pH of 5.25 and levels of 1.3% organic carbon, 42 ppm N, 15.0 ppm P and 56.8 ppm K. Treatments included 25, 50, 75 and 100% of the recommended fertilizer dose through drip irrigation, fertilizer application at 10-, 20- or 30-day intervals and one control with 100% direct fertilizer application to soil. Amounts of water equivalent to 100% evapotranspiration were applied by drip from December to May. Soil samples from two depths (0–30 cm and 30–60 cm) were collected and analysed for major nutrients. Crop height, girth and number of leaves produced were recorded. The highest level of soil available nitrogen was 69 ppm for the 75% fertilizer treatment. It was on a par with the control. Thus, a 25% fertilizer saving is possible by applying fertilizer through drip irrigation. The difference between treatments with respect to nitrogen content was not significant at lower depths. Available phosphorus and potassium content in soil were not significantly different across treatments.

Key words: drip irrigation, arecanut, fertigation.

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NO:1–022
Nitrogen transformations and movement under different water supply regimes for paddy rice

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Experiments were conducted to examine the interaction between irrigation practice and nitrogen supply for paddy rice. The data were used to investigate the changing patterns of nitrogen transformation and movement, losses of ammonia volatilization and nitrogen leaching, nitrogen distribution within rice plants, nitrogen balance in paddy fields and rice yields. Ammonia volatilization was high under water-saving irrigation conditions (WSI) compared with continuous flooding (CF) since soil solution concentrations were higher. While the concentration of NH_4^+ and NO_3^- in percolation water was higher under WSI, the total nitrogen leaching loss was lower because the total percolation loss was much lower than that under CF. More nitrogen supply splits could decrease nitrogen losses and increase nitrogen-use efficiency under WSI. WSI practice was propitious for nitrogen recovery and transfer to grain. The WSI regime produced optimal water and fertilizer management for paddy rice when 250–400 kg/ha urea were applied using three splits. A model is suggested for integrated management of water and fertilizer.

Key words: water-saving irrigation, paddy rice, nitrogen transformation and movement.

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NO:1–023
Model of crop response to water and nitrogen based on genetic algorithm and artificial neural networks

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A model of the crop response to water and nitrogen is the base for the rational regulation of field water and nitrogen regime, and the improvement of water- and nitrogen-use efficiency. The relationship between soil water, nitrogen and crop yield is very complex. Since artificial neural networks (ANN) are powerful in non-linear mapping, they can be used to model the water–nitrogen–yield relationship. Improved GA (combination of real number coding genetic algorithm and gradient descent algorithm) was applied to the weight training of ANN. The model was validated with field experiment data in Beijing suburb. Results showed that ANN was effective in modelling the water–nitrogen–yield relationship.

Key words: model of crop response to water and nitrogen, artificial neural networks, genetic algorithm, back propagation algorithm.

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NO:1–024
Effects of soil drying on photosynthesis and water-use efficiency of quinoa

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The sensitivity of stomatal conductance and photosynthesis of quinoa to progressive soil drying was investigated along with implications for altering water-use efficiency. The experiment was conducted in pots in a climate-controlled greenhouse. Measurements on well-watered and droughted plants included stomatal conductance (g_s), photosynthesis (A_{max}), photosynthetic water-use efficiency ($WUE_{Amax/gs}$), whole-plant WUE (total dry weight/cumulated transpiration per plant), root water potential (ψ_r), leaf water potential (ψ_l) and transpiration. The measured biophysical parameters of droughted plants were expressed relative to those of the fully watered controls. Initially, g_s and A_{max} were maintained in droughted plants as in soil dried, with relative g_s and A_{max} equalling 1, until the fraction of transpirable soil water (FTSW) decreased to 0.82 ± 0.152 and 0.33 ± 0.061, respectively. The relationship between relative g_s and relative A_{max} was represented by a logarithmic function ($r^2 = 0.79$), which resulted in a $WUE_{Amax/gs}$ of 1 when FTSW > 0.8. $WUE_{Amax/gs}$ increased by 50% at FTSW 0.7–0.4. ψ_r decreased rapidly with soil drying, whereas ψ_l was only slightly affected, due to stomatal closure. At the whole-plant level, transpiration was maintained until FTSW reached 0.58 ± 0.030, and simultaneously relative whole-plant WUE increased, when FTSW decreased below 0.6. We concluded that, during soil drying, quinoa has a sensitive stomatal closure maintaining ψ_l and A_{max}, resulting in an increase of WUE.

Key words: quinoa, soil water deficits, stomatal conductance, photosynthesis, water-use efficiency.

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NO:1–025
Yield response to pre-planned water-deficit irrigation

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Yield responses to pre-planned water-deficit irrigation are reviewed for cotton, maize, potato, soybean, wheat, common bean, groundnut, sunflower and sugar cane. Crops including cotton, potato, maize, wheat, groundnut, common bean, sunflower, soybean, sugar beat and sugar cane are well suited to deficit irrigation practices if reduced evapotranspiration is imposed only during a certain growth stage or stages. Among these crops, cotton, groundnut and maize can withstand reduced evapotranspiration imposed throughout the whole growing season without significant yield reduction. Mechanisms contributing to crop tolerance to temporal water stress, developed during deficit irrigation, differ depending on crop species. Maize develops an adaptive strategy of extending rooting depth and extracting water from deeper soil while simultaneously reducing leaf area to decrease transpiration. Soybean reduces shoot and root growth, decreases leaf chlorophyll and shoot soluble sugars, but increases soluble sugar content of roots to lower osmotic potential. Adaptation of cotton to deficit irrigation may be attributed to uninterrupted biosynthesis of fatty acids that strengthen cell membranes. Osmotic adjustment ability of wheat cultivars, largely controlled by leaf sugar and proline concentrations, is another complex mechanism of field crops, which make deficit irrigation a feasible option to increase water-use efficiency.

Key words: deficit irrigation, drought stress, drought tolerance, evapotranspiration, irrigation scheduling, osmotic adjustment, water stress.

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NO:1–026
Physiological response and water-saving effect of regulated deficit irrigation in cotton

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The physiological response and water-saving effects of regulated deficit irrigation (RDI) were studied with pot-grown cotton in a glasshouse. Low, moderate and high levels of controlled soil water deficit were applied at either the late seedling or flowering stage for comparison with a control. Results showed that, at water deficit stages, the root–shoot ratio of the plant increased, while transpiration rate and stomatal conductance (g_s) obviously decreased. The diminution of the rate of photosynthesis (P_h) was not obvious, and there was a compensating effect on P_h and g_s after re-watering. In addition, although average fruit diameter and final fruit numbers decreased, the dried weight per fruit increased, suggesting that whether final yields were enhanced was mainly determined by the dried weight per fruit. The final results show that RDI plants had less vegetative growth and similar or higher yield than the controls, and that more than 25% of the irrigation water can be saved.

Key words: cotton, regulation deficit irrigation, physiological response, water-use efficiency.

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NO:1–027
Mobilization and distribution of pre-anthesis carbon assimilates of wheat under dry–wet alternation

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Pot experiments were carried out with winter wheat grown under a rain shelter, using various watering treatments applied during the flowering and grain-filling growth stages. The cultivar was Shaan 229. The treatments were a control (A) and drying–wetting cycles of either 5 (B) or 10 days (C). The soil moisture content of the control and wet treatments was 70–75% of soil maximum capillary capacity (SMCC), with a dry treatment level of 50–55% SMCC. Seven days pre-anthesis, the wheat plants were labelled with $^{14}CO_2$, and the radioactivity of ^{14}C assimilates was measured for different organs. The distribution of ^{14}C assimilates in seeds increased during the flowering and grain-filling stages for all treatments. That of the B and C treatments was about 3–4% higher than that of the control at harvesting. This indicated enhanced mobilization of pre-anthesis carbon assimilates from other organs to seeds, by dry–wet alternation. Treatments B and C also improved the output proportion of ^{14}C assimilate in leaves, sheaths and ear stems. At harvest, assimilates were about 3% higher in B treatment leaves and about 4–7% higher in ear stems, by comparison with the control. The proportion of ^{14}C accumulation in seed assimilates showed that effects of mobilization for the B treatment were superior to those of the C treatment.

Key words: wheat, dry–wet alternation, ^{14}C assimilate, mobilization

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NO:1–028
Effects of limited water and N applications on physiological characteristics of winter wheat during later growth stages

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Effects of limited water and nitrogen (N) applications on the physiological characteristics of winter wheat were investigated during the later growth stages, using pot experiments. Leaf enzyme activities revealed that leaf protein content, nitrate reductase (NR) activity and assimilative capacity were enhanced under the intermediate water supply (21%) conditions, with the increase of N application. Protective enzyme activity also increased and senescence was postponed. A full water supply during the latter growth stages was found to be beneficial to winter wheat under restricted N supply conditions. Full water supply in the jointing stage enhanced assimilative capacity and promoted growth. Intermediate water supply in the filling stage apparently kept the sink activities of grains higher, which was good for a higher yield.

Key words: limited water applications, limited nitrogen applications, protective enzymes, photosynthetic rate, nitrate reductase, sink activity.

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NO:1–029
Compensatory effects of water stress on maize

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Compensatory effects of water stress on maize were studied using pots and through farm experiments. Results indicated that both stage of exposure and severity of water stress affected compensatory effects. Water stress during the seedling stage could increase root length, root/shoot ratio and TTC reduction capacity of roots during the stress period, while accumulation of dry matter and number of roots per plant decreased. These conditions remained unchanged after re-watering. The rate of photosynthesis, transpiration rate and area of green leaves were higher during the filling stage, in comparison with a full irrigation treatment, indicting that water stress could delay leaf senescence. Slight stress at the early jointing stage also improved root activity, while severe stress had adverse effects. The higher root activity might cause delayed leaf senescence.

Key words: maize, water stress, compensatory effects.

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NO:1–030
Effects of alternate water and nitrogen supply to divided root systems of maize

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The effects of alternate water and nitrogen supply to divided maize root systems were studied, when each half root system was grown with alternate use of a uniform Hoagland nutrient solution and one of a set of four other solutions. These solutions were a Hoagland nutrient solution control (CK), Hoagland with PEG 6000 at an osmotic potential of –0.4 MPa (AW), N-minus Hoagland (AN) and N-minus Hoagland with PEG 6000 at –0.4 MPa (AWN). Solutions were alternated every 6 days for each divided root system. After two solution alternations, the shoot dry weight of for AWN plants were significantly higher than shoot dry weights for CK plants but the AW and AN treatments had no significant effect. In contrast, combined root dry weight and nitrogen-use efficiency increased markedly for all treatments. The root to shoot ratio of the AW and AN treatments rose, while that for the AWN treatment was unchanged. For each treatment, TTC reductive intensity of each half root system bundle was compared with the control, after 1, 3 and 5 days from the beginning of an alternate supply treatment. The intensity increased a great deal. However, whether that of the other half system bundles with no water or nitrogen supply either increased or not depended on the treatment being received by the first half. The amount of oxalic acid exudate of the half system bundle, with N supply by AN treatment, increased markedly, but not for the other half. The exudate of all half system bundles of the AW and AWN treatments decreased after 6 days. Moreover, for all treatments, the rate of biomass accumulation of the half system bundles was significantly higher than that of the other half and the control, during the first and second alternation periods. These results suggested that growth compensation occurred in the process of alternate supply of water and/or nitrogen. As a result, under root-divided alternative supply of water and/or nitrogen, maize biomass was not decreased and the nitrogen-use efficiency increased markedly.

Key words: maize, root-divided alternate supply of water and/or nitrogen, dry biomass, root compensation effects, nitrogen-use efficiency.

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NO:1–031
Deficit irrigation effects on growth and yield of sunflower in saline soil

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From 2000 to 2002, a deficit irrigation experiment was carried out covering the different growth stages of sunflower. Saline soil of the Hetao Irrigation District was used, with American sunflower G101 being planted in the field and in pots. Soil moisture, soil salinity, height of plant, leaf area, leaf water potential and components of yield were measured regularly. Results showed that using prescribed water deficits at different growth stages brought about different effects on growth, physiological processes and yield. During the bud and flowering stage, crop growth was not harmed when soil moisture was in the range 55–75% θ_f, with soil salinity in the range 0.2–0.3%. Noticeable harm occurred for $\theta = 75$–85% θ_f, with soil salinity values of 0.3–0.5%, though yield was satisfactory. With $\theta < 75\%$ θ_f and soil salinity >0.6%, there was serious harm to plant growth and final yield.

Key words: saline soil, insufficient irrigation, sunflower.

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NO:1–032
Crop growth and WUE responses to soil wetting, drying and aquasorb treatment

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Maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.) and peppers (*Capsicum annuum*) were re-watered at low, medium and high levels of deficit during the vegetative growth stage, for pot-grown plants. The water deficit levels corresponded to 100–80%, 70–55% and 50–40% of field capacity (FC), respectively. The growth response and water use of crops were determined for aquasorb combined with each of the deficit treatments. Effects of the low, medium and high deficit conditions caused declining gross dry matter (DM) for all crops. Contrariwise, water-use efficiency (WUE) behaviour of the three crops differed. When re-watering at the medium level of deficit, WUE values of maize and beans were 20.2 g kg^{-1} and 3.70 g kg^{-1}, being 59.1% and 29.7% higher, respectively, than those under the low deficit, or high water supply, condition. On re-watering 15 day after water deficit treatment, the growth response and WUE of all crops differed markedly. For maize, the DM per plant and WUE values under medium tension reached 39.6 g and 13.3 g kg^{-1}, respectively, which were 75% and 74.5% higher than the values for the low deficit condition. Compared with the low deficit condition, these responses represent an overcompensation effect, meaning that growth and WUE of some crops will become higher than with the normal water supply treatment on re-watering. Also, fresh weight yields of peppers for medium deficit were 6% higher than for those kept at low deficit. This indicates a compensation effect for yield, when peppers were re-watered after medium deficit. When using aquasorb in soil at 1 kg m^{-3}, the WUE of all crops increased markedly in all water treatments, especially under the high deficit treatment. The WUE of maize, pepper and beans with aquasorb and low water supply treatment increased by 63.6%, 47% and 27.8% in comparison with values for no aquasorb and low water supply treatment.

Key words: dry–wet changing, compensation effect, water-use efficiency (WUE), crop, aquasorb.

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NO:1–033
Yields, evapotranspiration and eco-physiological conditions for paddy rice under water stress conditions

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Components of yield, evapotranspiration and eco-physiological conditions under different water stress conditions were identified, based on data for early and late rice from Guilin Irrigation Experiment Station and for middle rice from Tuanghai Irrigation Experiment Station. There appeared to be a ‘recovery’ effect for evapotranspiration and rice development, following light and medium levels of drought in the early and middle growth stages.

A corresponding principle for deficit irrigation was established for paddy rice, based on the 'recovery' effect.

Key words: water stress, rice, evapotranspiration, eco-physiology.

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NO:1–034
High crop water-use efficiency of limited water in semi-arid areas

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A review is presented of crop physiological adaptation and benefits associated with deficit and variable water conditions. Knowledge of compensating effects of limited irrigation and the breeding of new varieties for high water-use efficiency (WUE) could improve crop productivity under water-limited environments in the semi-arid regions. This potential seems to depend on effective conservation of moisture and efficient use of this limited water. Different crops, soil and water management strategies should be adjusted according to the conditions that prevail in various semi-arid areas.

Key words: semi-arid conditions, dry-land crop, physiological adaptation, WUE improvement.

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NO:1–035
Predicting photosynthetic water-use efficiency of crops under climate change

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Photosynthetic water use efficiency (WUE), the ratio of photosynthesis to transpiration, is critical in determining productivity of crops in water-limited areas, with or without abiotic stresses. WUE data are variable and a unifying approach is needed to assess and predict WUE of crops for different environments, especially in anticipation of future climate changes and increasing atmospheric CO_2. This study tests in the field simple paradigm equations based on single-leaf gas exchange and without up-scaling, for predicting variations in canopy WUE relative to a reference state. Canopy photosynthesis was taken as the downward CO_2 flux from the atmosphere measured by a Bowen ratio/energy balance/CO_2 gradient technique, plus the upward CO_2 flux from the soil measured by chambers. Canopy temperature, air CO_2 concentration and humidity were monitored. For a cotton crop, the predicted diurnal time course of WUE (at 5-min intervals) is nearly the same as the measured, provided that stomatal conductance as affected by humidity is accounted for. For a sunflower crop, the prediction is also good, but with slightly more deviation from the measured in comparison to cotton. Over a period of many weeks, the variation in midday WUE of cotton from day to day was well predicted by the equation. With maize, the prediction is often not good for the early morning. Possible reasons for the deviations will be discussed.

Key words: water-use efficiency, climate change, stomatal conductance, photosynthesis.

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NO:1–036
Physiological effects of new anti-transpirant applications on maize

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The physiological effects of a new anti-transpirant were studied by a field trial on maize. The new anti-transpirant was sprayed 10 days before the heading stage (A), at ear filling stage (B) or both 10 days before heading and ear filling stages (C), using the following concentrations: 0.5%, 1.0%, 1.5% and 2.0%. Results indicated that the new anti-transpirant raised nitrate reductase activity (NRA), free proline content, chlorophyll content and water content of leaves, thus drought stress could be mitigated. The new anti-transpirant augmented stomatal conductance and promoted photosynthesis. It also reduced the transpiration rate. Treatment C had a cumulative effect compared with treatments A and B, except for the NRA. The new anti-transpirant caused an increase of grain yield by 5.4% to 29.6%, depending on the treatment. The optimal concentration is 0.15%, with 75 g dissolved in 50 l of water, and an optimal application period 10 days before the heading and ear filling stages (C).

Key words: anti-transpirant, maize, physiological effect, drought stress.

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NO:1–037
Indices of regulated deficit irrigation for water-saving and yield improvement of winter wheat

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Regulated deficit irrigation (RDI) of winter wheat was studied using pot experiments. With an appropriate level of water deficit at specific growth stages, the transpiration rate decreased markedly but there was no diminution of photosynthesis. There were super-compensation effects in photosynthesis and accumulation of photosynthetic products after re-watering. The proportion of photosynthetic products within grains tended to increase. RDI controlled vegetative growth and promoted reproductive growth. The following indices for RDI were suggested for winter wheat to promote water savings and high yields. During the three-leaves–wintering stage, the optimal deficit was 40% θ_F–60% θ_F, typically maintained for a period of 40 days, followed by a level of deficit of 40% θ_F–55% θ_F during the wintering–returning green stage of about 25 days. θ_F represents a field capacity condition. This RDI treatment increased yields by 7.2% and decreased water consumption by 18.2%. Water-use efficiency (WUE) increased by 31.4% as compared with

conventional irrigation. So RDI in winter wheat is a practicable technology for high yield and water-use efficiency.

Key words: winter wheat, regulated deficit irrigation, water-saving, mechanisms, index.

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NO:1–038
Relationship between crop yield and water use of spring wheat in the Hetao Irrigation District of China

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The relationship between crop yield and water use of spring wheat (*Triticum aestivum* L.) in the Hetao Irrigation District of China was studied, based on a field deficit irrigation experiment conducted under local physical conditions. The results show that the crop yield of spring wheat holds a fairly good linear relationship with seasonal evapotranspiration, with a crop yield response of 40 kg ha^{-1} to 1 mm of evapotranspiration change. The yield response factor of the Stewart model, β_0, is 2.11 and is considerably larger than the value given by Doorenbos and Kassam due to a different water deficit pattern. The relationship of the crop yield of spring wheat with evapotranspiration at different growth stages was studied by two empirical models of Jensen and Minhas. Statistical analysis shows that both models are capable of describing the experimental data accurately. The sensitivity factors at different growth stages of the two models differ significantly, which indicates that the time of occurrence of water deficit has a great influence on the reduction of the yield of spring wheat. The flowering and head development stages are most sensitive to water deficit. The evapotranspiration of spring wheat for the field deficit irrigation experiment was calculated using the agro-hydrological simulation model SWAP (Soil Water Atmosphere Plant) rather than the water balance method traditionally used. With the capability of simulating water flow in the soil–plant environment for different irrigation levels, the SWAP model provides a clearer picture of the complex processes of water balance components in the root zone. It also overcomes the difficulties in determining the net drainage from the root zone, as commonly encountered in the water balance method.

Key words: evapotranspiration, crop yield, spring wheat (*Triticum aestivum* L.), deficit irrigation, SWAP model.

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NO:1–039
Maize water production functions for the Hebei Plain

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Maize is one of the main crops in the Hebei Plain. Two successive years of experimental data for maize evapotranspiration were obtained under different irrigation treatments. These data were used to examine the relationship between evapotranspiration and maize yield through fitting the Blank, Jensen and Morgan models.

Key words: water production function, maize, Hebei Plain.

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NO:1–040
Effects of nitrogen and phosphorus nutrition on maize root hydraulic conductivity under water deficiency

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The effects of nitrogen and phosphorus nutrition on root hydraulic conductivity of maize (*Zea mays* L.) were studied using a pressure chamber, both at the level of individual roots and of whole root systems. This was done using solution culture conditions. The results showed that the hydraulic conductivity of roots (Lp_r) at both levels differed with genotype and nutrient conditions. Results of inhibition experiments with $HgCl_2$ and de-inhibition experiments with 2-SH-C_2H_4OH suggested that nutrition directly affects individual Lp_r by affecting the properties of water channels or aquaporins in the root protoplast plasma membrane (PM). However, at the level of the whole root system, there is not only a direct effect but also an indirect effect resulting from root morphology changes. Compared with nitrogen-deficient roots, phosphorus-deficient maize roots have higher whole Lp_r, but lower individual Lp_r. This indicates that the two nutrient elements make different contributions to individual Lp_r and whole Lp_r, and that the functions they perform are also different. There is no straight-line relationship between individual Lp_r and whole Lp_r ($r^2 = 0.4957$, $P < 0.05$). This meant that when individual Lp_r was increased, the whole Lp_r was increased at the same time, but when the individual Lp_r was decreased, the whole Lp_r did not decrease in a linear way, which makes the plant continuously take up water from droughted soil. The whole Lp_r can reflect well the crop's capacity for absorbing water.

Key words: nutrition, maize, hydraulic conductivity, aquaporins.

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NO:1–041
Compensation effects of inorganic nutrition on yield components and water-use efficiency of dry land spring wheat

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To assess the compensation effect of inorganic nutrition on the crop yield and water-use efficiency (WUE), 2-year experiments on spring wheat planting density and influence of fertilization on yield formation were conducted in the semi-arid field conditions of a loess hilly area in Ningxia Uh Autonomous Region. A comparison of wheat yield and WUE sequences under four planting densities with five fertilization levels shows that maximum yield and highest WUE were achieved under the optimum fertilizer input of 90 kg N and 135 kg P_2O_5 ha^{-1} with 500 seeds m^{-2}. Increased soil fertilization was positively correlated with grain yield and WUE of spring wheat, with correlation coefficients of 0.959 and 0.894. Planting density,

however, showed a poor correlation with both. Increasing fertilizer level significantly increased the number of fertile spikelets, kernels per spike and kernel weight. These components were decreased with the increase in planting density. Fertile spikelet number was sensitive to fertilization, whereas kernel number and weight were mainly affected by plant density. Fertilization applied to spring wheat improved root system development and especially enhanced root growth in the cultivated soil layer of 0–20 cm. Ameliorated root system was able to improve crop water use and nutrient absorption and, hence, crop yield and WUE were increased. The grain yield of spring wheat increased by 44.6% and 55.4% when P and P + N + K were applied, respectively. A significant increase in yield was also obtained with N application but not with K. P or P + N promoted spike development and, hence, increased seed production. N + P + K improved the quality of seeds, and the content of N, P and K in seed increased by 18.5%, 18.4% and 8.1%, respectively, compared with no nutrient treatment. This study highlights the compensation effects of improving inorganic nutrition on the high efficient use of limited water in dry land spring wheat production.

Key words: dry land spring wheat, inorganic nutrition, compensation effect, water-use efficiency, grain yield.

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NO:1–042
Water-use efficiency of aerobic rice in North China Plain

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China Agricultural University and the International Rice Research Institute (IRRI) have co-operated over the selection of two aerobic varieties, Han Dao 297 (HD297) and Han Dao 502 (HD502), along with one popular lowland variety Jin Dao 305 (JD305). In one experiment, HD297, HD502 and JD305 were grown in aerobic soil under five irrigation regimes. In a second experiment, the same varieties were grown under flooded lowland conditions. Each test plot area was 60 m^2, with four replications. Results showed that when water inputs were 470–644 mm, HD297 yielded 2.5–4.7 t ha^{-1} and the water-use efficiency was 0.53–0.73 g kg^{-1}. HD502 yielded 3.0–5.3 t ha^{-1} and the water-use efficiency was 0.64–0.82 g kg^{-1}. Water-use efficiencies of the aerobic varieties (HD297 and HD502) were 12–16% higher than those of the lowland variety, under the maximal water input regime. Hence aerobic rice has a great water-saving advantage compared with paddy rice and maintains high yields.

Key words: aerobic rice varieties, paddy, water-use efficiency, flooded lowland conditions.

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NO:1–043
Monitoring crop water status based on variation of stem diameter

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The diurnal variation of stem diameter is a good indicator of crop water status. Progress in the development of indices is described for crop water status monitoring based on variation of stem diameter. Since the late 1960s, the use of indices can be divided into three stages. First, a qualitative approach was used to describe the relationship between stem diameter and crop water potential. Then dynamic relationships were developed to quantify the variation of stem diameter with crop water potential, taking account of environmental and plant growth conditions. These indices could be used for crops grown in field plots and in a greenhouse. Finally, it was found that dynamic monitoring of stem diameter variation via a computer system might be used for timing of irrigation.

Key words: stem diameter, crop water status, water potential, irrigation timing.

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NO:1–044
Improving water-use efficiency of mangos by regulating moisture regimes

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The role of moisture regimes was investigated in relation to the flowering and fruiting of Mango, cv. Chukanan. Four water regimes were imposed by using only rainfall or through additional irrigation using one, two and four emitters per plant. A micro-sprinkler was also run continuously for 45 min daily. Rainfall only represented the control. The un-irrigated plants and those with only one emitter showed the greatest reduction in soil water content, leaf water potential and stomatal conductance, with respect to the control. Plants supplied with adequate water failed to flower and set fruit, emphasizing the advantage of deficit irrigation. Yield and quality were severely depressed under high water availability. The highest yield was obtained when plants were irrigated with two emitters per plant. In a second experiment, flowering and fruiting responses were investigated for the varying moisture regimes produced by partial root drying (PRD). Responses were compared with water stress treatments and a control treatment of two emitters per plant. Plants subjected to PRD treatments showed an increase in fruit set and yield compared to the control and water stress treatments. There were no significant differences in plant water status, stomatal conductance and rate of photosynthesis between plants subjected to PRD and control plants.

Key words: water-use efficiency, stomatal conductance, partial rootzone drying, phytosynthesis.

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NO:1–045
Systematic improvement of agricultural water-use efficiency

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Effective management of scarce water resources requires a systems approach. The overall efficiency of delivering water from the reservoir to the root zone of the crop is the product of

the efficiency of each sequential step. So efficiencies of individual process steps are multiplicative in determining overall efficiency. Improvement in any one of the steps has equal effect in improving overall efficiency, and overall improvement is more than the sum of individual improvements. The economic implication of this principle is discussed. Process steps in the sequences for crop and animal production in rain-fed agriculture will be outlined and likely improvements will be assessed quantitatively for some scenarios. Improvements in the efficiency of process steps leading to reduced run-off, reduced soil evaporation, higher biomass production and higher harvest indices are discussed.

Key words: water-use efficiency, water management, improvement.

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NO:1–046
Relationship between plasma membrane redox system and elongation of mungbean hypocotyl under drought stress

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An osmotic agent, –0.9 MPa D-mannitol, imitating drought stress in mungbean roots, was used to investigate the relationship between the redox system in plant plasma membranes and elongation growth, under drought stress. Hypocotyl segments of 10 mm length, from seedlings grown in water (control) (D), were floated for 12 h in the dark, at room temperature in four different solutions. The solutions were a check buffer solution of pH 7, with 0.2 mmol l^{-1}NADH (N), with 0.02 mmol l^{-1} actinomycin D (D) and with both NADH and actinomycin D (ND). Other hypocotyl segments, from the seedlings grown in –0.9 MPa D-mannitol for 24 h, were floated for 12 h in four other similar solutions, except that all four contained –0.9 MPa D-mannitol in pH 7.0 buffer. The lengths of hypocotyls and the pH of the solution were then assayed. Results showed that the 0.9 MPa D-mannitol treatment significantly inhibited elongation, H^+ extrusion and NADH oxidative activity in the growing zone of a mungbean hypocotyl. Within 24 h, rates were reduced by 49.1%, 44.1% and 49.2%, respectively. Actinomycin D, the specific inhibitor of NADH oxidase, could inhibit growth of an isolated hypocotyl by 41.2% in the control and by 31.8% in the treatment. Applied NADH could enhance their growth by up to 27.8% in the control and by 14.2% in the treatment, but such an effect could be negated by actinomycin D. Applied NADH also enhanced H^+ extrusion by 20% and 14% for the control and treatment, respectively. Under drought stress, inhibited elongation growth of mungbean hypocotyls may relate to the NADH oxidase in the PM redox system, with the regulation role being carried out through H^+ extrusion.

Key words: drought stress, elongation growth, plasma membrane redox system, H^+ extrusion, mungbean (*Phaseolus radiatus* L.).

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NO:1–047
Crop water sensitivity changes and optimum water supply schedule in the semi-arid Loess Plateau of China

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Efficient use of limited water resources is critical for crop production in semi-arid regions, especially on the Loess Plateau in China. This study was conducted to determine crop water sensitivity during growth stages, and put forward an optimum water supply schedule for crops on the Loess Plateau region. The effects of water use during stages on winter wheat (*Triticum aestivum L.*) and spring corn (*Zea mays*) productivity were investigated at Changwu Agricultural Experiment Station of the Chinese Academy of Sciences. The crops' water sensitivity was calculated using the Jensen model. The results indicated that the Jensen model's water sensitivity index (λ) reaches its highest value during the seedling–vegetative phase, its second highest value during the booting to heading stage and the third highest value during the heading to milk phase. So the most important irrigation is the one before winter, the second most important one is that during the booting and heading phase, and the third most important one is that during the heading and milk phase. Optimum irrigation before winter and during the booting and heading stage should be maintained for winter wheat. For corn, the Jenson model's water sensitivity index (λ) reaches its highest value during the booting to heading stage and its second highest value during the heading to milk phase. This indicated that the most important irrigation for corn is the one during the booting to heading stage; the second most important one is that during the heading and milk phases.

Key words: crop water sensitivity, productivity, water supply strategy, winter wheat, spring corn.

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NO:1–048
Effect of shoot/root ratio and water transport path on WUE of tomato

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To investigate the effect of the root/shoot ratio and water transport path on water-use efficiency, two tomato varieties, Maofen802 and Qinfeng No.4, with different root/shoot ratios were grafted reciprocally, the former characterized by a relative large canopy and root system, and the latter by small ones. Tomatoes were cultivated in plastic pots under wet and water stress conditions. The results indicated that the cion and stock could keep its original characteristic after grafting, and the root was more sensitive to water conditions than the shoot. The root/shoot ratio of these four materials (Maofen802, Qinfeng No.4, the grafted tomato with the cion of Maofen802 and stock of Qinfeng No.4, and the grafted tomato with stock of Maofen802 and cion of Qinfeng No.4) varied with each other in different water conditions. It changed from 0.16, 0.18, 0.12 and 0.26 in wet conditions to 0.25, 0.23, 0.19 and 0.12 in water stress, respectively. Under wet conditions, transpiration was dom-

inated by the shoot and the transpiration rate was seemingly linear with the ratio of the root absorbing area and leaf area, whereas the effect of the root system on the transpiration rate was greater than that of the shoot under water stress conditions. It is suggested that the tomato compensates for the insufficiency of water uptake by enlarging its root system in water stress conditions. Moreover, water transport paths varied with the water conditions. The apoplastic path was the major one, the contributions of the aquaporins only accounted for 22.2%, 15.1%, 15.8% and 17.3%, respectively, in root water uptake under wet conditions, but the cell-to-cell path was predominant under water stress, water transported through the aquaporins by 33.4%, 46.9%, 71.8% and 66.8%, respectively. The photosynthetic rate was hardly reduced in water stress conditions. Therefore, it is concluded that the excessive root system not only used extra carbohydrate from the leaves, but also amplified the water depletion from soil, and the water-use efficiency could be promoted by optimizing the relationship of the root and shoot and enhancing the contribution of the cell-to-cell path in water uptake.

Key words: water transport path, water-use efficiency, water stress, shoot regulation.

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NO:1–049
Effect of fertigation depth on maize root morphology and nitrate uptake

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The influence of nitrate fertigation depth was determined for maize root weights (RW), root length density (RLD) and distribution. Relationships were established for root morphology versus nitrate uptake and localized nitrate supply versus sprouting or elongation of fine roots. At depths of 20, 30 and 40 cm, the localized nitrate supply by fertigation encouraged the distribution of roots in deeper soil, greatly increasing RLD and encouraging subsoil penetration. RLD was closely related to nitrate uptake ($r^2 = 0.950$). So localized supplies of nitrate stimulate fine root growth, with RLD increasing quickly and allowing further nitrate absorption.

Key words: fertigation depth, localized supply, nitrate, maize, root morphology, uptake.

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NO:1–050
Effect of growth, water-use efficiency and pH value in xylem sap of alternative split-root osmotic stress on maize

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Growth, water-use efficiency and xylem sap pH were measured in maize plants grown in a split-root alternate irrigation system. Half of the roots were exposed to a Hoagland + PEG solution and the other half to Hoagland only solution; after a some timethe solutions were changed over. Results showed that the stress had a significant compensatory effect on growth and can increase water-use efficiency. The pH value in xylem sap increased under the osmotic stress and there is a positive correlation between this increase and the amount of amino acid, and K^+ and NO_3^- concentration.

Key words: alternative split-root osmotic stress, water-use efficiency, xylem sap, pH value.

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NO:1–051
Change of proteins and free amino acids in xylem sap and roots under alternative split-root osmotic stress on maize

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Dividing root systems and supplying water to alternate halves is a new kind of water-saving irrigation technique, based on the water-saving irrigation technology and root signal theory, which can decrease crop water consumption and maintain yield. The effect of changes of protein in xylem sap, together with changes in amino acids, were determined under this pattern. Results showed the following. (i) 19 kDa and 23 kDa new proteins appeared in roots after 2 days of alternative split-root stress. (ii) In the xylem sap, the total content of free amino acids increased gradually with the stress time (20.10–32.72 mg ml^{-1}) and the proportion of Ser and Ala altered. The content of Ser increased with the stress time and change from 10.6% of amount of total amino acids to 32.4%. The content of Ala decreased with the stress time and change from 32.6% of amount of total amino acids to 8.2%. The proportion of Pro was not high (8.0%) and was steady during the time of stress (change from 7.3% of amount of total amino acids to 8.7%). (iii) When roots that were subjected to stress were watered again, the amount of amino acids was higher after 2 days and then decreased to day 4, and again increased to the highest value after 7 days. (iv) When the roots were subjected to stress, the amount of free amino acids increased after 3 days, and decreased to the lowest value after 5 days, then increased to the highest value after 7 days, and finally came to a steady value. (v) The Amino Acids were 30% higher 5 days after re-wateringthan under stress. (vi) The amounts of Asp, Ser, Glu and Ala were about 50–80% of total free amino acids, irrespective of stress. The amount of Pro was about 6.3% of total amino acids before stress, then decreased until 5–6 days treatment; although it increased again at 7 days, it was still lower than at the beginning. From the above, we concluded that many proteins are expressed in maize roots under alterative split-root osmotic stress.

Key words: alternative split-root osmotic stress, proteins, free amino acids, xylem sap, maize.

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NO:1–052
Comparison of root strength of different plant species

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Slope stability was investigated from a biological perspective, associated with the capability of roots to achieve soil stabilization. Four levels of soil stability were identified for plant roots, through experimental determinations made using various plants. Results revealed that various roots have different tensile strengths. Values of 85, 27.3, 24.6, 24.5, 19.7, 19.2, 17.5 and 13.5 MPa, respectively, were found for the maximum tensile strength of vetiver grass (*Vetiveria zizanioides*), common cetipede grass (*Eremochioa ophiuroides hack*), white clover (*Trifolium repens*), late juncellus (*Juncelles serotinus*), dallis grass (*Paspalum dilatatum poir*), Bahio grass (*Paspalum notatum flugge*), Manila grass (*Zoysia matrella merr*) and Bermuda grass (*Cynodon dactylon*). The differing tensile strengths of various plant roots and their soil stabilization capabilities are concerned with their inherited structures and various tissues. Knowledge of plant soil stabilization properties affords a rational biological approach which may substitute or combine with engineering measures for natural slope protection or restoration, in Chinese primary construction projects.

Key words: bio-engineering approach, root network, mechanics, soil stabilization, tensile strength, root-soil compounds, grasses.

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NO:1–053
Physiological effect of new antitranspirant application on winter wheat at grout filling stage

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The physiological effect of a new antitranspirant on winter wheat was studied by field trial. The new antitranspirant was sprayed at grain filling stage, using the following concentrations: 0, 0.5, 1.0, 1.5 and 2.0 ml l^{-1}. The results indicate that the new antitranspirant raised nitrate reductase activity (NRA), free proline content, chlorophyll content and water content of leaf, thus drought stress can be mitigated. The new antitranspirant raised photosynthesis and reduced the transpiration rate, and led to growth stimulation and water loss reduction.

Key words: antitranspirant, winter wheat, physiological effect, drought stress.

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NO:1–054
A Study on stem sap flow of even-aged saplings in the eastern mountainous region of Northeast China

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Sap-flow studies of even-aged saplings that contain Quercus mongolica, Fraxinus mandshurica, Phellodendron amurense, Juglans mandshurica, Tilia amurensis and Pinus koraiensis were conducted during the 2001 growing season. The study area is located at Forest Ecosystem Research Station(ranging from 127°30′ to 127°34′ east longitude, and from 45°20′ to 45°25′ northern latitude) of Maoershan Experimental forest belonging to Northeast Forestry University, Heilongjiang province. Climatic conditions in this area are typically continental temperate monsoon climate. The annual mean temperature is 2.8 °C. Annual mean precipitation is 772.9 mm, with more than 60% concentration in the two months during summer. The frost-free period is from the end of May to the end of August.

In this paper, the thermal dissipation method proposed by Granier was used to measure sap-flow density of even-aged saplings. The following instruments were installed above the sapling's crown: a RH1 humidity and temperature probe (Vaisala, UT); a SKP215 PAR Quantum Sensor (Skye, UK); a SKS1110 Silicon Cell Pyranometer (Skye, UK); an A100R wind sensor (Vector Instruments, UK); and a GMP111 CO_2 transmitter (Vaisala). STC soil-temperature sensor (Delta-T Devices Ltd., Cambrige, U.K.) and MP406 moisture probe (ICT Ltd. Australia) were used to measure soil temperature and soil volumetric water near the sapling's root distribution. Rainfall was measured in the clearing with an ARG100 tipping bucket raingauge (EM LTD., USA). TDP Dynamax, Houston TX, USA, and all environmental sensors were sampled every 15min (ZENO3200, Coastal Environmental systems, USA). Leaf area, leaf anatomy structure, stomata conductance, stem hydraulic characteristics and sapwood area were also measured. The results show that sap-flow density presents mostly mono-peak patterns during its sunny diurnal process, mostly between 10.00 a.m. and 14.00 p.m. (69%~91%) except for Phellodendron amurense. During the growing season, the maximum sap-flow density of Fraxinus mandshurica, Phellodendron amurense, Quercus mongolica, Juglans mandshurica, Tilia amurensis and Pinus koraiensis is in the following order: 516.36, 234.00, 625.93, 945.83, 507.93, 286.21 $cm^3\ cm^{-2}\ h^{-1}$. After all leaves fall, there still exists sap flow until mid October. Water-use quantity of the samples in the growing season is as following (ton tree–1): Juglans mandshurica (3.84) >Tilia amurensis (2.82) >Fraxinus mandshurica (2.71) >Pinus koraiensis (2.12) >Phellodendron amurense (1.47) >Quercus mongolica (1.39). Hydraulic characteristics, Hube value, stomata conductance and leaf anatomy structure of the saplings exist as homeostatic relations. Results of the statistical analysis showed that PAR and VPD are the main factors (R2=71%~92%) affecting sap-flow density in sunny diurnal process at different growth periods.

Key words: environmental factors, even-aged sapling, stem sap flow, thermal dissipation method.

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