Assessment of plant genetic resources for water-use efficiency (WUE): managing water scarcity

Proceedings of the Bioversity International/INRA/IDRC/AARINENA
Workshop for North Africa and West Asia, Marrakech, Morocco, 10–12 October 2005

A. Bari, scientific editor

المعهد الوطني للبحث الزراعي
Institut National de la Recherche Agronomique

IDRC
CANADA

IPGRI and INIBAP
operate under the name
Bioversity International

Supported by the CGIAR

Assessment of plant genetic resources for water-use efficiency (WUE): managing water scarcity

Proceedings of the Bioversity International/INRA/IDRC/AARINENA
Workshop for North Africa and West Asia, Marrakech, Morocco, 10–12 October 2005

A. Bari, scientific editor

Bioversity International (formerly known as IPGRI) is an independent international scientific organization that seeks to improve the well-being of present and future generations by enhancing conservation and the deployment of agricultural biodiversity on farms and in forests. It is one of 15 Future Harvest Centres of the Consultative Group on International Agricultural Research (CGIAR), a strategic alliance of countries, international and regional organizations, and private foundations that mobilize cutting-edge science to reduce hunger and poverty, improve human nutrition and health, and protect the environment. Bioversity International is headquartered in Maccarese, near Rome, Italy, and has offices in more than 20 countries worldwide. The institute operates through four scientific research programmes: Diversity for Livelihoods; Understanding and Managing Biodiversity; Global Partnerships; and Commodities for Livelihoods.

Citation: Bari, A. (editor). 2007. Assessment of plant genetic resources for Water-Use Efficiency (WUE): Managing water scarcity. Proceedings of the Bioversity International/INRA/IDRC/AARINENA Workshop for North Africa and West Asia. Marrakech, Morocco, 10–12 October 2005. Bioversity International, Rome, Italy.

Cover: ICARDA/Bioversity International arboretum consists of fruit and nut crops, which are commonly grown in CWANA region including olives. Part of the research is being conducted in this arboretum for the identification of traits associated with water-use efficiency. Prof. Adnan Hadjhasan from Bioversity CWANA sampling wild olive, characterized for its rooting traits in relation to water-use.

ISBN 978-92-9043-748-2

Au delà de l'outil, et à travers lui, c'est la vieille nature que nous retrouvons, celle du jardinier, du navigateur, ou du poète.

Beyond the work of tools, and through them, we find human nature, the nature of gardeners, navigators and poets.

Saint-Exupéry

Acknowledgements

Bioversity International would like to thank IDRC for their support in enabling the participants from the Central and West Asia and North Africa (CWANA) region to attend the workshop.

Special thanks go to INRA Morocco and to Professor Hamid Narjisse for organizing and hosting this workshop, as well as to AARINENA for launching the olive network, which served as a platform for this event and for others to follow. Bioversity International would also like to thank the workshop participants for their contributions and valuable discussion. Thanks go also to the various participating institutes and universities, namely: the Institut National de la Recherche Agronomique (INRA), Morocco; the Institut de l'Olivier, Tunisia; the National Centre for Agricultural Research and Technology Transfer (NCARTT), Jordan; the General Commission for Scientific Agricultural Research (GCSAR), Syria; and the University of Marrakech, Morocco.

Finally, our gratitude to the librarians of Bioversity International and of ICARDA, who helped enormously with regard to reference materials, and special thanks to Ron Smith and Hope Traficanti for their excellent assistance with editing.

Without the help of those mentioned above and others, this study could not have been completed.

Contents

Section 1 — Water issues and requirements

Section 2 — Research strategies for water use: managing water resources

Section 3 — Research strategies for water-use: exploration of genetic variation

Acronyms

AARINENA	Association of Agricultural Research Institutions in the Near East and North Africa
CAS	Comprehensive Assessment Secretariat
CGIAR	Consultative Group on International Agricultural Research
CSIS	Centre for Strategic and International Studies
FAO	Food and Agriculture Organization of the United Nations
GCSAR	General Commission for Scientific Agricultural Research
IAHS	International Association of Hydrological Sciences
IAWR	International Association for Waterworks in the Rhine
ICARDA	International Centre for Agricultural Research in the Dry Areas
IDRC	International Development Research Centre
IFPRI	International Food Policy Research Institute
INRA	Institut National de la Recherche Agronomique
IOOC	International Olive Oil Council
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
MA	Millennium Ecosystem Assessment (UN)
MENA	Middle East and North Africa
NCARTT	National Centre for Agricultural Research and Technology Transfer
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNEP	United Nations Environmental Programme
WANA	West Asia and North Africa
WMO	World Meteorological Organization
WWAP	World Water Assessment Programme (UN)
WWDR	United Nations World Water Development Report

Foreword

Although water is a renewable resource, its supply is not inexhaustible. It is unlikely that sufficient new water resources will be found to meet the projected increase in demand for water for food production, as existing water resources are already under pressure. It is vital, therefore, that existing resources be managed efficiently. This is particularly true with regard to agriculture, which utilizes more than two-thirds of the global water used by humans.

Continued successful management of the limited amount of water available for agriculture is dependent upon better agronomic practices and an enhanced understanding of genetic variation for water-use efficiency (WUE) among crop genotypes, especially in areas prone to water scarcity.

This document presents the proceedings of an inter-agency workshop dedicated to tackling the issue of water-use efficiency and water scarcity. Issues discussed relate to methods of managing water in agriculture, exploring opportunities for saving water and improving productivity by utilizing genetic resources, as well as other agronomic measures.

The document is divided into three sections: the first section addresses themes related to water availability, current and future water needs, and water scarcity. The second section focuses on research strategies for a more efficient use of water resources - particularly in olive orchards - while the third section details the potential of genetic resources to manage water scarcity. It also addresses innovative approaches towards exploring the valuable genetic variation within crops, especially olives and almonds. The aim of the undertaking is to facilitate assessment of genetic variation for WUE and measurement of water requirements at the genotypic level, rather than simply at the crop level.

Assessing plant genetic resources for complex traits such as those concerning water-use efficiency requires large numbers of samples to be taken. Lack of development of rapid, cost-effective methods has hindered the use of WUE in practice and breeding. The effectiveness of characterization is also hindered by the lack of novel 'smart and rapid screens' needed to identify desirable traits in a cost-effective manner.

The overview of concepts such as quantitative methods to model traits associated with water-use efficiency can also help in narrowing the phenotype gap.

The overall aim of this text is to enhance the use of diversity through characterization, using novel approaches in order to improve productivity, and to ensure that knowledge about ongoing research on efficient water-use of plant genetic resources is readily available to all stakeholders.

Laura Snook

Director, Understanding and Managing Biodiversity
Bioversity International,
Rome, Italy

George Ayad

Director, Regional Office of Bioversity International,
Aleppo, Syria

Preface

Adequate water resources are required to meet the needs of the anticipated increase in global food production within the next 25 years, yet additional sources are unlikely to be found. In North Africa and the West Asia region in particular, water scarcity is acute, as the region has experienced frequent dry spells in recent years. A number of initiatives are being taken place in the region to tackle the growing problem of water scarcity. Among these is the exploration of genetic variation for water-use efficiency (WUE) within crops and species, in the light of the recent findings on extensive within-crop variation in WUE.

In this context, the Institut National de la Recherche Agronomique (INRA) of Morocco, the International Development Research Centre (IDRC) Programme on Water (WaDimena), the Association of Agricultural Research Institutes in the Near East and North Africa (AARINENA) and the International Plant Genetic Resources Institute (now known as Bioversity International) organized a workshop on plant genetic resources and WUE. The workshop, held in Marrakech, Morocco, in October 2005, aimed at facilitating the exchange of knowledge and experience on the management of water under conditions of scarcity through the use of 'less-thirsty' genotypes within crops. This approach is in line with:

- WaDimena's aim of promoting tools, approaches and strategies to enhance WUE and sustainability;
- Bioversity International's strategy to enhance sustainable use of plant genetic resources to mitigate the effects of abiotic stresses such as drought; and
- AARINENA's mission to contribute to the enhancement of agricultural and rural development in the region.

The workshop was also an opportunity to strengthen collaboration and support the newly established AARINENA networks on olive and water-use efficiency.

Section 1
Water issues and requirements

The water issue

A. Bari and G. Ayad

Bioversity International, c/o ICARDA, Aleppo, Syria. Email: a.bari@cgiar.org

Abstract

It is estimated that approximately 70% of the water used by humans is consumed by agriculture, the remainder being used for domestic and industrial purposes. In developing countries, agricultural use of water may reach 90%. The West Asia and North Africa (WANA) region uses more of its water resources in irrigation than does any other region in the world. In recent years, the region has also experienced frequent intermittent and extended spells of dry weather. As a result, less water has been accumulating in artificial and natural reservoirs. Ground-water levels have therefore fallen, making water more difficult and costly to extract, and thus hampering the socio-economic development efforts of a number of countries in the region.

This workshop focused on exploration of genetic variation in water-use efficiency (WUE) in crops, i.e. looking for genotypes that are 'less thirsty'.

Key words: water availability, water scarcity, water crop requirements, water genotype requirements, within-crop diversity

Introduction

The agricultural sector is the dominant user of water by humans, accounting for more than two-thirds of withdrawals (Gleick 2002; Rosegrant et al. 2002a). In developing countries agricultural use may reach 90%, with the remainder being used for domestic and industrial purposes (FAO 2003). In the past 50 years, there has been a remarkable increase in agricultural water use (see Figure 1). However, the relative amount of water available to agriculture is declining, due to increasing human populations and a greater incidence of drought in recent years. The WANA region has the highest percentage of water withdrawal (Table 1), at approximately 70% of renewable water in 1995, and this is expected to reach 90% by 2025 (Rosegrant et al. 2002a). Withdrawal rates in the region are already in excess of the 40% threshold for scarcity, beyond which costs and ground-water depletion increase sharply (World Bank 2006). The region has also experienced more frequent, intermittent and consecutive dry weather conditions in recent years (IPCC 2001). This contrasts sharply with other regions, such as Latin America or sub-Saharan Africa, where the percentage of water withdrawal is 2% and is expected to increase only slightly in the future.

With decreasing rainfall, water inflow in the region has decreased, resulting in less water in reservoirs. Ground-water levels have also decreased as a result of overdraft above recharge capacity, which has depleted both water quantity and quality (Rosegrant et al. 2002a). This decrease is increasing the competition for water among agricultural, industrial and domestic users, which, in turn, is causing tension between rural and urban areas. Competing agricultural, municipal and industrial water usage will eventually threaten food security (UNESCO/WWAP 2003; World Bank 2006).

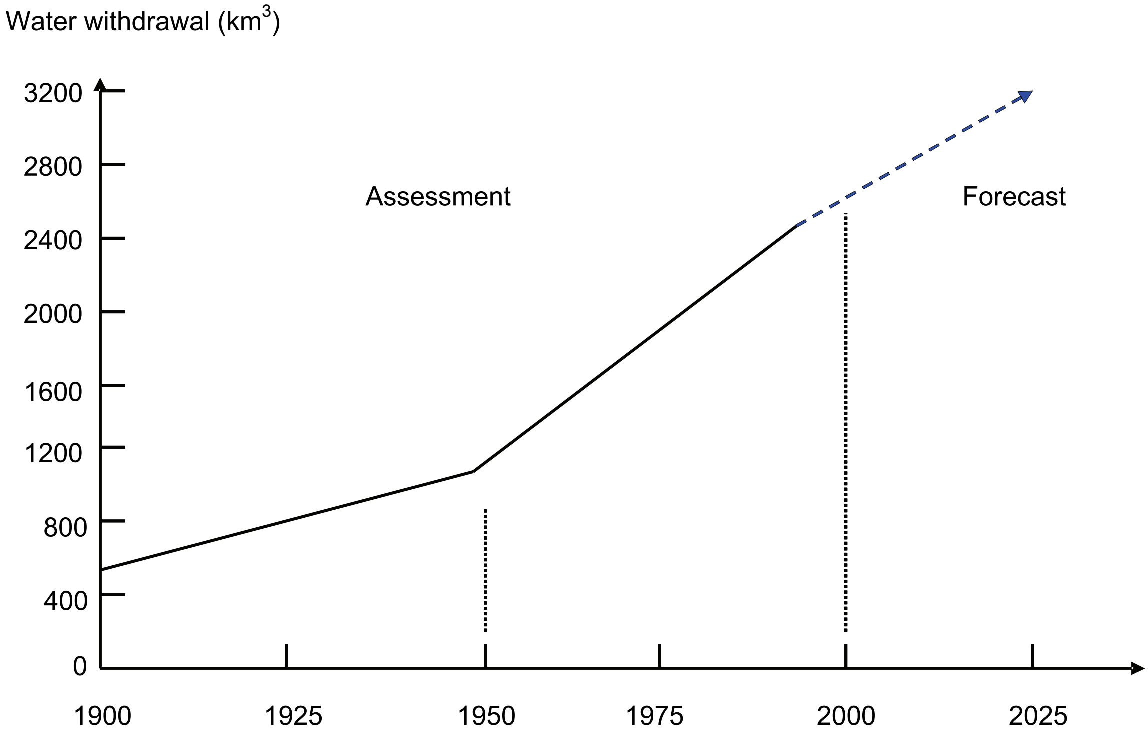


Figure 1. Trends in water use for agricultural purposes worldwide
Source: Shiklomanov 1999.

Table 1. Total water withdrawal as a percentage of renewable water per region.

Region	**Total water withdrawal** (km^3)		**Total water withdrawal as a percentage of renewable water** (%)	
	Baseline 1995	Projection 2025	Baseline 1995	Projection 2025
Asia	2165	2649	17	20
Latin America	298	410	2	3
Sub-Saharan Africa	128	214	2	4
West Asia and North Africa	236	297	69	90
Others†	1144	1265	9	10
World	3906	4772	8	10

Notes: † Developed countries.
Source: Rosegrant et al. 2002a

The recent report of the CGIAR's Systemwide Initiative on Water Management (SWIM) found that water is a constraint to acquiring food for hundreds of millions of people, and that competition for water resources is intense. The report also found that water in basins is often not enough to meet demand, to the extent that rivers may fail to even reach the sea (CAS 2006).

This steady decrease in water availability is detrimental to the development endeavours of countries in the WANA region. Water scarcity is responsible for the delay in cereal yield growth in developing countries worldwide and it is projected that the relative cereal crop yield will decline from 0.86 in 1995 to 0.75 in 2025, representing a loss of some 130 million tonnes of cereal (Rosegrant et al. 2002b).

There are two ways of managing water scarcity in agriculture:

- effective management of existing water supplies, for example through improved cropping systems and on-farm agronomic practices that include better soil and nutrient management; and
- screening for genetic variation for WUE, i.e. looking for 'less thirsty' varieties or genotypes (World Bank 2006).

This workshop focused on the second option: that of exploring the potential of intraspecific diversity to characterize those genotypes and ecotypes that have comparative advantages over others in terms of water demand.

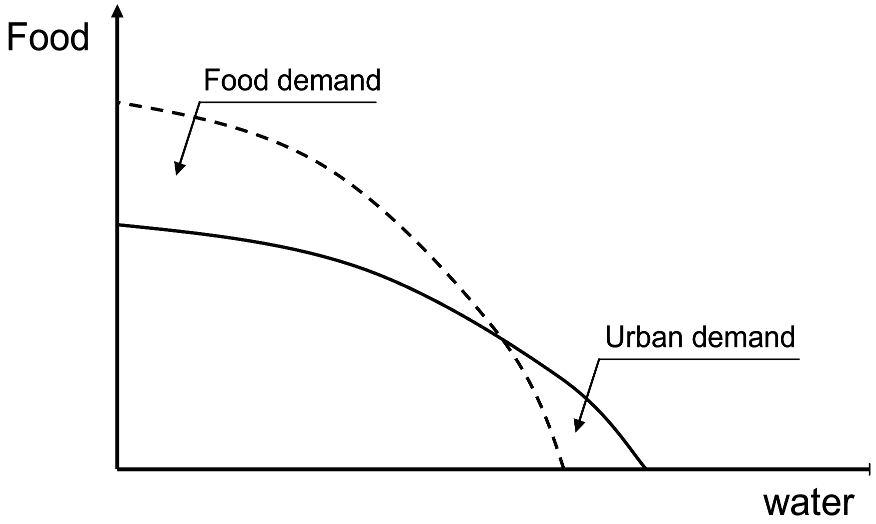


Figure 2. Trade-offs between water and food demand vs. urban demand, where food can be increased but only by diminishing water. The trade-offs may alter with the advent of new technologies.
Source: Millennium Ecosystem Assessment

Available fresh water consists predominantly of precipitation that falls on land surfaces. It is then returned to the atmosphere through evapotranspiration or enters the sea, lakes, etc. via drainage. Water absorbed from soil moisture by plants and returned to the atmosphere through evapotranspiration is termed 'green water' (CAS 2006) and is the main source of support for land-based biodiversity, including forests, grasslands and agriculture. Run-off water that enters rivers and tributaries and recharges aquifers is termed 'blue water' (IWMI 2006). It also flows back to the atmosphere through evaporation, interception and transpiration by plants (CAS 2006). Blue water is the primary source for use in irrigation, industry and homes (rural and urban) and for waste disposal, etc. Green water flows account for 65% of global precipitation, while blue water flows account for the remainder. About 10% of total blue water flows are withdrawn for irrigated agriculture (CAS 2006).

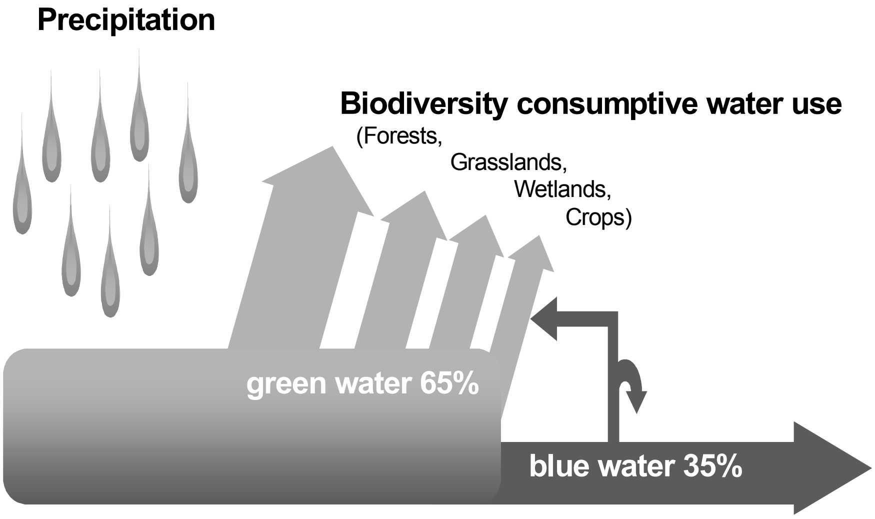


Figure 3. Biodiversity consumptive water use.
Source: Global Water System Project, 2005

Eighty percent of global agricultural water use is from green water sources. This is subject to large regional variation, however, and the WANA region in particular uses mainly blue water sources, accounting for more than 50% of agricultural usage (CAS 2006).

Water scarcity

Although water is a renewable natural resource, human exploitation often outweighs replenishment (Kroll 2000; Kirby 2004a). Over the past 50 years or so, water availability has been rapidly declining. Indicators of unsustainable water use, such as falling water tables, shrinking lakes and the drying up of rivers and streams, are numerous and can be encountered in most important food-producing regions of the world (Postel 1998, 2003). In addition to water quality problems, arid and semi-arid regions in particular face the challenge of absolute water scarcity (Vörösmarty et al. 2000). Recent concern over water resource scarcity problems has led many governmental and non-governmental organizations (e.g. UNESCO, WMO, UNEP, FAO, IAHS, IAWR and CGIAR) to initiate activities dealing with water issues, both at the global and at regional level (Shiklomanov 1999; CAS 2006). The recent report of the IWMI Comprehensive Assessment of Water Management in Agriculture says one-third of the world's population faces water scarcity (CAS 2006; BBC on 21 August 2006). Economic growth of a number of developing countries has already been hampered as a result of water scarcity and poor quality, leading to adverse health and livelihood conditions (UNESCO-WWAP 2006). It is estimated that up to 65% of the losses in current crop productivity are attributable to water stress (Boyce Thompson Institute 2006; Gleick 1998). The number of countries with catastrophically low annual water availability (<1000 m^3 per capita) has increased dramatically as a result of population growth, pollution and climate change (Shiklomanov 1999; IPCC 2001). The Center for Strategic and International Studies (CSIS 2005) has estimated that over half the world's population will live in water-stressed or water-scarce countries by 2025.

Population growth

The present global human population is approximately 6.4 thousand million and is growing at the rate of some 70 million per year, mostly in low-income countries (UNESCO-WWAP 2006). Along with this population increase, the proportion of water use has increased rapidly in recent decades. Human population growth has led to an increased demand for food, which has led to an increase in agricultural water use. The area of irrigated land more than doubled in the 20th century. Ground-water resources are depleting as a result of overexploitation and further increasing populations will create more pressure in the coming decades. This is detrimental to food security and water supply for both domestic and industrial uses.

Pollution

The industrial and human waste disposal processes, along with reduced downstream river flow volume, has led to a depletion in water quality, resulting in rivers of little or no value for other potential users. Some rivers in a number of countries now do not drain sufficient water from the land into the sea or lakes and instead contain a high level of toxic waste (World Commission on Water for the 21st century, 2000). In some developing countries, nearly 75% of all industrial waste and 90–95% of sewage is discharged into surface waters without any treatment (UNEP FI 2004).

Climate change

Climate change is also likely to lead to a decrease in water availability (IPCC 2001). In fact, recent estimates suggest that climate change will account for about 20% of the increase in global water scarcity (UNESCO/WWAP 2003). Some dry regions of the world, such as WANA, are already experiencing more frequent intermittent and consecutive dry weather in recent years than in the past (IPCC 2001). An increase in magnitude and frequency of drought cycles has been reported in the West Mediterranean region (e.g. North Africa) over the last two decades. As a result of climate change, it is probable that the regions facing water-scarcity now will become drier (Kirby 2004b). This increased frequency and intensity of water-related natural disasters, such as drought, is adding an additional burden to the human and environmental development of countries (UNESCO-WWAP 2006). Water resource deficits have a negative impact, causing deterioration in the living standards of populations, and retarding the economic and social development in most developing countries (Shiklomanov 1999).

Water challenge

Paradoxically, the agricultural sector will be facing the complex challenge of producing more food of a better quality while using less water per unit of produce (UNESCO-WWAP 2006). Here, technology can offer significant opportunities for the agricultural water sector (UNESCO-WWAP 2006). For example, irrigation efficiency in most developing countries is only 25-45%, while it reaches 50-60% in developed countries such as Japan (Rosegrant et al. 2002a).

This workshop explores some of the ways of better water management under conditions of water availability and scarcity, where water demand rather that water supply is the challenge (Brooks 2002).

Water demand

While water supplies are being depleted, water demand is growing rapidly, particularly in developing countries, where a large increase is expected (Vörösmarty et al. 2000; Rosegrant et al. 2002a). Water supplies are becoming limited at a time when more water is needed to produce more food. Although the increase in demand will be much faster for urban than for agricultural purposes, increasing water scarcity will affect agriculture to a greater extent (Rosegrant et al. 2002a).

Water requirements of many agricultural crops have been studied empirically, and their crop coefficients (K_c) for water demand based on evapotranspiration (ET_o) have been developed. The requirements are based on the reference crop ET_o, taking into consideration the different stages of development. Net crop water demand (NCWD) in a basin in a year is thus (Rosegrant et al. 2002a):

$$NCWD = \sum_{cp} \sum_{ct} kc^{cp,ct} \cdot ET_o^{ct} \cdot A^{cp} = \sum_{cp} \sum_{ct} ET_{crop}^{ct,cp} \cdot A^{cp}$$

ET_o is the reference evapotranspiration in mm per unit of time e.g. mm/day, mm/month or mm/season. It is defined as the rate of evapotranspiration from an area covered completely by green grass without water shortage (FAO 1998; Botia 2001; Orgaz and Fereres 2001).

ET_o provides a standard to which: a) evapotranspiration at different periods of the year or in other regions can be compared; and b) evapotranspiration of other crops can be related. ET_o is estimated based on the FAO Penman-Monteith combined methods which were developed to provide actual crop water use data worldwide. The equation combines the original Penman-Monteith equation and the equations of the aerodynamic and surface resistance, and uses standard climatological records as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

Where:

ET_o = reference evapotranspiration [mm day^{-1}],

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = soil heat flux density [MJ m^{-2} day^{-1}],

T = mean daily air temperature at 2 m height [°C],

u_2 = wind speed at 2 m height [m s^{-1}],

e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa],

$e_s - e_a$ = saturation vapour pressure deficit [kPa],

Δ = slope vapour pressure curve [kPa °C^{-1}],

γ = psychrometric constant [kPa °C^{-1}].

The rate at which a crop evaporates water through transpiration depends on the climate. ET_{crop} (potential crop evapotranspiration) estimates the water requirement of a given crop in mm per unit of time, e.g. mm/day, mm/month or mm/season. Kc is the crop coefficient, which depends on the crop (cp), the crop's growth stages (ct) and A the crop area. Part of the water requirement or demand can be satisfied from the water available in the root zone as a result of the rainfall infiltrated into the soil and called effective rainfall (*PE*).

The effective rainfall (PE) is a function of total rainfall (PT) and also plant evapotranspiration (ET_{crop}) in addition to soil characteristics in terms of effective water storage and hydraulic soil features (Rosegrant et al. 2002a), namely:

$$PE^{cp,st} = f \cdot \left(1.253\, PT^{st^{0.824}} - 2.935\right) \cdot 10^{\left(0.001\, ET_{crop}^{cp,st}\right)}$$

where f is the correction factor that depends on the depth of irrigation: f = 1 when the depth of irrigation is 75 mm.

PE can be improved through rainfall harvesting techniques so that more water is available to the roots, and thus increase water productivity

In terms of crop stages for olives, Pastor and Orgaz (1994) found monthly K_cs to be as follows: 0.50, 0.50, 0.65, 0.60, 0.55, 0.50, 0.45, 0.45, 0.55, 0.60, 0.65 and 0.50 for the months from January to December. These coefficients can be invoked by using K_c ini = 0.65, K_c mid = 0.45 and K_c end = 0.65, with stage lengths = 30, 90, 60 and 90 days, respectively, for initial, development, mid-season and late-season periods, and using K_c = 0.50 during the winter ("off season"), i.e. December to February (FAO 1998).

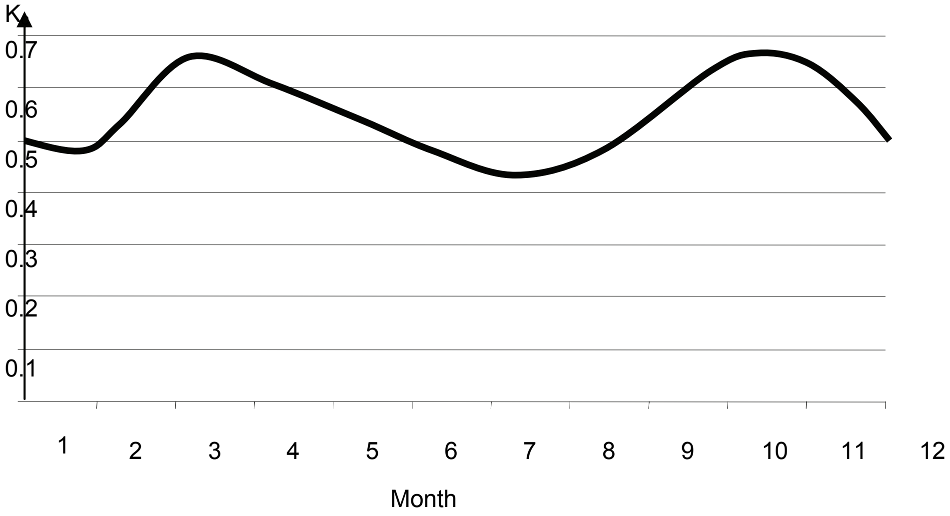


Figure 4. Monthly K_cs for months January to December found by Pastor and Orgaz (1994) in olive orchards in Spain having 60% ground cover.
Source: FAO, 1998.

Thus, the rate of evapotranspiration depends on climate, with the highest values of ET_o being found in areas that are hot, dry and sunny, such as those of the Mediterranean southern regions.

Table 2. Water demand and supply in the WANA region.

Country	Average annual ET_o (mm)	Average annual Precipitation (mm)	Internal water (km^3)	Inflow (km^3)
Egypt	1621	57	2.3	58.8
Other WANA	1605	417	77.4	50.5

Source: Rosegrant et al. 2002a

Water supply

Water supply is the total water available for use from all sources. Available water includes water renewed by natural cycling (rainfall), ground-water and basin water (artificial or natural), and also includes non-renewable water (aquifers).

Available water may not be fully utilized for human consumption. In terms of rainfall, which is the only water source under rain-fed conditions, the water used for crop growth is the effective rainfall, which is mentioned above. The effective water supply for irrigation (*EWIR*) is measured at the basin level and depends on both environmental and anthropogenic factors. Most agriculture is carried out under rain-fed conditions, but irrigated land accounts for about one-fifth of the total arable area in developing countries (UNESCO/WWAP 2003).

Water supply is thus calculated based on both hydrologic and anthropogenic factors, where the latter are crucial in defining the renewable water portion. The anthropogenic factors can be grouped into (1) water demands; (2) water flow and ground-water extraction; (3) water losses that include water used as disposal; and (4) water allocation policies that include diversion of water from agriculture to other uses, such as municipal use (Rosegrant et al. 2002a). The effectiveness with which the water supply is used in agriculture, which is the main user, affects also the water hydrologic processes, hence the importance of WUE.

Water-use efficiency

Increasing water productivity is an important strategy to increase food production (Rosegrant et al. 2002a) under conditions of limited water supply.

Water productivity (*WP*) is defined as crop yield (*P*) per cubic metre of water consumption (*WC*), including green water (effective rainfall in rain-fed areas) and/or blue water (from water systems in irrigated areas) (Rosegrant et al. 2002a):

$$WP = P/WC$$

Water productivity must be considerably increased in response to growing water scarcity if enough food is to be produced for a growing population (CAS 2006). As water resources are constrained, further water productivity improvements will be essential (World Bank 2006).

IWMI is currently developing an analysis of water productivity (Molden et al. [2006, in prep.]). A recent report by CAS stressed the importance of improving the performance of irrigated areas, and improving agricultural productivity from areas dependent on rainfall, in particular. In these areas, smallholder farmers are in possession of the greatest unexploited potential to directly influence land and water-use management. Around 70% of the world's poor live in rural areas where non-agricultural livelihood options are limited. Thus, improving agricultural productivity in rural areas has the greatest potential to reduce poverty and hunger (CAS 2006). In its broadest sense, crop water productivity relates to producing more food and generating more income, aiming at improving livelihoods at less social and environmental cost per unit of water used in agriculture (CAS 2006).

There is also a potential to improve production under on-farm conditions because of the gap between actual and theoretical yield, where physiology is yet to play an important role (Figure 5) (Falkenmark and Rockstrom 2004). Rain-fed farmers typically farm marginal or dry lands, with little or no access to a controlled water source. Although they account for 60% of current agricultural output in developing countries, they have been largely bypassed by the improvements made elsewhere in terms of yield and water management. This, coupled with smaller genetic gains compared to wetter areas or areas where irrigation is practised, has kept production low (World Bank, 2006; Richards et al. 2002).

A number of studies conducted by ICARDA on the economic assessment of on-farm water-use efficiency demonstrate the low values of WUE in crop production (Kamil et al. 2005).

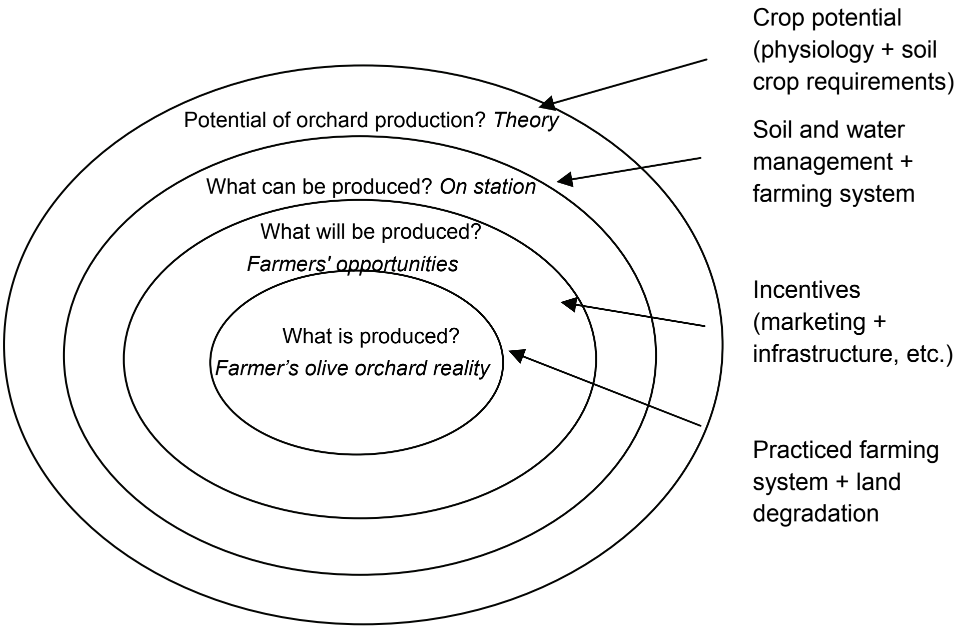


Figure 5. Conceptual framework of actual yield at the farm level and different potential yields at different levels.
Source: Adapted from Falkenmark and Rockstrom 2004.

Water productivity, therefore, relates agricultural production to water use and WUE is thus an effective measure for improving water productivity (Rosegrant et al. 2002a).

Table 3. WUE of commonly grown crops in the Mediterranean region.

Crop	**Yield** (10^3 t/yr)	**WUE** (m^3/t)		
		Mean	**Low**	**High**
Barley	159 021	1070	539	1 575
Wheat	557 420	1 482	787	2 643
Pistachio	386	415	200	1 080
Olive	11 100	583	500	667

Source: Rockstrom et al. 1999.

WUE is generally expressed as the ratio of total dry matter production to evapotranspiration. It is expressed in the following equation:

$$\text{WUE (biomass)} = \frac{TE}{1 + {}^{E_s}\!/_{T}}$$

where, *TE* is the transpiration efficiency (above ground dry weight/transpiration), *ES* is the water lost from the soil surface by evaporation, and *T* is water lost through transpiration by the crop (Richards et al. 2002). This equation shows that crop WUE can be increased either by increasing its nominator *TE* or decreasing the magnitude of its denominator *ES* (Richards et al. 2002).

In addition to agronomic options to improve WUE, another factor is the genetic variation (*cg*) that plays a role in water-use by different crops (Condon et al. 2002). Thus the equation for NCWD can be further refined into:

$$NCWD = \sum_{cp}\sum_{cg}\sum_{ct} kc^{cp,cg,ct} \cdot ET_0^{ct} \cdot A^{cp,cg} = \sum_{cp}\sum_{cg}\sum_{ct} ET_{crop}^{ct,cp,cg} \cdot A^{cp,cg}$$

Similarly, the equation for effective rainfall under rain-fed conditions can be also further refined into:

$$PE^{cp,cg,st} = f \cdot \left(1.253\, PT^{st^{0.824}} - 2.935\right) \cdot 10^{\left(0.001\, ET_{crop}^{cp,cg,st}\right)}$$

where (*cg*) is the index of genotypes, *f* is the correction factor that depends on the depth of irrigation, total rainfall (*PT*), both crop (*cp*) and genotype (*cg*) evapotranspiration, the crop stage (*st*) and effective soil water storage.

Conclusion

The papers presented during the workshop show that there are opportunities for saving water and improving productivity, aiming in particular at managing water demand. In this context, within-species diversity is also important as it provides an opportunity to mitigate water scarcity and stress (Chaves and Oliveira 2004; Richards et al. 2002). Natural variation can play a major role in locating potential genotypes with high water productivity (Condon et al. 2002; Ebdon and Kopp 2004). The screening of genetic diversity for WUE traits within species provides a valuable opportunity for improving water productivity in the arid regions, in light of the recent findings of extensive within crop variation in relation to WUE (Richards et al. 2002). Variation among genotypes with respect to WUE parameters (gas exchange and carbon isotope discrimination) and other traits associated with WUE, such as root architectural features, has been reported by a number of authors in recent years.

The role of diversity in managing water scarcity as a genetic option is further addressed in subsequent contributions.

References

BBC. 2006. Map details global water stress. http://news.bbc.co.uk/2/hi/science/nature/5269296.stm#graphic. Last Updated: Monday, 21 August 2006, 11:28 GMT 12:28 UK.

Botia, J.A., Gomez-Skrmeta, A.F., Valdes, M. & Padilla, A. 2001. Data mining applied to water irrigation management. pp. 547–554, in: J. Mira and A. Prieto (editors). Proceedings, Part II, of Bio-inspired Applications of Connectionism, 6th International Work-Conference on Artificial and

Natural Neural Networks, IWANN 2001. Granada, Spain, 13–15 June 2001. Springer-Verlag, Berlin, Germany.

Boyce Thompson Institute. 2006. The genomics of water-use efficiency project. http://isotope.bti.cornell.edu/home.html, accessed November 14th, 2006.

Brooks, D.B. 2002. Water: Local-level management. International Development Research Centre. Ottawa, Canada.

CSIS [Centre for Strategic and International Studies]. 2005. Addressing Our Global Water Future, Sandia National Laboratories.

Chaves, M.M. & Oliveira, M.M. 2004. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. *Journal of Experimental Botany* 55(407). Water-Saving in Agriculture Special Issue, pp. 2365–2384

CAS [Comprehensive Assessment Secretariat]. 2006. Insights from the Comprehensive Assessment of Water Management in Agriculture. International Water Management Institute (IWMI), Colombo, Sri Lanka, Stockholm World Water Week, 2006. Accessed 22nd of August 2006 at http://news.bbc.co.uk/2/shared/bsp/hi/pdfs/21_08_06_world_water_week.pdf

Condon, A.G., Richards, R.A., Rebetzke, G.J. & Farquhar, G.D. 2002. Improving intrinsic water-use efficiency and crop yield. *Crop Science*, 42:122–131.

Ebdon, J.S. & Kopp, K.L. 2004. Relationships between water use efficiency, carbon isotope discrimination and turf performance in genotypes of Kentucky bluegrass during drought. *Crop Science*, 44:1754–1762.

Falkenmark, M. & Rockstrom, J. 2004. Balancing water for humans and nature. Cromwell press, UK.

FAO. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper*, No. 56. http://www.fao.org/docrep/X0490E/x0490e00.HTM

FAO. 2003. Unlocking the water potential of agriculture. http://www.fao.org/DOCREP/006/Y4525E/y4525e05.htm

Gleick, P.H. 1998. The World's Water 1998–1999: The Biennial Report of Freshwater Resources. Island Press, Washington, DC, USA.

Gleick, P. 2002. Soft water paths. *Nature*, 418: 373.

Global Water System Project. 2005. *Global Water News*, Issue No. 2. http://www.gwsp.org/

IPCC [Intergovernmental Panel on Climate Change]. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson, eds.]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881pp. http://www.ipcc.ch/pub/un/syreng/spm.pdf.

IWMI [International Water Management Institute]. 2006. Presentation prepared for the 4th World Water Forum, Mexico, 16–22 March 2006. See: http://www.iwmi.cgiar.org/WWF4/html/watersituation.htm

Kamil, S., Oweis, T. Gabr, M. & Osman, M. 2005. Assessing on-farm WUE: A new approach. ICARDA. Aleppo, Syria.

Kirby, A. 2004a. Water scarcity: A looming crisis? Last Updated: Tuesday, 19 October 2004, 17:20 GMT 18:20 UK. BBC, UK

Kirby, A. 2004b. Climate change: Uncharted waters? BBC. Last Updated: Friday, 3 December, 2004, 09:56 GMT

Kroll, A. 2000. Water at the Third Earth Summit (Rio +10, 2002). Institute for Prospective Technological Studies, Seville.

Molden, D., Oweis, T.Y. et al. In preparation. Pathways to Improve Agricultural Water Productivity, IWMI. Chapter in : Water For Food, Water For Life. http://www.iwmi.cgiar.org/assessment/Synthesis/CAWorkingOutline.htm

Orgaz, F. & Fereres, E. 2001. Reigo. In: D. Barranco, R. Hernández-Escobar and L. Rallo (editors). El Cultivo del Olivo Junta de Andalucía. Consejería de Agricultura y Pesca. Ediciones Mundi-Prensa, Madrid, Spain.

Pastor, M. & Orgaz, F. 1994. Riego deficitario del olivo. *Agricultura,* 746:768–776

Postel, S.L. 1998. Water for food production: will there be enough in 2025? *Bioscience*, 48:629–637.

Postel, S.L. 2003. Securing water for people, crops and ecosystems: New mindset and new priorities. Natural Resources Forum, 27(2):89–98.

Richards, R.A., Rebetzke, G.J., Condon, A.G. &van Herwaarden, A.F. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Science*, 42:111–121.

Rockstrom, J., Gordon, L., Folke, C., Falkenmark, M. & Engwall, M. 1999. Linkages among water vapour flows, food production and terrestrial ecosystem services. *Conservation Ecology*, 3(2):5. http://www.consecol.org/vol3/iss2/art5

Rosegrant, M.W., Cai, X. & Cline, S.A. 2002a. World water and food to 2025: dealing with scarcity, International Food Policy Research Institute (IFPRI), Washington DC, USA.

Rosegrant, M.W., Cai, X. & Cline, S.A. 2002b. Global water outlook to 2025. A 2020 vision for food, agriculture and the environment. IFPRI/IWMI.

Rosenfeld, D. 2006. Aerosols, clouds and climate. *Science*, 312:1323–1324.

Shiklomanov, I.A. 1999. World water resources and their use. State Hydrological Institute (SHI)/UNSECO. http://webworld.unesco.org/water/ihp/db/shiklomanov/index.shtml

UNDP. 2006. Human Development Report 2006. Beyond scarcity: Power, poverty and the global water crisis. United Nations Development Programme, New York, New York, USA.

UNEP FI [United Nations Environment Programme Finance Initiative]. 2004. Challenges of Water Scarcity. Stockholm International Water Institute (SIWI). United Nations Environment Programme.

UNESCO/WWAP [United Nations/World Water Assessment Programme]. 2003. 1st UN World Water Development Report: Water for People, Water for Life. Paris, New York and Oxford. UNESCO (United Nations Educational, Scientific and Cultural Organization) and Berghahn Books. See: http://www.unesco.org/water/wwap/wwdr1/ and http://unesdoc.unesco.org/images/0012/001295/129556e.pdf

UNESCO-WWAP. 2006. Water: A Shared Responsibility. The United Nations World Water Development Report 2: Paris and New York. UNESCO (United Nations Educational, Scientific and Cultural Organization) and Berghahn Books. http://www.unesco.org/water/wwap/

Vörösmarty, C.J., Green, P., Salisbury, J. & Lammers, R.B. 2000. Global water resources: vulnerability from climate change and population growth. I, 289(5477):284–288.

World Bank. 2006. Reengaging in Agricultural Water Management: Challenges and Options. The International Bank for Reconstruction and Development/The World Bank, Washington, USA.

World Commission on Water for the 21st Century. 2000. World Water Vision. The Second World Water Forum. The Netherlands.

The effect of deficit irrigation on olive production

R. Al-Shayeb, G. Abboud, L. Allouna and A.J. Mjaweiz

General Commission for Scientific Agricultural Research, Damascus, Syria
E-mail: gcsarhortcul@mail.sy

Abstract

Olives play an important socio-economic role in Syria. According to 2002–2003 statistical data, the cultivated area under olive reached 517 000 ha, comprising approximately 74 million trees with a production of 726 000 t of olives and 137 000 t of olive oil, of which 30 000 t of the latter was exported. As a result, the General Commission for Scientific Agricultural Research (GCSAR) conducted research activities to study new water requirements with the aim of eventually regulating and reducing irrigation. Different water treatments were applied, as percentages of full water requirements, to study their effects on yield, oil and morphological properties of four commonly grown olive varieties in Syria. This research was conducted at Sirbaya research station, in southwest Aleppo. The station receives an average of 300 mm/year of rainfall, and total evaporation (ET_o) amounts to 1862 mm/year.

The total water requirement was estimated as 4370 m^3 ha^{-1} and the amount of applied irrigation was 4161 m^3 ha^{-1}. The water was applied through 13 irrigations with a total irrigation rate of 247 m^3 ha^{-1} and application efficiency of 89%. Yield by variety of the four cultivars, 'Jlot', 'Tamrani', 'Kayssi' and 'Sorani', were 3692, 3784, 3413 and 3100 kg ha^{-1} for fruits, and 581, 888, 820 and 915 kg ha^{-1} for oil, respectively. There were also differences between cultivars in terms of their WUE values, giving 1.15, 1.18, 1.06 and 0.96 kg m^3 for fruits, and 0.18, 0.28, 0.26 and 0.28 kg ha^{-1} for oil, respectively.

Applications of 100% and 75% of water requirements showed no significant difference in the results emerging from the different treatments, but there was a significant difference between these and the results of other treatments using less than the 75% requirement.

Key words: olive cultivation, deficit irrigation, olive cultivars

Introduction

Olives have been playing an increasingly important socio-economic role in Syria. According to 2002-2003 statistical data (Table 1), the cultivated area under olives reached 517 000 ha, comprising approximately 74 million trees, with a production of 726 000 t of olives and 137 000 t of olive oil, of which 30 000 t of the latter were exported.

Table 1. Trends in olive cultivation.

Year	Estimated tree number	Area (ha)	Production (t)	
			Fruit	Oil
1980-81	20 200 000	249 000	299 000	54 000
2002-03	74 000 000	517 000	726 000	137 000
% increase	266	108	143	154

Source: Ministry of Agriculture 2002/03.

This increase in olive cultivation over the last 2 decades has led the General Commission for Scientific Agricultural Research (GCSAR) to conduct research activities investigating the water requirements of olives, with the aim of reducing and regulating irrigation and, in so doing, meeting the needs of expanding olive cultivation. The aim of this work is to improve water-use efficiency (WUE) in olives, which is currently approximately 40–50%.

Material and methods

Different water treatments, as percentages of full water requirements, were applied to study their effects on yield, oil and morphological properties of four varieties, chosen on the basis of their reportedly different water-use attributes. These varieties are commonly grown in Syria and their characteristics and distribution in the country is described in Table 2.

The research was conducted at Sirbaya research station, southwest of Aleppo. The station receives an average of 300 mm/year of rainfall, and the total evaporation (ET_o) amounts to 1862 mm/year. The total water requirement was estimated to be 4370 m^3 ha^{-1}, based on prevailing conditions at Sirbaya. The amount of water applied in each treatment, (maximum 4161 m^3 ha^{-1}) was based on almost 90% of the total requirement (Table 3). The water was applied through 13 irrigations with a total maximum irrigation rate of 291 m^3 ha^{-1}. These were applied unevenly over the year, based on water consumption according to the phenological stages of the olive tree and the environment (monthly K_c). The highest frequency of irrigation was observed during June, July and August.

Oil and fruit yield results were compiled and compared with water supply data in order to measure WUE. Analysis was undertaken to detect any correlation between the amount of water applied and the performance of the cultivars under the different water treatments. Analysis of variance was also undertaken to determine any significant difference between water treatments and whether WUE differs significantly between cultivars.

Results and discussion

Applications of 100% and 75% of the water requirement were not significantly different from each other, whereas both treatments were significantly different from those utilizing less than 75% of the water requirement (Table 4).

This suggests that water saving of at least 25% is a realistic goal under similar circumstances, with Jlot and Tamrani producing significantly higher fruit yields. However, in terms of oil yield, Jlot produces the least (Table 5).

There were differences between cultivars in terms of their WUE values (Table 5). Jlot had the lowest WUE of the four cultivars with regard to oil production, but this may be offset by the relatively high fruit production WUE. The difference between the cultivars is more pronounced when the water applied is less than 75%, reaching 50% (Figure 1), but this occurs at the expense of potential yield. In this regard, Sorani is the most efficient cultivar as its WUE value reaches 0.36, far exceeding that of the three other cultivars (Figure 1b).

The results show that diversity within olives can play a role in improving WUE, particularly when the plant is under stress (below water requirements). The difference between the cultivars is highly significant based on average values across the 4 treatments for both fruit and oil yield (Table 6). Sorani would be more efficient as a dual-propose cultivar aimed at producing either fruit or oil under relatively limited water resource conditions when compared to the others (Table 6 and Figure 1).

Table 2. Olive cultivars, characteristics and distribution.

	Cultivar*			
	Jlot	**Sorani**	**Kayssi**	**Tamrani**
Agronomic and economic considerations	Grown as a table olive. It produces abundant fruit	Produces abundant fruit; used for pickling and oil production, which is much appreciated for its quality. There are different types of Sourani and thus this cultivar may in fact be a mixture of genotypes.	Appreciated mostly for its oil quality, but also consumed as a table olive	This is a cultivar that grows well in humid areas but it can also tolerate drought to a certain degree.
Area of cultivation	Mainly confined to the southern provinces (Damascus, Sweida and Kuneitra), but can also grow in other areas	Grows in almost all provinces, most abundantly in Idelb and Homs	Commonly grown in Aleppo, Idle, Homs, Hama and Damascus and the southern provinces.	Latakia, Tartus and Tel-Kalakh
Leaf	Long with medium width.	Long with medium to small width	Small in size and relatively wide	Very large
Fruit	Large size, elongated	Medium sized	Medium sized, rounded, with clear lenticels	Very large and ovoid
Stress tolerance	It is cold tolerant and, to some extent, drought tolerant	Tolerant to drought, cold and salinity	Cold and drought tolerant	Drought tolerant to some degree

Note: * when comparing cultivars, caution is needed as some cultivars may have the same name in different regions.
Source: Barranco et al. 2000; Zaghloula 2000.

Table 3. Water requirements of the different treatments.

Treatment	**Water applied**	**Net irrigation rate** (m^3/ha)
Full	4161	291
75%	3208	220
50%	2147	144
25%	1132	74

Table 4. Average fruit and oil yield (kg/ha) for each water treatment.

Water treatment	**Average fruit yield** (kg/ha)	**Average oil yield** (kg/ha**)**
100%	3654^{a*}	842^{a}
75%	3497.3^{a}	808^{a}
50%	2488.8^{b}	556.3^{b}
25%	1136.5^{c}	234.5^{c}

Note: * Values with the same letter are not statistically different at both confidence levels of 5% and 1%.

Table 5. Yield and WUE of the 4 cultivars for 75% of water requirements.

Cultivar	**Yield (kg/ha)**		**WUE**	
	Fruit	**Oil**	**Fruit (kg/m3)**	**Oil (kg/ha)**
Jlot	3692	581	1.15	0.18
Kayssi	3413	820	1.06	0.26
Sorani	3100	915	0.96	0.29
Tamrani	3784	888	1.18	0.28

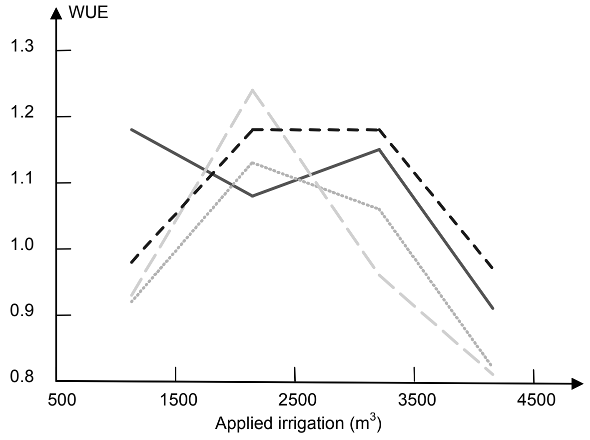
Table 6. Average fruit and oil yield per cultivar (kg/ha).

Cultivar	Fruit	Oil
Jlot	2494.2^{a*}	370^{d}
Tamrani	2496^{a}	568^{b}
Kayssi	2266.6^{b}	533^{c}
Sorani	2224^{b}	649^{a}

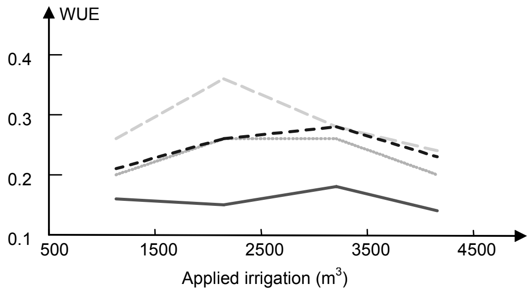
Note: * Values with the same letter are not statistically different at both confidence levels of 5% and 1%.

Difference between cultivars in terms of WUE has been reported, based on the ratio of CO_2 (g) per H2O (1000 g) and the carbon isotope discrimination ^{13}C values in olives and grapes, respectively (Fernández and Moreno 1999; Gaudillere et al. 2002). Drought-tolerant and water-use efficient genotypes, including Kayssi, known for its drought tolerance, have also been reported in Syria (Barranco et al. 2000; Zaghloula 2000; Bari et al. 2004).

Overall, WUE is not linear, as more water may not necessarily mean more yield, particularly where quality is important, as in olive oil production (Figure 1).



a) Fruit production

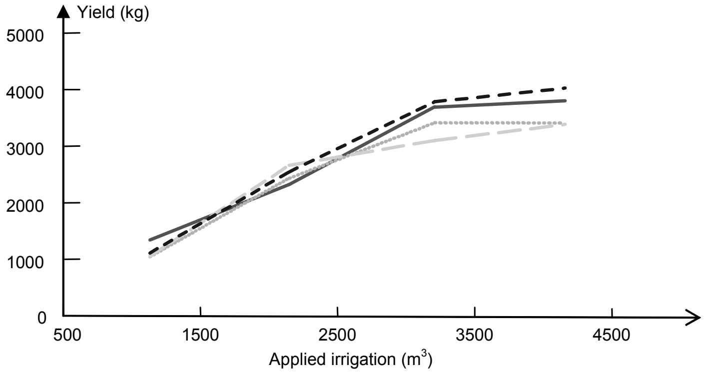


b) Oil production

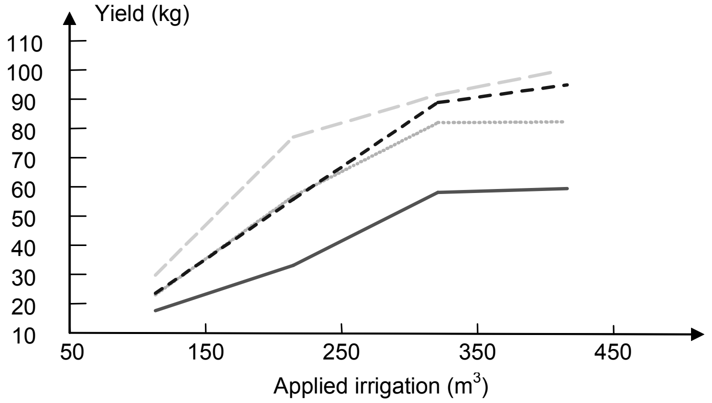
Figure 1. Changes in WUE of both fruit (a) and oil (b) yields relative to the amount of irrigation.

Key to cultivars: —— **Jlot** ┈┈ **Kayssi** – – – **Sorani** - - - - **Tamrani**

WUE is high for both oil and fruits within the range of 2000-3000 m^3/ha. Savings can therefore be made without significantly jeopardizing the overall yield, particularly if the most appropriate cultivar is used. For example, if the aim is oil production, Sorani would be most appropriate under conditions similar to those of Sirbaya Station, as this cultivar produces more oil per kg of fruit than do all the others, while maintaining a similar WUE. Figure 2 shows the difference in yield for the different cultivars.



a) Fruit yield per cultivar



b) Oil yield per cultivar

Figure 2. Fruit (a) and oil (b) yield versus irrigation applications.

Key to cultivars: —— **Jlot** ········ **Kayssi** – – – **Sorani** - - - - **Tamrani**

References

Bari, A., Ayad, G., Martin, A., Gonzalez-Andujar, J.L., Nachit, M. & Elouafi, I. 2004. Fractals and water use efficiency. *in:* M.M. Novak (editor) Thinking in patterns. pp. 315–316. World Scientific, Singapore.

Barranco, D., Cimato, A., Fiorino, P., Rallo, L., Touzani, A., Castañeda, C., Serafini, F. & Trujillo, I. 2000. World Catalogue of Olive Varieties. International Olive Oil Council (IOOC), Madrid, Spain.

Gaudillere, J.P, Leeuwen, C.V. & Ollat, N. 2002. Carbon isotope composition of sugars in grapevine, an integrated indicator of vineyard water status. *Journal of Experimental Botany*, 53(369): 757–763.

Fernández, E. & Moreno, F. 1999. Water use by the olive tree. *Journal of Crop Production*, 2(2): 101–162.

Zaghloula, M.A. 2000. Catalogue of main local and introduced olive cultivars in Syria. General Commission for Scientific Agricultural Research, Damascus, Syria.

Future vision of olive plantation and water-use efficiency in Jordan

S.M. Al-Shdiefat

National Center of Agricultural Research and Technology Transfer (NCARTT), Jordan
E-mail: salehshd2002@yahoo.com; salehshd@ncartt.gov.jo

Abstract

Olive (*Olea europaea* L.) is a major agricultural crop in the Mediterranean basin, where it has been grown for centuries. Its cultivation originated from the eastern part of the Mediterranean, over 6000 years ago. From there, the Phoenicians and successive civilizations spread it to the rest of the Mediterranean region. Jordan is considered a centre of origin for olive cultivation. Today, the country's olive trees cover some 72% (123 000 ha) of the total area planted to fruit trees, representing 36% of the total cultivated area. The two main producing areas are the western mountains (rain-fed), accounting for some 76% of production, and the remainder from the eastern desert area (irrigated). Water-use efficiency (WUE) is defined as the ratio of photosynthesis to water loss due to transpiration. Water productivity is measured by the volume of water used to produce a unit of the product – in this case, a kilogram of olive fruits or olive oil. In general, the lower the water needed per unit of production, the higher the efficiency. Thus, to improve water-use efficiency in olive plantations, the water requirement per unit of olive production should be lowered. In order to maintain soil moisture content at field capacity and thus avoid drought stress conditions during Jordan's olive production season, some 350–400 mm of annual precipitation is required, evenly distributed during the winter season (October-March), is required. In terms of olive genetic resources, the main drought tolerant cultivars are 'Souri', 'Nabali' and 'Rasei'. Efforts will be made to further explore olive diversity so as to develop more water-use efficient cultivars and thus keep pace with the growth in olive production over the last decade.

Key words: Olive production, water requirement, water-use

Introduction

Jordan lies between 29° and 32° N latitude and 35° to 39° E longitude, and is considered one of the homelands of olive cultivation. Its climate is predominantly Mediterranean, and can be divided into three zones: 1) the West Mountains area, characterized by cool winters and temperate summers; 2) the Jordan Valley area, characterized by warm winters and hot summers; and 3) Badia (desert areas), characterized by cool winters and hot summers. The rainfall season lasts from mid-November to the following April or May. Annual rainfall varies across these zones, with the highest precipitation falling in the West Mountains (>400 mm). Precipitation levels decrease gradually west to east, east to south and into the desert areas, where less than 100 mm of rain falls each year (Metrology Department Website 2005; FAO 2003). Only about 20% of the country receives >200 mm of rainfall per year (Jitan 2004). Moreover, rainfall varies widely from year to year, and crops are affected by periodic drought. Wind is predominantly northwest to southwest.

Water is thus the most important environmental parameter determining crop production in Jordan, and olive production in particular. As a result, the major part of olive cultivation (76%) is in the rain-fed area (western mountains) with the remaining 24% cultivated under irrigation in the eastern desert area (Ministry of Agriculture 2003). A doubling of the area of olive plantations between 1991 and 2003 means that they now cover about 123 000 ha of agricultural area (Table 1).

Table 1. Olive cultivation (×1000).

	Year			
	1991	1995	2000	2003
Area (ha)	67 900	85 700	110 300	123 000
Production* (t)	31 300	64 900	184 800	162 000

Note: * Taking into consideration the alternate bearing habit, which results in production variation from year to year (odd years in Jordan are generally Off-Years. At the same time, there has been an increasing production trend since 1991 for both odd and even years.

In terms of the amount of water required for olive production in Jordan in order to maintain soil moisture content at field capacity and thus avoid drought stress conditions during the olive production season, some 350–400 mm of annual precipitation is necessary, evenly distributed during the winter season (October–March).

Historically, use of surface run-off and rain harvesting techniques were practiced extensively in the country as far back as 4000 years ago. Archaeological remains indicate that farmers had practiced agriculture in areas with annual rainfall as low as 100 mm. Pools, hafirs and cisterns have been found on many archaeological sites, and continued to be in widespread use as late as the 1860s. Some of these structures are still in good operating condition, such as the Roman pools near Madaba, Mwaggar and Ajloun, and Nabatiean's dams and cisterns. Harvested rain from the surrounding mountains was channelled and piped to Petra during winter, and stored in cisterns and excavated rock reservoirs for domestic use during the rest of year. Rain-fed agriculture outside the cities was supported by harvested water (Jitan 2004; Nydahl 2002).

Soil and water management have been very important in improving water-use efficiency for the country's sustainable olive production under rain-fed conditions. In order to encourage farmers to adopt more productive and stable land use systems, the Jordanian government, through the Ministry of Agriculture and some other official agencies, and in cooperation with international organizations, initiated several programmes for soil and moisture conservation and water harvesting projects (Jitan 2004; FAO 2003), the objectives of which were:

- to control soil erosion, and combat desertification;
- to ensure better utilization of limited water resources and minimize stress on water demand and the national water budget; and
- to improve and stabilize agricultural production and introduce a sustainable, productive dry farming system in Jordan through optimal management and utilization of limited rainfall.

The most commonly grown drought-tolerant olive cultivars are 'Nabali', 'Rasei' and 'Souri'. The use of these cultivars in combination with appropriate water management techniques, including soil water conservation measures and water harvesting techniques, are important in ensuring efficient water use in Jordan.

Although the olive crop is hardy and yields reasonably well even under water-limited conditions, it is well known that the yield of olive fruit and oil responds positively to additional water (up to a limit). Scarcity of water and lack of irrigation, rather than availability of arable land, are thus the limiting factors to further olive cultivation in Jordan.

Future perspectives for water use in olive production

Water-use efficiency (WUE) is the result of complex plant, soil and water interrelationships (Cornell University 2006). Hence, current and future work should concentrate on the management of three main components in order to increase WUE in olive production.

The plant (the olive tree)

Emphasis should be placed on carrying out studies on olive diversity to determine heat-tolerant and -resistant cultivars. Morphological and physiological characteristics should be studied to screen for better WUE, taking into consideration root system types and structure, stomatal properties and leaf features (Gucci et al. 2002).

There is enormous diversity in olive production in Jordan, with a large prospective list of genotypes that have the potential for efficient water-use. Drought-tolerant or water-use-efficient genotypes currently used across the country are:

Nabali Baladi. This is widespread and grown mostly in rain-fed areas. It is considered hardy and well adapted, but has a low rooting ability when propagated. It is a dual-purpose cultivar used both as a table olive and for oil production. It has a high oil content of 28-33% and high productivity, but has an alternate bearing habit, producing only every second year. It is tolerant to cold and drought but susceptible to olive fly and olive leaf spot (Barranco et al. 2000).

Rasei (Rasi'i). This is commonly grown, mostly in mountainous regions with >330 mm annual precipitation. It is tolerant to salinity, cold and drought (Barranco et al. 2000) and has an oil content of 15–28%.

Souri. Sometimes called 'Roman trees', this is an ancient cultivar that resembles Nabali in tree shape, but with clear differences in fruit shape and characteristics. It is a dual-purpose cultivar with an oil content of 25–35%. The oil has excellent, distinctive organoleptic characteristics that are sought after both in Jordan and in the entire region. It requires deep fertile soil, moderate climate and high annual rainfall (>400 mm). As such, it is commonly grown in the rain-fed areas, mostly in the hilly areas of Jerash and Ajlun, and is not suitable for planting in the desert and semi-highland regions. It is tolerant to cold and drought but sensitive to olive peacock eye spot disease, especially in humid areas.

Soil

Intermediate soil structure and texture are best for olive plantations. The adding of organic matter to soils is a very important practice, particularly in saline areas, in order to increase water holding capacity and to improve soil fertility and mineral availability.

Water

Water-harvesting techniques are practicable particularly in areas that receive >200 mm of annual precipitation, and appropriate methods should be adopted to maximize WUE.

Besides encouraging beneficial cultural practices, such as the addition of organic matter (manure, crop residues, etc.), integration of research activities among institutions in the

Mediterranean countries will enable growers to benefit from each others' experience and through exchange of experts.

Acknowledgements

I would like to thank Dr Abdel Nabi Fardous for giving me the opportunity to participate in this important workshop. My sincere appreciation and thanks are also extended to my colleagues, Eng. Waiel Al-Sharif, Dr Mohammad Jittan, Eng. Khaleel Jamjoum and Eng. Hamzeh Al-Rwashdeh in NCARTT, for all their help.

References

Barranco, D., Cimato, A., Fiorino, P., Rallo, L., Touzani, A., Castañeda, C., Serafini, F. & Trujillo, I. 2000. World Catalogue of Olive Varieties. International Olive Oil Council (IOOC), Madrid, Spain.

Cornell University. 2006. The Genomics of Plant Water Use Efficiency Project. http://isotope.bti.cornell.edu/intro/science.html, accessed November 13th, 2006

FAO-Aquastat. 2003. Jordan Profile. http://www.fao.org/ag/agl/aglw/aquastat/countries/jordan/index.stm.

Gucci, R., Grimelli, A. Costagli, G., Tognetti, R., Minnocci, A. & Vitagliano, C. 2002. Stomatal characteristics of two olive cultivars, "Frantoio" and "Leccino". *Acta Horticulturae (ISHS)*, 586: 541–544.

Jitan, M.A. 2004. Water harvesting in Jordan. PowerPoint presentation for the Middle East Regional Agricultural Program-Dry Land Agriculture-Water Harvesting Training Course, Amman, 14 -19 March 2004.

Metrology Department Website. 2005. Jordan

Ministry of Agriculture, Jordan. 2003. Annual Report.

Nydahl, Hanna. 2002. Archaeology and water management in Jordan. http://www.arkeologi.uu.se/ark/education/CD/Cuppsats/nydahl.pdf.

Increase in olive cultivation: implications for both water use and genetic resources use in the southern countries of the Mediterranean region (WANA)

B. Boulouha and L. Sikaoui

Institut National de la Recherche Agronomique (INRA), Marrakech
E-mail: bboulouha@yahoo.fr; sikaouilhassane@yahoo.fr

Abstract

The olive is an important crop, both for its commercial value and for the role it plays in the rural economy of the Mediterranean countries. It is expected that its area of cultivation will expand from the current figure of approximately 9.5 million ha to some 10 million hectares by 2010, and this increase will occur mainly in the countries located to the south and east of the Mediterranean basin, such as Syria, Algeria, Morocco, Lebanon and Jordan. However, such expansion will be constrained by drought and water scarcity.

The major challenge is how to keep pace with the increase in olive cultivation in the face of diminishing water resources. INRA Marrakech is currently working on the development of tools to help in screening for ‘less-thirsty’ olive genotypes.

Key words: Olive cultivation, water-use efficiency, drought-tolerance, olive diversity

Introduction

The olive is an important crop in terms of both commercial value and the role it plays in the rural economy of the Mediterranean countries. It is expected that its area of cultivation will increase from about current 9.5 million ha to about 10 million hectares by 2010, and this will occur mainly in the countries located to the south and east of the Mediterranean basin, including Algeria, Egypt, Jordan, Lebanon, Morocco, Syria and Tunisia. In countries with a history of commercial olive production, the cultivated area has almost doubled over the last 20 years (with the exception of Algeria and Tunisia). In Egypt, the cultivated area has grown enormously, by over 2000% during the same period (Table 1), although this is due more to the adoption of a new crop than to increasing already-established production. Egypt is a relatively new olive producer with cultivation increasing only over the last 10 years. If this trend is to continue, further increases will be constrained by harsh environmental conditions, in particular, drought and water scarcity.

In these countries, olives are grown mainly under rain-fed conditions (e.g. Morocco 70%, Syria 95% and Jordan 77%) where annual rainfall varies between 200 and 600 mm. Rain distribution during the growth and development stages of olives are also irregular. The trend of frequent cycles of drought as a result of climate change predicts a further decline in water availability in the region

The aim of this paper, therefore, is to investigate the possibility of increasing water productivity for olives in the Mediterranean region.

Water scarcity

In recent decades, drought has become almost a structural phenomenon in the region, and predictions indicate that the effects of global warming will increase water scarcity. Recent estimates suggest that climate change will account for about 20% of the increase in global water scarcity (UN/WWAP 2003). Such increase is coupled with a trend towards increasing water withdrawals, particularly in the WANA region (Table 2). This will place a great burden on development endeavours in WANA countries.

Table 1. Olive cultivation in WANA region.

Country	**Harvested area** (×1000 ha)					**Area Increase** (%)
	1985	1990	1995	2000	2005	
Algeria	162	170	160	168	200	23
Egypt	2	9	22	45	49	*
Jordan	29	36	62	63	64	121
Lebanon	33	42	43	55	58	76
Morocco	293	365	415	540	480	64
Syria	295	391	421	477	500	69
Tunisia	1315	1392	1460	1387	1500	14

Source: FAOSTAT http://faostat.fao.org/

Note: * Egypt is a relatively recent olive producer.

Table 2. Water withdrawals in comparison with the total renewable water.

Region/country	**Total water withdrawals** (km^3)		**Ratio of withdrawals to TRW**	
	1995	2010	1995	2010
Egypt	54.3	60.4	0.89	0.99
WANA	143.2	156.0	1.16	1.25
Developing countries	2 761.9	3 133.6	0.08	0.09
World	3 906.1	4 356.2	0.08	0.09

Source: Rosegrant et al. 2002a (IFPRI).
Note: TRW refers to total renewable water.

Water availability is an important limiting factor in olive production, as productivity tends to increase with water supply. At the global level, production in irrigated areas is between 1 and 3.5 t/ha, compared to just 1–2.5 t/ha in non-irrigated areas under water-limited conditions (Touzani 1999).

Managing water scarcity in olive groves

There are a number of techniques that can offset the effects of drought and water scarcity, such as the use of drought-tolerant cultivars and the development of cultural practices that reduce water loss from soil and evapotranspiration, and thus improve water productivity.

Strategies could be based on two major activities: exploration of olive genetic variability; and the development of cultural practices that increase water availability in the soil.

Exploration of olive genetic variability would include:

- identification of drought-tolerant cultivars;
- exchange of drought-tolerant genetic material between countries facing drought problems;
- establishment of olive orchard trials to evaluate drought tolerance; and
- selection, using carbon isotope discrimination (CID) to identify genotypes resistant to drought.

Development of cultural practices that increase water availability in the soil would address:

- development of tools and cultural practice techniques that increase soil water availability at the farm level in areas where rainfall ranges between 200 and 300 mm; and
- development and evaluation of technological packages that comprise tools and cultural practice techniques.

In terms of drought-tolerant cultivars, there is considerable variability in olives which can be explored. According to the information available so far, a number of cultivars have been reported to be drought-tolerant (Table 3).

In terms of cultural practices, there are several techniques that can be used to increase water productivity in areas where the rainfall is 200–300 mm, such as water harvesting techniques, mulching and tillage.

Olive diversity: a potential for managing water demand

There is a large number of olive cultivars and some may, in fact, be a mixture of genotypes. One example is 'Picholine Marocaine', where each tree may be of a different genotype within the same orchard (Boulouha et al. 2004; Sikaoui et al. 2005). This pattern has been also found among local cultivars, such as 'Ladolia', an old cultivar of Cyprus (Banilas et al. 2003), and in a number of cultivars in Spain (Sanz-Cortés et al. 2003). This variation presents potential for assessment of water-use efficiency.

Table 3. Prospective list of drought-tolerant cultivars.

Cultivar	Origin	Response to abiotic stresses
AZERADJ	Algeria	Tolerant to drought and salinity
CHEMLAL	Tunisia	Tolerant to drought and moderately so to salinity
LIMLI	Algeria	Tolerant to drought and highly so to salinity
AGEZZI SHAMI	Egypt	Tolerant to high radiation and low humidity
RASI'I	Jordan	Tolerant to dry conditions
SOURY	Lebanon	Moderately tolerant to drought, cold and salinity
KAYSSI	Syria	Tolerant to drought and cold
SORANI	Syria	Tolerant to drought, cold and salinity

Source: Barranco et al. 2000

Variability within olive species in terms of drought or WUE among cultivars has been reported in recent years (Bari et al. 2005, 2005; Oddo et al. 2005; Samson et al. 2005, Sikaoui et al. 2005). In general, variation in the uptake and return of nutrients is influenced by genotype (root structure and function) and soil heterogeneity (nutrient availability and root structure) (Care et al. 2002). Intra-species variation has also been reported in a number of crops (Comstock et al. 1992, 1993, 2000). Productivity of olive groves in the Mediterranean area is affected by water scarcity but if appropriate resistant cultivars are selected, greater productivity may result (Giorio et al. 1999; Oddo et al. 2005). Even under non-limited conditions, different cultivars of olive show differences with regard to their plant-water relationships, whereby drought-tolerant cultivars can also perform well under irrigated conditions (Samson et al. 2005). Diversity within olive crop cultivars thus provides potential for cultivar selection to improve water productivity.

Assessment of olive diversity

The assessment of olive diversity is carried out by INRA Marrakech, based on a whole-plant approach, where both aerial and root features of the plant are measured. The former is based on carbon isotope discrimination and the latter on root architectural traits.

In conjunction with Bioversity International, further research is intended to develop and refine the traits associated with WUE used in the screening of genotypes.

References

Banilas, G., Minas, J., Gregoriou, C., Demoliou, C., Kourti, A. & Hatzopoulos, P. 2003. Genetic diversity among accessions of an ancient olive variety of Cyprus. *Genome/Génome*, 46(3): 370–376.

Bari A., Boulouha, B., Martin, A., Sikaoui, L., Gonzalez-Andujar, J.L., Ayad, G., Elouafi, I., Nachit, M., Hajhassan, A. & Rao, V.R. 2005. Exploration of genetic variation in relation to drought tolerance in olives (*Olea europaea* L.) The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy, 24–28 September 2005. See: http://www.plantstress.com/id2/

Barranco, D., Cimato, A., Fiorino, P., Rallo, L., Touzani, A., Castañeda, C., Serafini, F. & Trujillo, I. 2000. World Catalogue of Olive Varieties. International Olive Oil Council (IOOC), Madrid, Spain.

Boulouha, B., Sikaoui, L., Bari, A., Elouafi, I., Nachit, M., El Heirech, A. & Mathu, P. 2004. Etude de la diversité de l'olivier au Maroc: Caractérisation morphologique, par traitement d'images et analyse moléculaire. The First International Seminar on Biotechnology and Quality of Olive tree Products around the Mediterranean basin – OLIVEBIOTEQ-2004. Errachidia (Morocco), IOOC.

Care, D.A., Crush, J.R. & Dodd, M.B. 2002. Application of digital image capture techniques to study root growth of white clover (*Trifolium repens* L.) cultivars with contrasting root morphologies. *In:* Interactions in the Root Environment: An Integrated Approach: Proceedings of the Millennium Conference on Rhizosphere Interactions, IACR-Rothamsted. Kluwer, Dordrecht, The Netherlands.

Comstock, J.P. 2000. Variation in hydraulic architecture and gas-exchange in two desert sub-shrubs, *Hymenoclea salsola* (T. & G.) and *Ambrosia dumosa* (Payne). *Oecologia*, 125: 1–10.

Comstock, J. & Ehleringer, J. 1992. Correlating genetic-variation in carbon isotopic composition with complex climatic gradients. *Proceedings of The National Academy of Sciences of the United States of America*, 89(16): 7747–7751.

Comstock, J. & Ehleringer, J. 1993. Stomatal response to humidity in common bean (*Phaseolus vulgaris*): Implications for maximum transpiration rate, water-use efficiency and productivity. *Australian Journal of Plant Physiology*, 20: 669–691.

FAO. 2006. FAOSTAT . FAO Statistics Division 2006. Accessed 16 August 2006. URL: http://faostat.fao.org/

Giorio, P., Sorrentino, G. & D'Andria, R. 1999. Stomatal behaviour, leaf water status and photosynthetic response in field-grown olive trees under water deficit. *Environmental and Experimental Botany*, 42: 95–104.

Oddo, E., Virgilio, F., Calderòn, A.A., Ferrer, M.A. & Grisafi, F. 2005. Effects of water stress on Sicilian olive cultivars. The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy, 24–28 September 2005. See: http://www.plantstress.com/id2/

Samson, R., Maes, I., Supré, A., Braham, M., Mahjoub Boujnah D. & Lemeur, R. 2005. Is drought stress resistance important under irrigation? A case study for two olive varieties in Tunisia. The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy, 24–28 September 2005. See: http://www.plantstress.com/id2/

Sanz-Cortés, F., Parfitt, D.E., Romero, C., Struss, D., Llácer, G. & Badenes, M.L. 2003. Intraspecific olive diversity assessed with AFLP. *Plant Breeding*, 122(2): 173–177.

Sikaoui, L., Boulouha, B., Dahhan, R. & Bari, A. 2005. Patterns of carbon isotope discrimination in olives (*Olea europaea* L.) in southwest of Morocco. The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy, 24–28 September 2005. See: http://www.plantstress.com/id2/

Smirnoff, N. 1998. Plant resistance to environmental stress. *Current Opinion in Biotechnology*, 9: 214–219.

Touzani, A. 1999. Oléiculture et environnement. Séminaire international sur les innovations scientifiques et leur application en oléiculture et oléotechnie. Florence, Italy, 10–12 March 1999.

UN/WWAP [United Nations/World Water Assessment Programme]. 2003. 1st UN World Water Development Report: Water for People, Water for Life. Paris, New York and Oxford. UNESCO and Berghahn Books. See: http://www.unesco.org/water/wwap/wwdr1/

Section 2

Research strategies for water-use: managing water resources

Water saving in olive orchards: partial root-zone drying strategy
M. Ghrab, K. Gargouri, M. Ayadi And H. Bentaher

Physiological traits in relation to water-use efficiency: Case study on cereals
M. Boutfiras

Partial root-zone drying (PRD) on olive tree
S. Wahbi

Water saving in olive orchards: partial root-zone drying strategy

M. Ghrab, K. Gargouri, M. Ayadi and H. Bentaher

Olive Tree Institute, Sfax, Tunisia. E-mail: kamelgargouri@altern.org

Abstract

The increasing scarcity of water in dry areas is a well-recognized problem. The need to produce more food with less water poses enormous challenges in these areas, as water availability is the limiting factor. Maximizing water productivity should therefore be given higher priority than maximizing yield. Deficit irrigation approaches were adopted in olive orchards in Tunisia to improve water-use efficiency (WUE) under arid and semi-arid conditions. Effects of irrigation deprivation on olive trees were investigated during a 2-year field experiment. A partial root-zone drying (PRD) strategy was applied to olive trees (*Olea europaea* L., cv. Chemlali) planted at 4×4 m spacing. The PRD irrigation technique consists of irrigating one side of the root system only. Three irrigation treatments consisting of water restriction (a reduction of irrigation water by 50%) were applied with regard to the control (full irrigation): PRD1 (where irrigation was applied every two weeks); PRD2 (where irrigation was applied every month); and DRY (no irrigation). Ten trees were investigated per treatment. Yield components of the adult olive trees under the different treatments were then evaluated. Pre-dawn water potential, stem water potential, total water supply from precipitation (P) and irrigation (I) were monitored over the growing season. Water supply was scaled by Penman-Monteith reference evapotranspiration (ETo) that was estimated from local weather data. PRD treatments induced a slight reduction in pre-dawn and stem water potential. The most important yield reduction was observed for the DRY treatment. There was an improvement in terms of oil content and quality with the increasing deficits, which resulted in the saving of up to 50% of water requirements.

Key words: Deficit irrigation, water status, partial rootzone drying (PRD), water scarcity, olive orchards

Introduction

The agricultural sector accounts for more than two-thirds of fresh water consumption by humans worldwide, and in many countries and regions irrigation is the principal water user (Shiklomanov 1999; Gleik 2002). As water is becoming increasingly scarce in these regions, the need to produce more with less water poses an enormous challenge. In these areas, maximizing water productivity is now being given higher priority than maximizing yield. In Tunisia, which is situated in the Mediterranean arid region, the average rainfall is about 230 mm/yr, representing some 36×10^9 m^3 of water. Large variation in precipitation over time and place has been recorded in the country, which has also a large number of aquifers and deep ground-water resources, mostly of limited extent. Most of the water is diverted to agriculture which, in Tunisia, is dominated by olive trees grown under rain-fed conditions. However, new trials have been conducted to intensify olive production through high-density plantings using irrigation. In this context, new approaches for managing irrigation and improving water-use efficiency are tested alongside intensification trials. Among these approaches is the application of deficit irrigation strategies as an alternative tool, aimed at significant water savings while improving both fruit quality and water productivity. Regulation of vegetative growth by regulated deficit irrigation has been suggested for many crops (Chalmers et al. 1981; Li et al. 1989; Behboudian and Lawes 1994; Ben Mechlia et al. 2002; Girona et al. 2004). Following some physiological research, an alternative approach – that of drying part of the root system while keeping the rest well watered - has been proposed (Stoll et al. 2000). Roots in drying soil send chemical signals to leaves, leading to a reduction in stomatal conductance and growth, and significant water saving. Partial rootzone drying is a new irrigation technique that improves water-use efficiency in crop production without significantly reducing yield. This strategy has been successfully adopted for many crops, such as grapevine (Stoll et al. 2000) and olive (Wahbi et al. 2005; Centritto et al. 2005).

Material and methods

Material

An olive orchard trial was conducted in 2003, in the region of Sfax (central Tunisia), to quantify the effect of deficit irrigation on water status and yield of mature olive trees. The main cultivar grown in this trial is 'Chemlali', which is planted at a density of 625 trees/ha and trained in drip irrigation. Chemlali (de Sfax) is a local Tunisian cultivar that can grow in areas with an annual mean rainfall of 200 mm (Barranco et al. 2000).

Water treatments

Water was applied, based on a scale for water demand for four treatments, as follows:

- Control: Full irrigation
- PRD 1: Alternate irrigation applied every 15 days.
- PRD 2: Alternate irrigation applied every month.
- DRY: Rain-fed conditions

Water restriction was about 50% of the Control.

Evapotranspiration (ET_o) (Pennman-Monteith) was calculated from daily climatic data to estimate the evaporative demand and to scale water supply. The weather data used was recorded at an Institut National de Météorologie (INM) station, located about 3 km from the experimental site.

The global water supply was estimated as the quantity of irrigation and rain recorded (Table 1). Yearly variation of rainfall was observed, with most rainfall occurring during autumn and winter. Furthermore, the region was characterized by high climatic demand (ET_o). Total water received was 800 mm for the control and 563 mm for the PRD treatments during 2003. For the first year of study, irrigation was applied from June to November. However, in 2004, irrigation was scheduled according to the variable needs during the olive growing season (Figure 1). Needs were estimated from monthly values of the crop coefficient (K_c), which ranged between 0.6 and 0.65 (Pastor 2003). Consequently, the water supplies were 681 mm for the control and 430 mm for the PRD treatments.

Table 1. Climatic demand, rainfall and water irrigation quantities for the control and PRD treatments.

Year	**ETo** (mm)	**Rainfall** (mm)	**Control** (mm)	**PRD** (mm)	**WS/ETo**
2003	1485	327	472	236	0.54
2004	1479	179	502	251	0.46

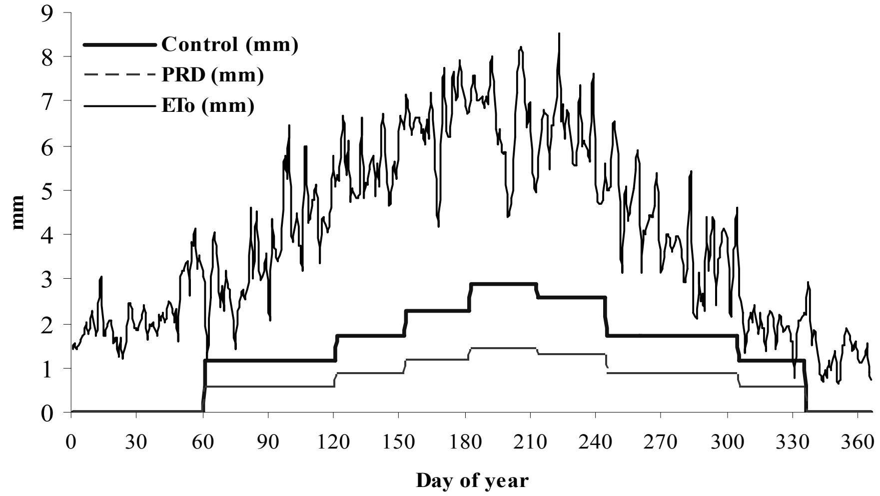


Figure 1. Pattern of daily evolution of climatic demand (ET_o) and water supply for the control and PRD treatments in 2004.

Parameters

Stem water potential (ψ_t) was measured with a pressure chamber to determine tree water status (Figure 2). Leaves were enclosed in a dark plastic bag covered with aluminium foil, for at least 2 hours before measurement. Measurements were carried out weekly between 1100 and 1300. Soil water content was determined monthly by a gravimetric method at 0.2 m depth intervals within 0 to 0.8 m soil depth. Measurements of soil moisture were carried out monthly (Table 2).

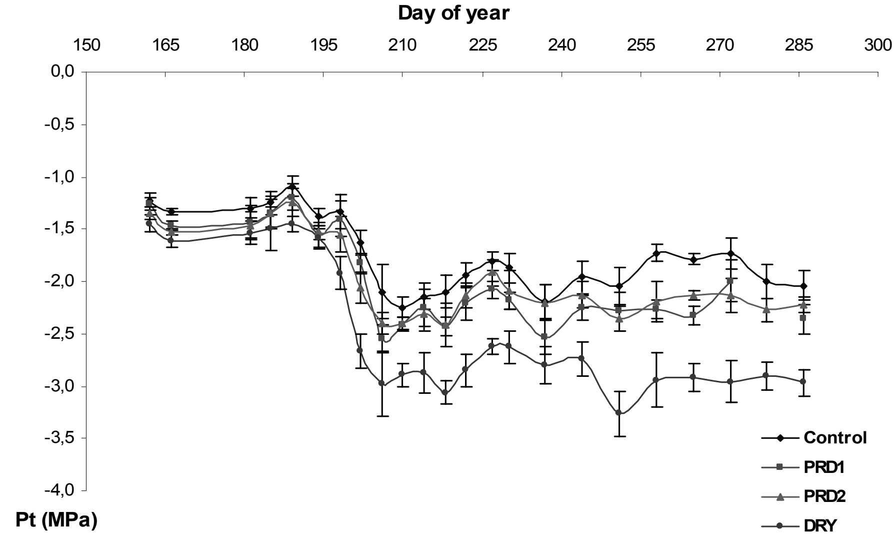


Figure 2. Stem water potential under different irrigation treatments during 2004.

Table 2. Parameters used for the different measurements related to water (timing and duration).

Parameter	Description	Timing
Ψms	Stem Water potential	Weekly
SWC	Soil water content	Monthly

The effects of the partial root zone drying (PRD) irrigation strategy on tree production, fruit quality and olive oil quality were also investigated (Table 3). A number of parameters were measured to evaluate the efficiency of the deficit irrigation approach, such as:

- total yield (t/ha): calculated from the production of individual trees;
- fruit pomological quality; and
- fat content and fatty acid composition.

These measurements were taken to ascertain whether the different treatments affected quantity and quality in terms of fruit and oil and, if so, to what extent.

Table 3. Parameters used for the different measurements related to root drying efficiency

Parameter	Description	Timing
Yield (kg/tree)	Yield measured based on individual tree	December
MGPF (%)	Descriptors related to fruit quality	December
FWC (%)	Bio-chemical composition	December
Acidity	Oil quality	December

Results and discussion

Water supply

Using monthly values of the crop coefficient (K_c) ranging from 0.6 to 0.65 (Pastor 2003), water supply was 681 mm and 430 mm, respectively, for the control and PRD treatments. Wahbi et al. (2005) found that using a K_c of about 0.7 resulted in a total water supply of 640 mm for the control (full irrigation) and half of this quantity for PRD treatment. However, mean seasonal irrigations ranging between 232 mm and 1016 mm were reported by Goldhamer et al. (1993, 1994), using K_c values of between 0.16 and 0.85 for olive trees (cv. Manzanillo). They found that there was no significant effect related to water stress within a K_c range of 0.65–0.85. The scale of water supply in relation to ET_o during the season reveals a coefficient of water deficit compensation (WS/ET_o) of about 0.46.

Soil water content

Soil water content showed weakest values for the DRY treatment. The recorded values were 1.44 to 6% (Figure 3). A decrease in soil water content was observed in the summer, reaching a minimum in August. Thereafter, a humectation of soil was recorded in the autumn, following rains.

At the beginning of the season, soil moisture was very variable throughout the horizons. At the control, humidity was close to 15% at the 0–20 cm horizon, but was less than 6% in the 60–80 cm horizon (Figure 3). Thereafter, a humectation of all horizons took place within the same range of fluctuation. Humidity lay between 8 and 10% at the beginning of the summer season, and between 6 and 8% in the autumnal period.

For the PRD treatments, a fluctuation in humidity was observed in relation to the irrigated part and period of application. Dry and wet cycles were identified over the season. Alternate monthly irrigation seemed to be more efficient and induced a clear cycle of dry and wet periods that can contribute to an improvement in water use.

Plant water status

The water status of the olive tree was measured. Stem water potential showed the same trend of evolution for all treatments. A significant difference was observed from the 195th day, with a fall of between -2.7 and -3.3 MPa (Figure 2) for the DRY treatment.

Partial root-zone drying results in an intermediate water status. PRD treatments presented a stem water potential ranging between 1.8 and 2.5 Mpa (control was between -1.7 and -2.3 Mpa).

Yield and fruit quality

A significant olive yield, ranging between 18 and 28 kg/tree over the different treatments (Table 4), was obtained during the first year of the study. PRD treatments resulted in a significant yield reduction (15–20%). DRY treatment resulted in a reduction of yield by about 35%. The second year was characterized by the alternate bearing of Chemlali. Olive production ranged between 5.5 and 6.2 kg/tree, with no significant difference in the results emerging from the different treatments (Table 4).

The yield responses to water deficits suggest that there are phenological stages when stress is not detrimental to yield. Consequently, deficit irrigation strategies can reduce water supply while maintaining yield (Chalmers et al. 1981; Mitchell et al. 1989). Furthermore, other investigations on olive trees reported a non-linear response in olive yield to water deficit (Moriana et al. 2003; Goldhamer 1999) and found that 15 and 25% reduction in applied water did not have a significant impact on canning olive yield. An even more severe deficit imposed by a 44% reduction in applied water decreased yield by only 10%.

Yield reduction caused by water restriction was compensated for by an improvement in fruit and oil quality (Table 4). An increase in oil content was observed in relation to increasing water deficit. The oil quality had also improved slightly. Indeed, oil acidity showed little decrease as a result of reduction in water supply. Several irrigation experiments with olive trees reported that oil content with rain-fed treatments was the same or even higher than with the irrigated trees (Lavee and Wodner 1991; Patumi et al. 1999).

Conclusion and future work

The current situation in Tunisia is constrained by an increase in water demand from the agricultural sector. This sector already consumes more than 80% of available water. Water resources are limited, however, both in quantity and quality. This situation is particularly accentuated in the centre and south of the country, where 70% of surface water has a salinity content of more than 1.5 g/L.

With regard to the state orientation policy (intensification and creation of new olive orchards under drip irrigation), deficit irrigation seems to be an adequate technique to improve water efficiency and to promote the irrigated-olive sector. Moreover, the RDI, and especially the PRD, maintain a good yield and improve product quality and WUE.

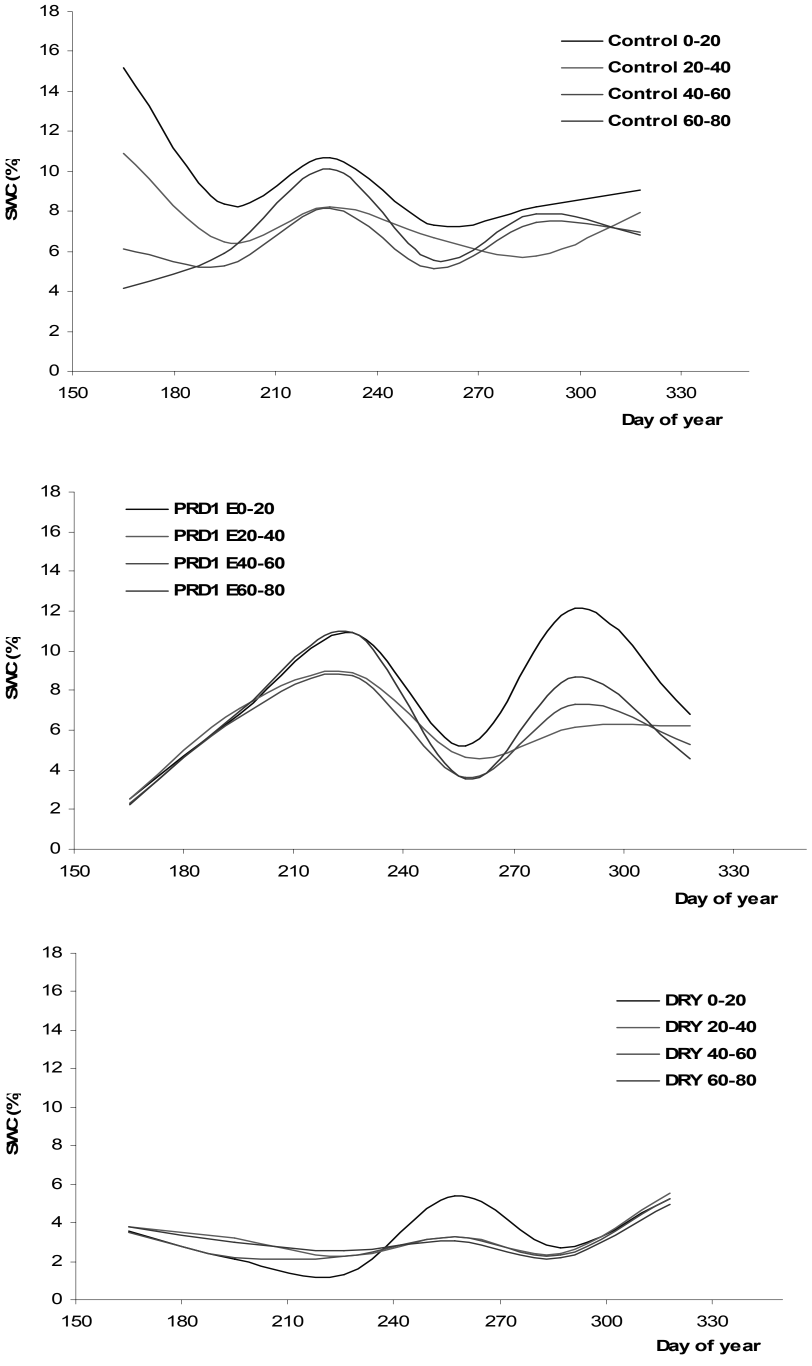


Figure 3. Soil water content (SWC) for irrigation treatments during 2003.

Table 4. Yield, oil content (MGPF), fruit water content (FWC) and oil acidity during 2003/04.

	Yield (kg/tree)	**MGPF** (%)	**FWC** (%)	**Acidity**
2003				
Control	28.0 ^{a}	19.45	57.71	0.320
PRD 1	22.0 ^{b}	21.51	55.96	0.240
PRD 2	23.9 ^{b}	20.86	55.56	0.300
DRY	17.7 ^{c}	23.92	49.83	0.190
2004				
Control	6.2 ^{a}	22.61	55.89	0.355
PRD	5.8 ^{a}	23.07	55.14	0.273
DRY	5.5 ^{a}	27.54	48.55	0.410

Note: Columns followed by the same letter were not significantly different according to the multiple range test of Duncan at *P=0.05.*

The work also intends to explore the genetic option so that water-use-efficient genotypes can be used together with other water-saving measures. Tunisia has considerable diversity in olives, with many cultivars than can potentially tolerate greater water scarcity.

Among the cultivars with a potential to survive water stress is Chemlali (de Sfax), which is a drought-tolerant cultivar that grows in areas with an annual mean rainfall of 200 mm (Barranco et al. 2000).

References

Barranco, D., Cimato, A., Fiorino, P., Rallo, L., Touzani, A., Castañeda, C., Serafini, F. & Trujillo, I. 2000. World Catalogue of Olive Varieties. International Olive Oil Council (IOOC), Madrid, Spain.

Behboudian, M.H. & Lawes, G.S. 1994. Fruit quality in 'Nijisseiki' Asian pear under deficit irrigation: physical attributes, sugar and mineral content and development of flesh spot decay. New Zealand Journal of Crop and Horticultural Science, 22: 393–400.

Ben Mechlia, N., Ghrab, M., Zitouna, R., Ben Mimoun, M. & Masmoudi, M.M. 2002. Cumulative effect over five years of deficit irrigation on peach yield and quality. *Acta Horticulturae (ISHA)*, 592: 301–307.

Centritto, M., Wahbi, S., Serraj, R. & Chaves, M.M. 2005. Effects of partial root drying (PRD) on adult olive tree (*Olea europaea*) in field conditions under arid climate. II - Photosynthetic responses. *Agriculture, Ecosystems & Environment,* 106: 303–311.

Chalmers, D.J., Mitchell, P.D. & van Heek, L. 1981. Control of peach growth and productivity by regulated water supply, tree density and summer pruning. *Journal of the American Society for Horticultural Science,* 106(3): 307–312.

FAO. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper.* No. 56. See pp. 59–72.

Girona, J., Marsal, J., Mata, M., Arbones, A. & DeJong, T.M. 2004. A comparison of the combined effect of water stress and crop load on fruit growth during different phenological stages in young peach trees. *Journal of Horticultural Science Biotechnology,* 79(2): 308–315.

Gleick, P. 2002. Soft water paths. *Nature,* 418: 373.

Goldhamer, D.A. 1999. Regulated deficit irrigation for California canning olives. *Acta Horticulturae (ISHS),* 374: 369–372.

Goldhamer, D.A., Dunai, J. & Ferguson, L. 1993. Water use requirements of Manzanillo olives and responses to sustained deficit irrigation. *Acta Horticulturae (ISHS),* 335: 365–371.

Goldhamer, D.A., Dunai, J. Ferguson, L. 1994. Irrigation requirements of olive trees and responses to sustained deficit irrigation. *Acta Horticulturae (ISHS),* 356: 172–175.

Lavee, S. & Wodner, M. 1991. Factors affecting the nature of oil accumulation in fruit of olive (*Olea europaea* L.) cultivars. *Journal of Horticultural Science,* 66: 583–591.

Li, S.H., Huguet, J.G., Schoch, P.G. & Orlando, P. 1989. Responses of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. *Journal of Horticultural Science,* 64(5): 541–552.

Mitchell, P.D., van den Ende, P.H. & Chalmers, D.J. 1989. Responses of Bartlett pear to withholding irrigation, regulated deficit irrigation and tree spacing. *Journal of the American Society for Horticultural Science,* 114: 15–19.

Moriana, A., Orgaz, F., Pastor, M. & Fereres, E. 2003. Yield responses of a mature olive orchard to water deficits. *Journal of the American Society for Horticultural Science,* 128(3): 425–431.

Pastor, M. 2003. Amélioration des techniques de programmation de l'irrigation dans des situations de faible disponibilité hydrique dans les oliveraies de la province de Jaén. *Olivae,* 95: 39–47.

Patumi, M., D'Andria, R., Fontanazza, G., Morelli, G., Giorio, P. & Sorrentino, G. 1999. Yield and oil quality of intensively trained trees of three cultivars of olive (*Olea europaea* L.) under different irrigation regimes. *Journal of Horticultural Science Biotechnology,* 74: 729–737.

Shiklomanov, I.A. 1999. World water resources and their use. State Hydrological Institute (SHI)/UNSECO. See: http://webworld.unesco.org/water/ihp/db/shiklomanov/

Stoll, M., Loveys, B. & Dry, P. 2000. Hormonal changes induced by partial rootzone drying of irrigated grapevine. *Journal of Experimental Botany*, 51: 1627–1634.

Wahbi, S., Wakrim, R., Aganchich, B. & Serraj, R. 2005. Effects of partial root drying (PRD) on adult olive tree (*Olea europaea*) in field conditions under arid climate. I - Physiological and agronomic responses. *Agriculture, Ecosystems & Environment*, 106: 289–301.

Physiological traits in relation to water-use efficiency: case study of cereals

M. Boutfiras

Institut National de la Recherche Agronomique (INRA), Settat, Morocco
Email: mboutfirass@yahoo.fr

Abstract

The rational use of water in agriculture under both harsh and favourable environments is a challenging priority in today's national agendas. The increasing need for food production creates pressure on water supplies; consequently there is a need to improve the water-use efficiency (WUE) of crops. Improved WUE can be achieved either through crop improvement by increasing transpiration efficiency, or through better agronomic practices that maximize transpiration efficiency (TE) by reducing soil evaporation (Es). This presentation is an overview of crop physiological traits in relation to TE and reduction of Es through agronomic practices.

Key words: water-use efficiency, physiological traits, carbon isotope discrimination

Introduction

Fresh-water supplies are decreasing as a result of several severe drought cycles prevailing in recent years, thought to be due mainly to global climate change (Vörösmarty et al. 2000). As a result, the rational use of water in agricultural production is a challenging issue, both for the water-limited conditions of harsh environments and for non-limited water conditions where irrigation is possible.

The increasing need for food creates pressure on water supplies (Vörösmarty et al. 2000), and hence the need to improve crop productivity. The scarcity of water, coupled with recent rapid increases in energy costs, necessitates producing more for less water consumed. Therefore, research on water-use efficiency (WUE) is a prerequisite for improved plant productivity.

Research on WUE is an attempt to simplify the complex mechanisms linking water use and yield. This concept has been approached in different ways, using several models or equations expressing different processes and ratios, depending on the objective and the targeted area (field, crop, plant, organ, etc.) (Gregory et al. 2000; Angus and Herwaarden 2001; Condon et al. 2002; Chen et al. 2003).

The simplest expression is:

WUE = Yield per unit area / Water used to produce yield

Total water use is the sum of transpiration (T) and soil evaporation (Es). Therefore, many researchers have concentrated on Transpiration efficiency (TE), i.e. Yield/Transpiration (Angus and Herwaarden 2001; Hatfield et al. 2001; Condon et al. 2002).

Improved WUE can come about either by crop improvement to increase TE, or by agronomic practices that maximize T by reducing Es.

Physiological traits for improved WUE

A number of traits associated with WUE have been used to select genotypes. These include: 1) carbon isotope discrimination (CID or $\delta^{13}C$); 2) seedling vigour; 3) Stay green; 4) phenological characteristics; and 5) harvest index.

Carbon discrimination Δ ($^{13}C/^{12}C$)

The processes that influence the extent of $\delta^{13}C$ discrimination are also important in determining the TE of leaf gas exchange (Condon et al. 2002; Fisher et al. 1998; Richards 2000). Thus, Δ provides a relative measure of leaf-level TE. Discrimination is less when TE is high. In terms of leaf gas exchange, TE is a ratio that describes how much CO_2 is assimilated in photosynthesis per unit water lost in transpiration. The rate of CO_2 uptake into the leaf is determined by:

- the 'sucking' power of the leaf for CO_2 (amount of photosynthetic machinery per unit leaf area); and
- how easily CO_2 can move into the leaf, which is determined by stomatal conductance

Improved establishment and seedling vigour

Rapid seedling establishment has been proposed for different cereals as a useful trait to improve yield under Mediterranean conditions (Richards et al. 2002). Indeed, early vigour may reduce evaporation from the soil, due to increased ground cover, and thereby ensure sufficient moisture throughout the crop season. There is considerable potential for gain because as much as half of the growing season rainfall may be lost through evaporation from soil, and widely-grown semi-dwarf cereals have inherently lower vigour than do taller cereals. When increased vigour results in more growth under low vapour pressure deficit (VPD), this will mean a higher TE (Richards et al. 2002). It should also result in a higher leaf area index, and hence more light interception. Early crop establishment and vigour is also an effective way of reducing weed competition.

'Stay-green' or delayed senescence

Plant senescence is a genetically programmed process, accelerated by environmental stresses such as drought, heat and nitrogen deficiency. The primary expression of leaf senescence is the breakdown of chlorophyll and the subsequent collapse of photosynthesis. Stay-green plants sustain leaf greenness and photosynthesis longer, and yield more (Richards et al. 2002).

Leaf pubescence

Leaf pubescence is a common feature in xerophytes as well as in some field crops, such as soybean. Generally, it increases reflectance from the leaf in the 400 to 700 nm range, and sometimes up 900 nm, resulting in lower leaf temperature under high irradiance. In the soybean, high-pubescence lines expressed lower net radiation and transpiration with sustained photosynthesis, leading to high WUE (Garay and Wilhelm 1983).

Phenology

Manipulation of flowering time or anthesis is very important in determining the duration of vegetative growth, reproductive growth and grain growth in relation to water supply, frost and evaporative demand.

Early flowering constitutes an important feature of drought escape, especially for late-season drought-stress conditions. In contrast, late flowering is often associated with high yield potential, especially under favourable conditions.

Phenology is also a major determinant of drought-independent harvest indexes as it can determine the amount of pre-anthesis and post-anthesis water-use (Richards et al. 2002).

Harvest index

Harvest index (HI) is the third component of Passioura's framework (Passioura 1977) which has been used as the most appropriate manner in which to identify traits that may limit wheat yields in dry environments. HI is determined by two factors which can be manipulated to achieve a higher yield (Richards et al. 2002): drought-independent HI that is a function of differential partitioning of dry matter to reproductive and non-reproductive organs; and drought-dependant HI which is a function of post-anthesis water use.

Agronomic practices

Great improvements have been reported through change in crop management practices. At this level, we can consider the numerator and the denominator of the WUE equation separately: WUE = Yield per unit area / Water used to produce yield.

Yield per unit area

Water deficit is usually perceived to be the most important factor resulting in low yield under dry environments. However, this may not always be true. Other factors, such as disease and insects, soil nutritional problems, weed infestation or waterlogging during periodic heavy rains, may easily limit yield and should be overcome as far as possible before applying physiological knowledge to improve yield under water-limiting conditions (Gregory et al. 2000).

Water used

The total water used (WU) to produce yield can be considered as the sum of: soil evaporation (Es), transpiration (T), the net run-off (R) and drainage below the root zone (D).

$$WU = Es + T + R + D \qquad \text{(Gregory 1989)}$$

Increasing T at the expense of other losses from the root zone can increase WUE. This can be achieved through crop or soil management practices that modify the growth of the crop canopy, the root system, or both.

Management to increase crop growth during the vegetative phase in a period of low evaporative demand would lead to reduced Es by additional canopy cover (Gregory 1989).

Management to increase root system development enables the plant to explore deeper soil layers and greater soil volume for moisture, and reduces the upward flow to the surface (Es) and downward flow (D).

Irrigation

Water scarcity in irrigated areas requires improvement in irrigation water productivity. Reducing water losses is one way of increasing water productivity. In this regard, we can mention:

- choice of irrigation system;
- irrigation scheduling; and
- supplemental irrigation.

Conclusion

Improved WUE can be achieved by combining better agronomic practices with crop improvement. While the agronomic measures aim at reducing soil evaporation, crop improvement aims at maximizing transpiration efficiency so that more food per crop per drop can be achieved. In this context, crop physiological traits can play a role in screening for better water-use efficient genotypes within crops.

References

Angus J.F. & van Herwaarden, A.F. 2001. Increasing water use efficiency in dryland wheat. *Agronomy Journal,* 93: 290–298.

Chen, C., Payne, W.A., Smiley, R.W. & Stoltz, M.A. 2003. Yield and water-use efficiency of eight wheat cultivars planted on seven dates in north-eastern Oregon. *Agronomy Journal,* 95: 836–843.

Condon, A.G., Richards, R.A., Rebetzke, G.J. & Farquhar, G.D. 2002. Improving intrinsic water-use efficiency and crop yield. *Crop Science,* 42: 122–131.

Fisher, R.A., Rees, D., Sayre, K.D., Lu, Z., Condon, A.G. and Saavedra, A.L. 1998. Wheat yield progress is associated with higher stomatal conductance, higher photosynthetic rate and cooler canopies. *Crop Science,* 38: 1467–1475.

Garay, A.F. & Wilhelm, W.W. 1983. Root system characteristics of two soybean isolines undergoing water stress conditions. *Agronomy Journal,* 75: 973–977.

Gregory, P.J. 1989. Water-use efficiency of crops in the semi-arid tropics. pp. 85–98. *In:* Soil, crop, and water management systems for rain-fed agriculture in the Sudano-Sahelien zone, Niamey, Niger. ICRISAT, Patancheru A.P. 502324, India.

Gregory, P.J., Simmonds, L.P. & Pilbeam, C.J. 2000. Soil type, climatic regime, and the response of water use efficiency to crop management. *Agronomy Journal,* 92: 814–820.

Hatfield, J.L., Sauer, T.J. & Prueger, J.H. 2001. Managing soils to achieve water use efficiency: a review. *Agronomy Journal,* 93: 271–280.

Passioura. J.B. 1977. Grain yield, harvest index and water use of wheat. *Journal of the Australian Institute for Agricultural Science*, 43:117-120.

Richards, R.A., Condon, A.G. & Rebetzke, G.J. 2002. Traits to improve yield in dry environments. pp. 88–100. *in:* M. Reynolds, I. Ortiz-Mosterio and A. McNab (editors). Applying physiology to wheat breeding. CIMMYT. Mexico.

Richards, R.A. 2000. Selectable traits to increase crop photosynthesis and yield of grain crops. *Journal of Experimental Botany,* 51: 447–458.

Vörösmarty , C.J., Green, P., Salisbury, J. & Lammers, R.B. 2000. Global Water Resources: Vulnerability from climatic change and population growth. *Science,* 289(5477): 284–288.

Partial root-zone drying (PRD) on olive tree

S. Wahbi

University of Marrakech, Morocco. E-mail: wahbi@ucam.ac.ma

Abstract

Partial Root-zone Drying (PRD) is a new irrigation technique in which half a plant root system is exposed to drying soil, while the other half is kept in wet soil. Field experiments were conducted on olive trees (*Olea europaea*) grown under arid conditions in southern Morocco and subjected to four irrigation treatments using a localized irrigation system: Control (irrigated with 100% of crop evapotranspiration (ETc) on both sides of the root system); PRD1 (50% of ETc applied to one side of the root system, alternating every two weeks); PRD2 (50% of ETc applied to one side of the root system, alternating every two irrigations [every four weeks]); and PRD3 (100% of ETc applied to one side of the root system, and alternating every two weeks).

The PRD treatments significantly affected olive tree-water relations, starting with an increase in stomatal resistance and, subsequently, leaf water potential. The hypothesis of a PRD-induced chemical signal was supported by the observation that stomatal closure was similar in all PRD treatments, including PRD3, which had exactly the same level and evolution of leaf as did the control. The PRD1 and PRD2 treatments induced a slight reduction in the average shoot length and fruit yield. Olive yield was significantly higher for the control and PRD3 treatments compared to PRD1 and PRD2. The oil percentage in olive fruit and oil acidity did not show any significant differences between PRD treatments and the control. The PRD-induced yield reduction (15–20%), as compared to the control, was achieved with a 50% reduction in the total amount of water applied, a water-use efficiency increase of 70% under PRD treatments. Values of the photosynthetic parameters A_{max}, J_{max}, V_{cmax}, R_d and J_{max}/V_{cmax} ratio were not significantly influenced by the irrigation treatments.

Key words: Partial Rootzone Drying (PRD), olive irrigation, water-use efficiency

Introduction

Olive (*Olea europaea*) can grow and produce reasonably well under limited water conditions. It does, however, produce more when additional water is supplied through irrigation (Fernandez et al. 2001). Nonetheless, water resources are diminishing and predictions indicate that additional water will not be available for agriculture in the future, due to both human and environmental factors. Thus, there is a need to manage water scarcity and to develop sound and efficient irrigation methods for olive groves, with irrigation scheduling techniques based on the plant's actual need and optimal use of water (Fernandez et al. 2001). In Morocco, olives are grown both in rain-fed conditions and under irrigation. The present work focuses on irrigated olive and aims to reduce the amount of water required in the country, where average irrigation efficiency is low, varying between 40 and 45% (Rosegrant 2002a).

Positive relationships were found between stomatal conductance, leaf water potential and soil moisture. This indicated that both hydraulic feedback and feed-forward mechanisms could be invoked in the response of stomata to soil drying (Giorio et al. 1999). Soil or root water status directly affecting stomata has been recognized in many plants when submitted either to split-root or to root pressurization experiments, but root to shoot chemical signalling has also been invoked to explain the independence of conductance (*gs)* from shoot water status (Zhang and Davies 1990). A large number of field studies have recently validated the existence of root-to-shoot chemical signalling, supporting the previous studies under controlled environments (Davies et al. 2000), and opened new possibilities for agronomic applications. Partial root-zone drying (PRD) is an irrigation technique that requires approximately half of the root system being maintained in a dry state while the remainder of the root system is irrigated.

Work was carried out to evaluate the effect of the PRD system on vegetative and reproductive growth, and the water-use efficiency of olive trees under the semi-arid conditions of south Morocco. In addition to growth analysis and plant water relations parameters, yield components and fruit quality were evaluated under several PRD irrigation treatments. The overall aim is to manage the water scarcity facing agriculture in Morocco in general, and the olive sector in particular.

Material and methods

The field experiment was conducted on olive trees grown under semi-arid conditions in southern Morocco at the Office Régional de la Mise en Valeur Agricole (ORMVA), Station Saada, which is situated 20 km west of Marrakech city). This trial consisted of 100 trees (*Olea europaea* cv. Picholine Marocaine) planted in 1989 over an area of approximately 0.36 ha, with a spacing of 6×6 m. The orchard is grown as a split-plot experimental design, with 4 blocks and 4 treatments, and each individual plot contains 4 trees. Of one hundred trees, 64 were used directly in the trial, and 36 used as borders. The cultural practices carried out were similar to those commonly used in the region: the trees receive, on a yearly basis, chemical fertilizers in the form of potassium phosphate (45%), potassium sulphate (48%) and ammonium sulphate (7%) at the beginning of the year. Olive trees were also pruned at the end of each year.

The application of water treatments started in March 2000, with the application of four irrigation treatments: Control (PRD0), which received 100% of crop evapotranspiration (ETc) on both sides of the trees every 2 weeks; PRD1, which was irrigated with 50% ETc on one side only, and switching every irrigation; PRD2, irrigated with 50% ETc on one side only and switching sides every second irrigation (i.e. every 4 weeks); and PRD3, irrigated with 100% of the control on one side, switching sides every irrigation.

The full irrigation is based on the crop evapotranspiration (ETc) estimated from the potential evapotranspiration (ETo). ETo was calculated from the class A pan evaporation and using the Penman-Monteith crop coefficients (Kc = 0.7) proposed by FAO (2002).

$ET_{crop} = K_c * ET_o$.

The period of irrigation treatments was between March and October, which corresponds to the flowering and fruit ripening stages, respectively. A 3×3 m basin, divided into two parts by a small ridge, surrounded each tree. Irrigation was conducted by filling the two sides of the basin with drip emitters, discharging 8 litres per hour, placed on both sides of the trees a metre from the trunk. For the Control, PRD1 and PRD2, one drip emitter was used per side, i.e. 2 per tree, while for PRD3, 2 drip emitters were used per side (4 in total).

Effects of the different treatments were measured using the photosynthetic parameters A_{max}, J_{max}, V_{cmax}, R_d and yield in terms of olive oil production.

Data and data analysis

Water status

Soil and plant water status was monitored. The soil water content was measured using a tethaprobe (Delta-T Devices, Cambridge, UK) at different depths (0, 25, 50, 75 and 100 cm), from the surface to 100 cm, at 3 positions on both sides of each olive tree. The leaf water potential (ψ) was measured using a Scholander pressure chamber (model SKPM 1400, Skye Instruments, Powys, UK) on three fully-developed young leaves per tree at different positions. For each treatment, eight readings were performed where the leaf was immediately enclosed in an air filled bag and the balancing pressure measured. This measurement was carried out every 2 weeks. For diurnal leaf water potential, measurements were carried out at 06:00, at midday and at 16:00.

The water loss or transpiration by the plant was measured based on leaf stomatal resistance (r_s), which was determined using a portable porometer (Delta-T AP4, Delta-T Devices, Cambridge, UK). The technique consisted in having the terminal part of the main leaf lobe placed into the cup on the head unit, which was positioned towards the sun.

Measurement of maximum water loss by the plant was conducted on exposed leaves during cloudless periods, between 10:00 and 16:00. The device was calibrated before use on every occasion, using the calibration plate which was provided for the experiment. Leaf r_s measurements were made on three different leaves per plant and eight trees for each treatment. Three leaves per plant were detached from a similar position on each tree, to determine relative water content (RWC) from eight trees for each treatment. After cutting, the petiole was immediately immersed in a known weight of distilled water inside a glass tube, which was then sealed. The tubes were taken to the laboratory where the increased weight of the tubes was used to determine leaf fresh weight (FW). After 48 hours in dim light, the leaves were weighed to obtain turgid weight (TW). Dry weight (DW) was then measured after oven drying at 80°C for 48 hours. Relative water content was calculated as:

RWC =100 (FW-DW) / (TW-DW).

Growth, yield and fruit quality estimation

To see the effect of the different treatments, a number of parameters were measured, relating to tree behaviour and performance, such as growth, yield and quality, were measured.

Shoot vegetative growth was measured every two weeks during the season on 4 different shoots per tree. Olive yield of the monitored trees was measured by hand harvesting and weighing of the fruits with a field balance. Olive fruit final diameter was measured on 30 olives per tree, with eight replicates. Oil extraction was carried out with hexane (soxhlet) using the modified Folch method (Marzouk and Cherif 1981). Thirty crushed olives were extracted three times for 20 minutes. Filtrates obtained after each extraction were mixed and washed with water. The extracted lipids were weighed after solvent removal under reduced pressure. Free fatty acids were determined according to the AFNOR method (NF. T.60-204) (AFNOR 1984).

Data analysis

All the measurements were compiled into a data worksheet. The data was then analysed using the Sigmastat software (version 2.0, Jandel scientific software). An analysis of variance (ANOVA) was also undertaken, to determine the significance of each treatment.

Results and discussion

Water status

The analysis showed patterns of variation at different scales over time and space. Variations on a daily and annual basis throughout the seasons, as well as over the two-years of treatment, were observed.

In terms of diurnal variation during a typical PRD cycle, r_s values were higher in the afternoon than at noon or in the morning. Maximum stomatal openings were observed to be 1.6-2.0 s/cm in the morning, 2.5-3.1 s/cm at noon, and in the afternoon 3.1-4.9 s/cm.

No significant differences were observed between the treatments for the leaf r_s measurements made in the morning and at noon. However, all PRD treatments showed significantly higher r_s values in the afternoon, when the PRD-treated plants closed their stomata earlier than did the control. The pre-dawn measurement of leaf water potential during a typical PRD cycle showed that PRD1 and PRD2 had significantly lower values compared to the control. Differences were not significant later in the day, as leaf water potential became more negative.

Over the growing season, the leaf r_s showed significantly lower values in the fully irrigated trees compared to those that received PRD treatments. This was also observed in PRD3, which received the same amount of water as the control, but on one side of the tree only. However, leaf water potential was not significantly affected by the PRD treatments during the first 80 days, with an exception during the summer period, when the values of leaf water potential decreased substantially for all treatments. The values decreased from around -2.0 MPa to reach values in the region of –3.4 MPa for PRD1 and PRD2, and –2.7 MPa for the Control and PRD3 treatments.

Leaf relative water content decreased significantly from around 99% at the beginning of the experiment to around 60% by the end, with no significant differences between the control and PRD treatments. Despite the different responses of water relationship parameters to PRD treatments, there were significant linear correlations between Ψ and r_s ($p<0.001$) and between Ψ and RWC ($p<0.01$).

During the first season of the experiment (2002), olive yield was very low, ranging between 25 and 38 kg per tree. PRD treatments did not show any significant difference in yield, other than between PRD 1 and PRD 3 (Table 2). During the second year, olive yield was almost three times higher than during the previous year, and it was significantly higher for the control and PRD3 treatments (92.8 and 88.9 kg, respectively), compared to PRD1 and PRD2 treatments (78.7 and 74.5 kg, respectively). This PRD-induced yield reduction of only 15–20% was the result of a 50% reduction in the total amount of water applied. Therefore, water-use efficiency increased by 60–70% under PRD1 and PRD2 treatments, compared to the control and PRD3.

There was a slight increase in the percentage of oil in olive fruit under PRD1 and PRD2 treatments, compared with the control. However, PRD3 had the highest value (47.3%), although these differences were not statistically significant (Table 1). Similarly, oil acidity did not show any significant differences between PRD treatments and the control.

The PRD treatments significantly affected olive tree-water relations, starting with an increase in stomatal resistance and, subsequently, leaf water potential (Ψ), with a small, non-significant effect on relative leaf water content. The hypothesis of a PRD-induced chemical signal was supported by the observation that stomatal closure was similar in all PRD treatments, including PRD3, which had exactly the same level and evolution of leaf as did the control. The PRD1 and PRD2 treatments induced a slight reduction of average shoot length, which was comparable to fruit yield reduction. Olive yield was significantly higher for the control and PRD3 treatments, compared to PRD1 and PRD2 treatments. Values of the photosynthetic parameters A_{max}, J_{max}, V_{cmax}, R_d and J_{max}/V_{cmax} ratio were not significantly influenced by the irrigation treatments.

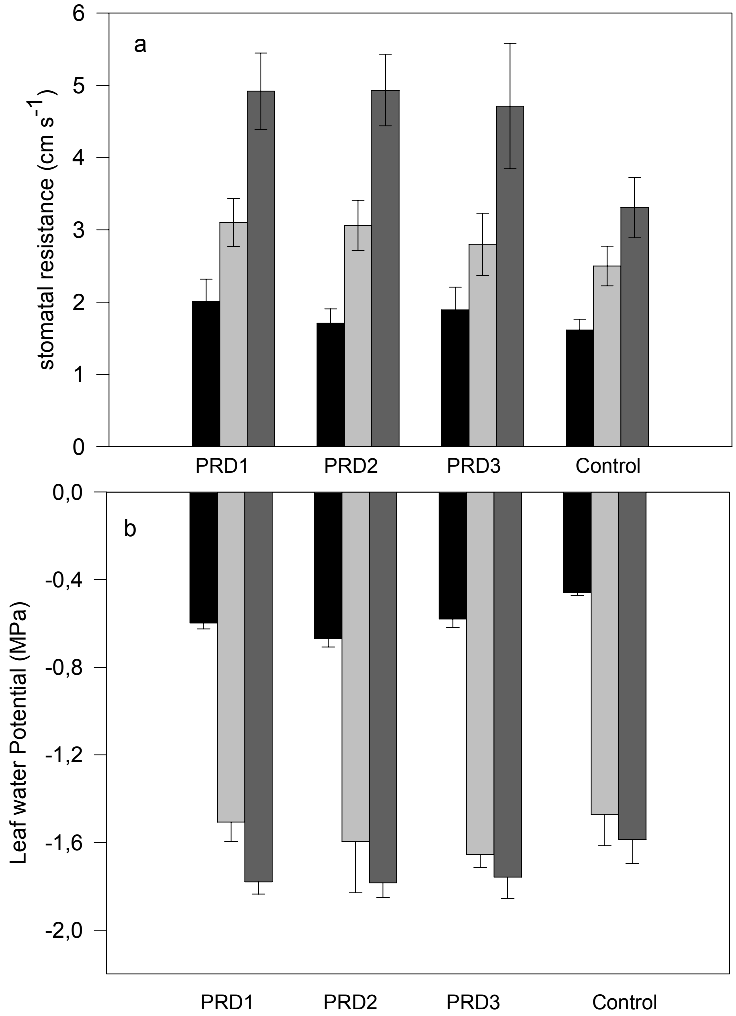


Figure 1. Diurnal mean (SD) fluctuation for the 4 treatments (Control, PRD1, PRD2 and PRD3) of a) olive stomatal resistance in the morning, at noon and in the afternoon; and b) Leaf water potential at pre-dawn (~06:00) and 16:00.

Table 1. Fruit growth and oil content of olives exposed to different irrigation treatments (Control, PRD1, PRD2, PRD3)

Parameter	Control	PRD1	PRD2	PRD3
Fruit weight (g/fruit)	4.31 ±0.06	4.27 ±0.04	4.14 ±0.07	4.32 ±0.06
Oil (% of DW)	37.8 ± 3.01	39.6 ±0.80	40.4 ±2.80	47.5 ±0.27

More importantly, the oil percentage in olive fruit and oil acidity showed no significant differences between PRD treatments and the control. The PRD-induced yield reduction (15–20%) compared to the control was achieved with a 50% reduction in the total amount of water applied - a water-use efficiency increase of up to 70% under PRD treatments. Thus, quality can be maintained with far less than 100% ET (total water requirements). This was shown previously in a high-tree-density (spacing 1.5 m × 3.9 m) olive (*Olea europaea* L. 'Arbequina') orchard in Spain, using values between 40-71% ET treatments (Berenguer et al. 2002). The work also shows the importance of deficit irrigation programmes under conditions of limited water resources, such as prevails in the Mediterranean region (Mariscal et al. 2000).

Conclusion and future work

The PRD irrigation technique aims at maintaining vegetative vigour and yield while reducing water use. If successful, it also results in higher water-use efficiency (Loveys et al. 2000). This technique has already been adapted in irrigated production of a number of crops, such as grapes, cereals, citrus and vegetables (Dry and Loveys 1999, 2000; Dry et al. 2001, Davies et al. 2000; Hutton 2000; Stoll et al. 2000; dos Santos et al. 2003). However, such work is limited when assessing the agronomic value of the PRD technique under arid or semi-arid conditions. This present work is the first systematic evaluation of olive growth and yield under PRD regulation, and confirms the hypothetical benefit of PRD for water-use efficiency in olive by maintaining adequate yield and fruit quality while using half of the water supply.

Although olive yield was significantly affected by the reduction of water, it did not affect olive oil quality or content. The present work indicates that water saving can be achieved while aiming at quality of olive production.

The techniques and tools developed under the present work can be applied in the further exploration of water savings by combining agronomic and genetic aspects, which should eventually enable increased saving and gains in terms of olive quality and quantity.

References

Afnor. 1984. Recueil de normes françaises des corps gras, graines oléagineuses et produits dérivés. 3ème Ed. AFNOR, Paris.

Berenguer, M.J., S.R. Grattan, J.H. Connell, V.S. Polito, P.M. Vossen. 2002. Irrigation management to optimise olive growth, production and sensorial oil quality. *Acta Horticulturae (ISHS),* 664: 79–85.

Davies, W.J., Bacon, M.A., Thompson, D.S., Sobeih, W. & Rodriguez, L.G. 2000. Regulation of leaf and fruit growth in plants in drying soil: exploitation of the plant's chemical signalling system and hydraulic architecture to increase the efficiency of water use in agriculture. *Journal of Experimental Botany,* 51: 1617–1626.

dos Santos, T.P., Lopes, C.M., Rodrigues, M.L., de Souza, C.R., Maroco, J.P., Pereira, J.S., Silva, J.R. & Chaves, M.M. 2003. Partial rootzone drying: effects on growth and fruit quality of field-grown grapevines (*Vitis vinifera*). *Functional Plant Biology,* 30: 663–671.

Dry, P.R., Loveys, B.R., McCarthy, M.G. & Stoll, M. 2001. Strategic irrigation management in Australian vineyards. *Journal International des Sciences de la Vigne et du Vin,* 35: 129–139.

Dry, P.R., Loveys, B.R. & During, H. 2000. Partial drying of rootzone of grape. I. Transient changes in shoot growth and gas exchange. *Vitis,* 39: 3–7.

Dry, P.R. & Loveys, B.R. 1999. Grapevine shoot growth and stomatal conductance are reduced when part of the root system is dried. *Vitis,* 38: 151–156.

FAO [Food and Agriculture Organization of the United Nations]. 2002. FAO Production Yearbook. Rome, Italy. http://apps.fao.org.

Fernández, J.E., Palomo, M.J., Diaz-Espejo, A., Clothier, B.E., Green, S.R., Giron, I.F. & Moreno, F. 2001. Heat-pulse measurements of sap flow in olives for automating irrigation: Tests, root flow and diagnostics of water stress. *Agricultural Water Management*, 51: 99–123.

Giorio, P., Sorrentino, G. & d'Andria, R. 1999. Stomatal behaviour, leaf water status and photosynthetic response in field-grown olive trees under water deficit. *Environmental and Experimental Botany,* 42: 95–104.

Holbrook, M.N., Shashidar, V.R., James, R.A. & Munns, R. 2002. Stomatal control in tomato with ABA-deficient roots: response of grafted plants to soil drying. *Journal of Experimental Botany,* 53: 1503–1514.

Hutton, R. 2000. Improving the water use efficiency of citrus at Yanco Agricultural Institute. *Farmers' Newsletter-Horticulture*, 184: 47–49.

Loveys, B.R., Dry, P.R., Stoll, M. & McCarthy, M.G. 2000. Using plant physiology to improve the water use efficiency of horticultural crops. *Acta Horticulturae (ISHS),* 537:187–199.

Mariscal, M.J., Lavado, M., Moñino M.J. & Prieto, M.H. 2000. Olive tree (*Olea europaea* L.) CV. *Acta Horticulturae (ISHS),* 537: 917–922

Marzouk, B. & Cherif, A. 1981. Lipogénèse dans l'olive, I. Formation des lipides neutres. *Oléagineux*, 36: 77–82.

Stoll, M., Loveys, B. & Dry, P. 2000. Hormonal changes induced by partial rootzone drying of irrigated grapevine. *Journal of Experimental Botany,* 51: 1627–1634.

Zhang, J. & Davies, W.J. 1990. Changes in the concentration of ABA in the xylem sap as a function of changing soil water status can account for changes in leaf conductance and growth. *Plant Cell and Environment,* 13: 277–285.

Section 3
Research strategies for water-use: exploration of genetic variation

Genetic variation of water-use efficiency within crops: prospects and opportunities for managing water scarcity

A. Bari, G. Ayad and R.V. Rao

Assessment of olive diversity for water-use efficiency in Morocco

L. Sikaoui, B. Boulouha and A. Bari

Genetic variation of WUE within the almond crop

M. Ibnou Ali El Alaoui, A. Bari and A. Oukabli

Identification of fig genotypes tolerant to drought in Morocco

A. Oukabli, A. Bari, A. Mckkaoui And M. Lahlou

Genetic variation of water-use efficiency within crops: prospects and opportunities for managing water scarcity

A. Bari, G. Ayad and R.V. Rao

Bioversity International. Email: a.bari@cgiar.org; g.ayad@cgiar.org, v.rao@cgiar.org

Abstract

According to the latest predictions, a 15–20% increase in water availability is needed to meet the global demand for food production in the coming years. Yet, such increase in water demand is unlikely to be met and so alternative water saving methods need to be developed. Given the current situation, a viable solution to this critical problem can be found through more effective management of existing water resources, particularly those used in agriculture - for which approximately two-thirds of the potential water resources worldwide are utilized. Although the water requirements of many agricultural crops have been studied, the data produced are usually measured at the crop level, through the use of crop coefficients at the different stages of development. In addition, the evaluation of genotypes is usually expressed in terms of yield per genotype, but less frequently in terms of the amount of water used by the genotype. The genetic option for managing water scarcity envisages the use of water-use efficient crop genotypes to manage water scarcity, based on their genotypic coefficient (K_g) instead. Knowledge about genotypic variation in terms of water-use efficiency (WUE) helps to better deploy the genetic diversity in crops. Screening to identify water-use efficient genotypes with low K_g can generate both savings in water consumption and improve productivity. The proposed work intends to research the intraspecific diversity and assess the variation of such coefficients across varieties, landraces and ecotypes in order to identify those genotypes that use less water (m^3 genotype^{-1}).

Key words: Genotypic variation, water-use efficiency traits, quantative modelling of traits, QTLs, and gene networks.

Introduction

According to the latest predictions, a 15–20% increase in water availability is needed to meet rising global demand for food production in the coming years. Yet, such increase in water demand is unlikely to be met, and so alternative water saving methods need to be developed. However, efficiency can be increased through innovation, new policies and improvement in operations (Gleick 2002). Successful management of limited water supplies for agriculture depends on two options: better agronomic practices and application of genetics. The latter option is based on an understanding of genetic diversity for water-use efficiency among crop genotypes, and better deployment of such genetic diversity within crops. Studies conducted on water requirements are normally based on crop coefficients (K_c), the ratio between crop evapotranspiration (ET_{crop}) and a reference evapotranspiration based on climate data (ET_o). Plants tend to lower their K_c either by conservation mechanisms or by enhancing their up-take of soil moisture. K_c can be lowered further by better deployment of genetic diversity within crops, utilizing those with a low genotypic coefficient (K_g).

Competition for limited supplies of fresh water in many parts of the world has led to a number of studies in recent years mapping Quantitative Trait Loci (QTL) for water-use efficiency (WUE) in crops (Xu et al. 2004). The benefits of selective plant breeding are yet to be fully optimized for the farmer because of limited characterization of varieties and their interaction with the environment (Snape 2001), which might include characterization for K_g

of WUE values. There is also potential for further improving productivity, in order to narrow the gap between the actual yield and the theoretical yield based on physiological traits (Figure 1) (Falkenmark and Rockstrom 2004).

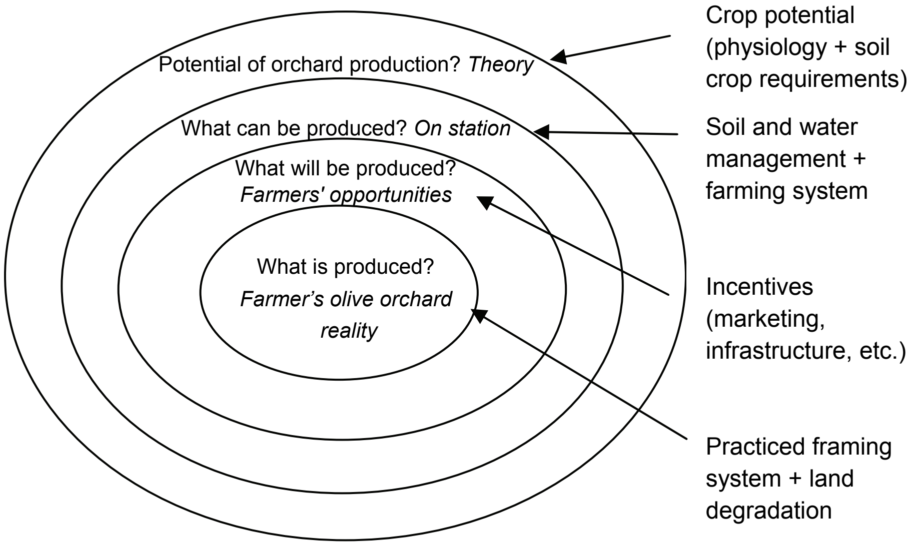


Figure 1. Conceptual framework of actual yield at the farm level and different potential yields at different levels.
Source: modified from Falkenmark and Rockstrom, 2004.

The aim of this work is to show the potential of within crop variation that can be explored for water-use efficient genotypes. It aims at setting up a framework to screen for this variation, along with methods for the effective and objective assessment of WUE traits.

Given the nature and complexity of WUE traits in terms of the number of genes involved and the interaction among these genes (gene networks), modelling of gene networks has been also discussed. Both quantitative modelling of traits and quantitative models of gene networks can help in the systematic analysis of phenotypes required to detect subtle changes that characterize quantitative traits, such as those that govern WUE (Tardieu 2005; Kaminuma et al. 2005).

Genotypic variation conceptual framework

Although the water requirements of many agricultural crops have been studied, the data produced are usually developed from the use of crop coefficients at the different stages of development and evapotranspiration (ET_o) figures based on climate data. In addition, the evaluation is usually expressed in terms of yield per genotype, but less commonly in terms of the amount of water used. Hence, the proposed work intends to research the intraspecific diversity and assess the variation of such coefficients across varieties, landraces and ecotypes in order to identify those genotypes that use less water (m^3 $genotype^{-1}$) and may contribute to increased efficiency of water-use within agriculture. Water-use efficient crop cultivars are based on the genotypic coefficient (K_g), as proposed in equation 1 (Bari et al. 2004):

$$ET_{crop} = K_g{}^{*}\ K_c \times ET_o \quad \text{(Eq. 1)}$$

Where:

ET_{crop} estimates the water requirement of a given crop in mm per unit of time, e.g. mm/day, mm/month or mm/season;

K_c is the crop coefficient;

K_g is the genotype coefficient; and

ET_o is the reference crop evapotranspiration in mm per unit of time, e.g. mm/day, mm/month or mm/season.

Variability of K_c mainly depends on growth stage and on environmental factors (Table 1; Figure 2) whereas variability of K_g is due to the genetic makeup of the plant. Differences in K_g are a result of segregating allelic variants of one or more genes within the species.

Table 1. K_c per crop at 3 stages of plant growth for 5 different crops common in the Mediterranean/WANA region.

Crop	**$K_{c\ ini}$**	**$K_{c\ midi}$**	**$K_{c\ end}$**	**Maximum crop height** (m)
Barley	0.30	1.15	0.25	1
Wheat	0.30	1.15	0.30	1
Almond	0.40	0.90	0.65	5
Olive	0.65	0.70	0.70	3-5
Pistachio	0.40	1.10	0.45	3-5

Source: FAO 1998.

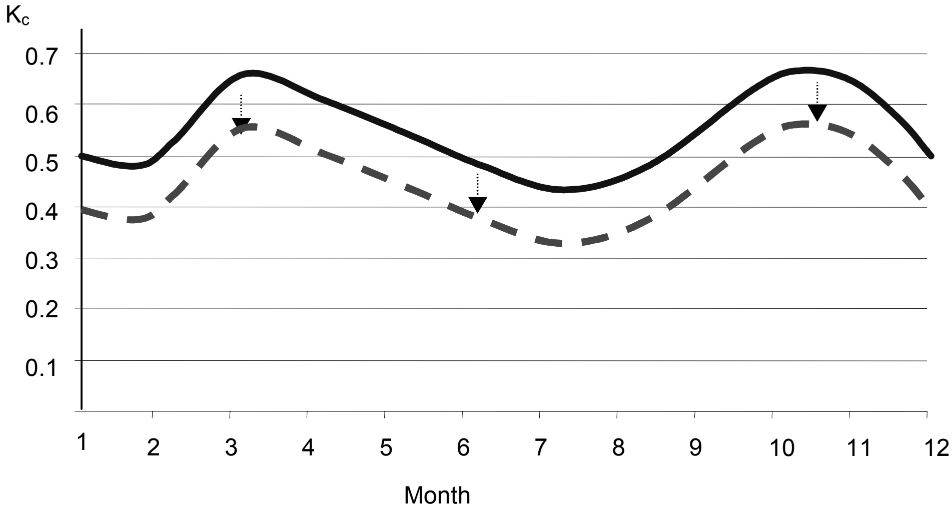


Figure 2. Monthly K_cs (plain line) for the months January to December found by Pastor and Orgaz (1994) in olive orchards in Spain having 60% ground cover (Source: FAO 1998). The dashed line is the prospective line to eventually lower K_c values based on the genetic option.

If K_g is determined by one locus with two alleles, *Q* and *q*, the phenotypic distribution of a population with two alleles is a mixture of distributions associated with the following three underlying genotypes:

$$p(x) = p_{QQ}(x)P_r(_{QQ}) + p_{Qq}(x)P_r(_{Qq}) + p_{qq}(x)P_r(_{qq})$$

The net statistical effect of both genetic (K_g) and environmental variation (K_c) with a model such as this is (Boyce Thompson Institute 2006):

$$P_{ij} = \mu + G_i + E_j + I_{ij} + \varepsilon$$

where:

Pij is the observed phenotype,

μ is the mean phenotype in the population,

G_i and E_j are the net effects due to an individual having genotype *i* (with a coefficient K*g*) and environment *j* (K*c*),

Iij is the interaction effect between *i* and *j*, and

ε is a random contribution to the phenotype, generally assumed to be normally distributed with mean zero and variance equal for all *i* and *j*.

Combining these two equations helps to partition G_i into its underlying distribution as a result of segregating genetic factors, *i* = 1… *n*, (*i* here refers to the underlying distributions) in the case of more than one locus where each distribution has *Pr(i)* probability:

$$p(x) = \sum_{i=1}^{n} \Pr(i).p_i(x)$$

$$p(x) = \sum_{i=1}^{n} \Pr(i).\varphi(x, \mu_i, \sigma_i^2)$$

$$\varphi(x, \mu_i, \sigma_i^2) = \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp\left[-\frac{(x-\mu_i)^2}{2\sigma_i^2}\right]$$

where *p(x)*, the joint probability density function, is the product of each univariate (assumed) normal distribution random variable $\varphi(x)$ with mean μ_i and variance σ_i^2.

The distribution above, in terms of genotypes and phenotypes of a segregating population, helps in the prediction of the number of factors involved and their interaction. This can be carried out by crossing two different genotypes (Lynch and Walsh 1998).

For quantitative traits, such as those of WUE that are controlled by multiple quantitative trait loci (QTLs), the situation is complex but there are prospects to unveil each QTL individually (Doebley 2000). In contrast to qualitative traits that fall into discrete categories, quantitative phenotypic trait variation is continuous, where each QTL explains only a portion of the total variation. The expression of each QTL is also modified by interaction with other genes and by the environment, and is thus complex.

The genetics of WUE

A study conducted by Lin et al. (1998) to map QTLs associated with WUE in tomato based on carbon isotope discrimination (CID) showed that 22 genomic regions distributed on 11 chromosomes were associated with WUE, where each trait had its own unique set of QTLs. These data demonstrate the existence of a number of linked markers for WUE parameters and confirm that WUE is a polygenically controlled trait in various environments similar to root branching (Martin et al. 1999). In soybean, Mian et al. (1996) found molecular markers associated with WUE and leaf ash, while Specht and Lark (2002) used regression of seed yield on the seasonal water amount (SY = T × WUE × HI) to generate a linear regression coefficient (i.e. β) that is a season-specific estimate of genotypic WUE. The authors conducted genomic analysis on a soybean population of recombinant inbred lines and found significant genotypic heterogeneity, with the responsiveness to water abundance being a key contributor to higher mean yield. A number of species show the existence of this genotypic variation, e.g. Wright in 1996 found large genotypic variation in WUE, of the order of 40–60% in ground-nut, navybean, soybean and chickpea.

In terms of root features associated with WUE, the heritability and inheritance pattern of roots in wheat and maize suggest that the root features are controlled by a polygenetic system in which control of the root system is influenced by interacting genes (Feix et al. 2002; Manske and Vlek 2002). Investigations of wheat rooting traits in combination with root modelling have suggested the identification of key rooting traits that confer competitive advantages in breeding (Dunbabin 2003).

In natural populations, such as that of olives, most phenotypic variation is continuous due to different alleles at multiple loci. This quantitative variation has been exploited through domestication to select highly productive cultivars with large fruit size. Yet such variation under the control of many genes poses problems since plants with the same phenotype can carry different alleles at each of many QTLs and are under the influence of both environmental and genetic factors (Doebley 2000; Juenger et al. 2000). These QTLs have been studied based on association analysis. There are, however, prospects to unveil each QTL individually, for example QTL *fw2.2* for fruit size found in tomato (Frary et al. 2000). Unlocking the secret of quantitative traits such as those of WUE may be the greatest challenge facing geneticists in the 21st century (Doebley 2000).

Challenges to mitigating water scarcity

Traits associated with WUE (Phenotyping)

As discussed above, a number of traits (Table 2) are used to measure WUE. However, defining such traits is difficult, given the fact that there is as yet very little information on the genetics and inheritance of these traits. Nevertheless, defining these traits is a prerequisite for genotyping and hence the importance of phenotyping. The identification of traits can help in better tagging the genes known to improve those traits, which in turn can help in the selection for improved genotypes. Lack of characterization of crop germplasm in general, and crop cultivars, has so far hindered the use of WUE in practice and breeding (Snape 2001). The effectiveness of characterization is also hindered by the lack of novel 'smart and rapid screens' needed to identify desirable traits in a cost-effective manner and with regard to the large number of plants and segregating populations (Snape 2001).

Table 2. Some of the parameters for measuring WUE.

Physiological and biometrical traits	Indication or Indicator
Leaf water potential (Ψ)	Used as water stress indicator for each crop (Ψ)
Turgor pressure (*P*)	leaf-to-air vapour pressure deficit (VPD)
Carbon isotope composition ($\delta^{13}C$)	Carbon isotope composition ($\delta^{13}C$) is a useful surrogate for integrated plant water-use efficiency (WUE). Negative $\delta^{13}C$ is an indicative of lower WUE
Plant Growth	Speed of emergence of seedlings
Stomatal conductance (g) usually used in gas exchange analysis	Decrease of *g*, assuming uniform stomatal behaviour
Stomatal resistance (*r*)	Increase of *r*, inverse of *g*
Root branching or structure	Increase in structural/branching parameters such as fractal geometry (D), where a high D value indicates high branching.

Note: The above list is not exhaustive and trends may be site- and condition-dependent as the ranking of genotypes in terms of their WUE may vary between sites; thus caution needs to be taken.

Tools to assess WUE (Traits capture)

Capturing and assessing genetic resources for these traits is a challenge, given their complexity and the large number of samples required to characterize plant genetic resources. Both capturing and assessing complex traits and large numbers of samples is costly and difficult and this hinders the effective use of genetic resources. Some studies may require the measurement of a large number of samples simultaneously (Shinomura 2005). This is even more challenging but is a prerequisite for phenome analysis, where systematic analysis of phenotypes is vital in order to determine all functions of genes involved. Conventional phenotypic screening methods depend mainly on visual observation of qualitative traits, but this presents difficulties in detecting subtle changes, such as mutants that may have useful traits (Kaminuma et al. 2005).

Modelling of gene networks

A large number of networked genes have been found to be involved with traits associated with WUE. The expression of some genes may increase or decrease the expression of others, forming a complex network of interactions (Liebovitch et al. 2006). There are a number of such complex networks of genes involving genotype-by-environment interaction as well as epistatic interaction between genes regulating variation for traits (Cooper et al. 1999; Dennis 2002). The interaction and functioning among these networks of genes could be predicted if the said networks were sufficiently understood and appropriately quantified (van Oosterom et al. 2004). The gene network models are based on the expression of gene *i* as a level of mRNA, at time with value X, among N genes, represented by a connection matrix M, and at a subsequent time with a new value, X′ = MX. In addition to the capture of complex traits based on quantitative modelling of plant features, quantitative models for predicting functioning of gene networks can also help the WUE undertaking to show phenotypes that emerge from gene expression dynamics (Welch et al. 2004). The trend over the last few years is to incorporate varietal differences in the model, in the form of genetic coefficients, to quantify genetic effects and reveal the networks that actually control important plant processes, such as evapotranspiration. Among the models used is the neural network model, which includes, in addition to quantitative mathematical formulas, mutant screenings, epitasis detection experiments and phenotype rescue testament, and yields qualitative relationships (Welch et al. 2003).

Plant genetic resources and WUE: opportunities and prospects

The genetic or plant option relies mainly on germplasm improvements (FAO 2003). Plant genetic resources (PGR) are closely linked to water issues in view of their great potential in terms of WUE variation within species. Variation between genotypes with respect to WUE parameters (e.g. gas exchange and carbon isotope discrimination) has been reported by a number of authors (Comstock and Ehleringer 1992; Tauer et al. 1992; Weyhrich et al. 1995; Nienhuis 1994; Johnson and Rumbaugh 1996; Sun et al. 1996; Novello and de Palma 1997; Grossnickle et al. 1997; Pennington 1999; Mencuccini et al. 1999, 2000; Gaudillere et al. 2002; Xu et al. 2004; Rowland et al. 2004). Overall, WUE was found to be associated with carbon isotope discrimination ($\delta^{13}C$), which also has a genetic basis. Carbon isotope discrimination refers to changes in the $^{13}C/^{12}C$ ratio based on the relationship between the atmospheric and the intercellular CO_2 concentration and is used as an integrative tool for water status (Gaudillere et al. 2002). $\delta^{13}C$ has thus been used as a surrogate for WUE and to select suitable genotypes without compromising yield (Sun et al. 1996, 1999). Work on grapevine, which requires cultivation under mild, limited water stress to guarantee quality, showed large variation of $\delta^{13}C$ between -22 to -24.4 (Gaudillere et al. 2002). However, partly due to the lack of screening methodologies (Anyia et al. 2005), and despite the importance of efficient water-use, WUE has been utilized in plant breeding and pre-breeding only recently, using the indirect measurement of leaf $\delta^{13}C$ and specific leaf area (SLA) (Wright 1996).

There is a tremendous diversity in olives which needs to be explored and assessed for WUE traits. The large genetic variation found in olives is the result of crosses between forms of different geographic origin (Besnard et al. 1998; Lumaret and Ouazzani 2001). The process of displacement-hybridization-selection of olive diversity around the Mediterranean basin has led to the creation of a large number of local cultivars (Barranco 2001). Bartolini et al. (1994) reported that there are more than 1000 cultivars classified, with some 3000 synonyms. Work on WUE within olive diversity showed that there are differences among these cultivars with regard to their WUE values. The work by Bongi and Palliotti in 1994 showed WUE values of 2.16 and 3.48 g CO_2 kg H_2O^{-1} for the cultivars Ascolana and Moraiolo, respectively (Fernández and Moreno 1999). Moraiolo is a rustic cultivar of Italian origin with a high rooting capacity, while Ascolana, also from Italy, requires more favourable conditions in order to produce abundantly (Barranco et al. 2000).

Efficient genotypes will require greater access to, and efficient exploitation of, sub-soil water (Paveley 2000). Studies on root systems are also important to screen for water-use efficient genotypes. Genetic variation with respect to root architecture has been reported by a number of authors (Care et al. 2002; Costa et al. 2001, 2002; Bari et al. 2004; Serraj et al. 2005). Root systems vary not only between species but also within species (Fitter 2002). Selection for specific root traits has sometimes been successful, but the constraints lie mostly in measurement (Paveley 2000). Overall, knowledge of the genetic background of plant root features is a prerequisite for effective breeding (Manske and Vlek 2002). Because a plant's root system is a highly organized structure that not only serves as anchorage but also in the acquisition of water and nutrients, Lynch (2002) suggested the consideration of the relationship between the architecture of root structure and its function, and eventually the relationship between root architecture and plant productivity.

New concepts of water and nutrient capture by roots need to be sought, just as Beer's Law provides a solid conceptual framework for canopy management (Snape 2001). New techniques for measurement of root system activities are highly desirable, and should be sought to accelerate the use of genetic resources (Snape 2001).

References

Anyia, A.O., Archambault, D.J., Slaski, J.J. & Nyachiro, J.M. 2005. Carbon isotope discrimination as a selection criterion for improved water use efficiency and productivity of barley on the prairies. North American Barley Researchers Workshop. The 18th North American Barley Researchers Workshop, 17–20 July 2005, Red Deer, Alberta, Canada.

Bari, A., Ayad, G., Martin, A., Gonzalez-Andujar, J.L., Nachit, M. & Elouafi, I. 2004. Fractals and Water Use Efficiency. pp. 315–316, *in:* M.M. Novak (editor). *Thinking in Patterns*. World Scientific, Singapore.

Barranco, D., Cimato, A., Fiorino, P., Rallo, L., Touzani, A., Castañeda, C., Serafini, F. & Trujillo, I. 2000. World Catalogue of Olive Varieties. International Olive Oil Council (IOOC), Madrid, Spain.

Barranco, D. 2001. Variedades y Patrones. *In*: D. Barrnco, R. Fernández-Escoba and L. Rallo (editors). El Cultivo del Olivo. Junta de Andalucía, Sevilla, Spain.

Bartolini, G., Messeri, C. & Prevost, G. 1994. Olive tree germplasm: descriptor lists of cultivated varieties in the world. *Acta Horticulturae (ISHS)*, 356: 116-118.

Besnard, G., Moukhli, A., Sommerlatte, H., Hosseinpour, H., Tersac, M., Villemur, P., Dosba, F. & Bervillé, A. 1998. Origins and domestication of Mediterranean olive determined through RAPD marker analysis. *In:* (A.B. Damania, J. Valkoun, G. Willcox and C.O. Qualset (editors). The Origins of Agriculture and Crop Domestication. ICARDA, IPGRI, FAO and UC (USA).

Bongi, G. & Palliotti, A. 1994. Olive. pp. 165–187, *in:* B. Schaffer and P.C. Andersen (editors). Handbook of Environmental Physiology of Fruit Crops. Vol. I: Temperate Crops. CRC Press, Boca Raton, FL, USA.

Boyce Thompson Institute. 2006. The genomics of water-use efficiency project. See: http://isotope.bti.cornell.edu/home.html, accessed November 14th, 2006

Care, D.A., Crush, J.R. & Dodd, M.B. 2002. Application of digital image capture techniques to study root growth of white clover (*Trifolium repens* L.) cultivars with contrasting root morphologies. *In:* Interactions in the Root Environment: An Integrated Approach. Proceedings of the Millennium Conference on Rhizosphere Interactions, IACR-Rothamsted. Kluwer, Dordrecht, The Netherlands.

Comstock, J. & Ehleringer, J. 1992. Correlating genetic-variation in carbon isotopic composition with complex climatic gradients. *Proceedings of The National Academy of Sciences of the United States of America*, 89(16): 7747–7751.

Cooper, M., Podlich, D.W. & Chapman, S.C. 1999. Computer simulation linked to gene information databases as a strategic research tool to evaluate molecular approaches for genetic improvement of crops. Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments. CIMMYT, Mexico. See: http://www.cimmyt.org/

Costa C., Dwyer, L.M., Hamel, C., Muamba, D.F., Wang, X.L., Nantais, L. & Smith, D.L. 2001. Root contrast enhancement for measurement with optical scanner-based image analysis. *Canadian Journal of Botany*, 79: 23–29.

Costa C., Dwyer, L.M., Zhou, X., Dutilleul, P., Hamel, C., Reid, L.M. & Smith, D.L. 2002. Root morphology of contrasting maize genotypes. *Agronomy Journal*, 94: 96–101.

Dennis, C. 2002. The brave new world of RNA. News Features, *Nature* 418: 122-124.

Doebley, J. 2000. A tomato gene weighs in. *Science*, 289(5476): 71–72.

Falkenmark, M. & Rockstrom, J. 2004. Balancing water for humans and nature. Cromwell Press, UK.

FAO [Food and Agriculture Organization of the United Nations]. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. Prepared by R.G. Allen, L.S. Pereira, D. Raes and M. Smith. *FAO Irrigation and Drainage Paper*, No. 56. Rome, Italy.

FAO. 2003. Unlocking the Water Potential of Agriculture. See: http://www.fao.org/docrep/006/Y4525E/y4525e00.HTM

Feix, G., Hochholdinger, F. & Park, W.J. 2002. Maize root system and genetic analysis of its function. pp. 239–248, *in:* Y. Waisel, A. Eshel and U. Kafkafi (editors). Plant Roots: The Hidden Half. Marcel Dekker, USA.

Fernández, E. & Moreno, F. 1999. Water use by the olive tree. *Journal of Crop Production,* 2(2): 101–162.

Fitter, A. 2002. Characteristics and function of root systems. pp. 15–32, *in:* Y. Waisel, A. Eshel and U. Kafkafi (editors). Plant Roots: The Hidden Half. Marcel Dekker, USA.

Frary A., Nesbitt, C., Frary, A., Grandillo, S., van der Knapp, E., Cong, B., Liu, J., Meller, J., Elber, R., Alpert, K. & Tanksley, S. 2000. fw2.2: a quantitative trait locus key to the evolution of tomato fruit. *Science*, 289: 85–88.

Gaudillere, J.P., Leeuwen, C.V. & Ollat, N. 2002. Carbon isotope composition of sugars in grapevine, an integrated indicator of vineyard water status. *Journal of Experimental Botany*, 53(369): 757–763.

Gleick, P. 2002. Soft water paths. *Nature*, 418: 373.

Grossnickle, S.C., Fan, S. & Russell, J. 1997. Adaptive physiology of Western Red Cedar. WFGA 1997 Program Berkeley, California, USA.

Johnson, D.A. &Rumbaugh, M.D. 1996. Genetic variation and inheritance characteristics for carbon isotope discrimination in alfalfa. *Journal of Range Management*, 48: 126–131.

Juenger, T., Purugganan, M. & Mackay, T.F.C. 2000. Quantitative trait loci for floral morphology in *Arabidopsis thaliana*. *Genetics,* 156: 1379–1392.

Kaminuma, E., Heida, N., Yoshizumi, T., Hasegawa, Y., Nakazawa, M., Matsui, M. & Toyoda, T. 2005. In-silico phenotypic screening method based on statistical modelling for phenome analysis. Phenome 2005. 2nd annual Meeting on Phenomics: From Phenome to Genome Functions. 25–26 October, 2005. RIKEN Yokohama Institute, Yokohama, Japan. See: http://omicspace.riken.jp/ph05/index.html

Liebovitch, L.S., Jirsa, V.K. & Shehadeh, L.A. 2006. Structure of genetic regulatory networks: evidence for scale free networks. pp. 1–8, *in:* M. Novak (editor). Complexus Mundi, Emergent Patterns in Nature. World Scientific, Singapore. See: http://www.worldscibooks.com/chaos/6032.html

Lumaret, R. & Ouazzani, N. 2001. Ancient wild olives in Mediterranean forests. *Nature*, 413(1): 700.

Lynch, M. & Walsh, B. 1998. Genetics and Analysis of Quantitative Traits. Sinauer Associates, Sunderland, MA, USA.

Lynch, J. 2002. Relationship between root architecture and plant productivity. *In:* Interactions in the Root Environment: An Integrated Approach: Proceedings of the Millennium Conference on Rhizosphere Interactions, IACR-Rothamsted. Kluwer, Dordrecht, The Netherlands.

Manske, G.G. B. & Vlek, P.L.G. 2002. Root architecture –Wheat as a model plant. pp. 249–259, *in:* Y. Waisel, A. Eshel and U. Kafkafi (editors). Plant Roots: The Hidden Half. Marcel Dekker, USA.

Martin, B.C., Tauer, C.G. & Lin, K.R. 1999. Carbon isotope discrimination as a tool to improve water-use efficiency in tomato. *Crop Science*, 39: 1775–1783.

Mencuccini, M. & Comstock, J.P. 1999. Variability in hydraulic architecture and gas exchange of common bean (*Phaseolus vulgaris* L.) cultivars under well-watered conditions: Interactions with leaf size. *Australian Journal of Plant Physiology*, 26: 115–124.

Mencuccini, M., Mambelli, S. & Comstock, J.P. 2000. Stomatal responsiveness to leaf water status in common bean is a function of time of day. *Plant, Cell and Environment*, 23: 1109–1118.

Mian, M.A.R., Bailey, M.A. & Boerma, H.R. 1996. Molecular markers associated with water use efficiency and leaf ash in soybean. *Crop Science*, 36(5): 1252–1257.

Nienhuis, J., Sills, G.R., Martin, B. & King, G. 1994. Variance for water-use efficiency among ecotypes and recombinant inbred lines of *Arabidopsis thaliana* (Brassicaceae). *American Journal of Botany,* 81: 943–947.

Novello, V. & de Palma, L. 1997. Genotype, rootstock and irrigation influence on water relations, photosynthesis and water use efficiency in grapevine. *Acta Horticulturae (ISHS),* 449: 467–474.

Pennington, R.E., Tischler, C.R., Johnson, H.B. & Polley, H.W. 1999. Genetic variation for carbon isotope composition in honey mesquite (*Prosopis glandulosa*). *Tree Physiology,* 19: 583–589.

Paveley, N.D. 2000. Crop physiology to improve crop protection. Ministry of Agriculture and Fisheries, UK.

Rowland, D., Blankenship, P., Puppala, N., Beasley, J., Burow, M., Gorbet, D., Jordan, D., Melouk, H., Simpson, C. & Bostick, J. 2004. Variation in water-use efficiency of peanut varieties across peanut production regions. The 4th International Crop Science Congress, Brisbane, Australia. See: http://www.cropscience.org.au/icsc2004

Serraj, R., Hash, C.T., Crouch, J.H., Rizvi, M.S. & Lagoda, P.J. 2005. Genetic and management options to enhance drought resistance and water use efficiency in dryland agriculture. The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy, 24–28 September 2005. (abstract). See: http://www.plantstress.com/id2/

Shinomura, T. 2005. Automatic imaging system and computational image analysis for the measurement of visible phenotypes in plants. Phenome 2005, 2nd annual meeting on phenomics:

From Phenome To Genome Functions. 25–26 October 2005. RIKEN Yokohama Institute, Yokohama, Japan. See: http://omicspace.riken.jp/ph05/index.html

Snape, J. 2001. The influence of genetics on future crop production: from traits to genes, and genes to traits. *Annals of Applied Biology* 138: 203–206.

Specht, J.E. & Lark, K.G. 2002. Genomics and the scientific principle: SY = T × WUE × HI. First International Conference on Legumes Genomics and Genetics: Translation to Crop Improvement. Minneapolis- St Paul, USA.

Sun, Z.J., Livingston, N.J. Guy, R.D. & Ethier, G.J. 1996. Stable carbon isotopes as indicators of increased water use efficiency and productivity in white spruce (*Picea glauca* (Moench) Voss) seedlings. *Plant, Cell and Environment*, 19(7): 887–894 .

Tardieu, F. 2005. Assessing crop simulation models as a research tool for analysing crop responses to water deficit. The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy, 24–28 September 2005. (abstract) See: http://www.plantstress.com/id2/

Tauer, C.G., Hallgren, S.W. & Martin, B. 1992. Using marker-aided selection to improve tree growth response to abiotic stress. *Canadian Journal of Forest Research*, 22: 1018–1030.

van Oosterom, E., Hammer, G. & Chapman, S. 2004. Can transition to flowering be modelled dynamically from the gene level? *In:* Tony Fischer (editor-in-chief). New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia. See: www.cropscience.org.au

Welch, S.M., Dong, Z. & Roe, J.L. 2004. Modelling gene networks controlling transition to flowering in Arabidopsis. *In:* Tony Fischer (editor-in-chief). New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia. See: www.cropscience.org.au

Welch, S.M., Roe, J.L. & Dong, Z. 2003. A genetic neural network model of flowering time control in *Arabidopsis thaliana*. *Agronomy Journal*, 95: 71–81.

Weyhrich, R.A., Carver, B.F. & Martin, B. 1995. Photosynthesis and water-use efficiency of awned and awnletted near-isogenic lines of hard red winter wheat. *Crop Science*, 35: 172–176.

Wright, G.C. 1996. Selection for water-use efficiency in grain legume species. Proceedings of the 8th Australian Agronomy Conference, Toowoomba, 1996.

Xu, Y., Coburn, J.R., Gollands, B.E., Pausch, R.C., Fleet, C.F., McCouch, S.R., Comstock, J.P. 2004. Mapping quantitative trait loci for water use efficiency in rice. Plant & Animal Genomes XII Conference. Town & Country Convention Center, San Diego, CA, USA, 10–14 January 2004.

Assessment of olive diversity for water-use efficiency in Morocco

L. Sikaoui[1], B. Boulouha[1] and A. Bari[2]

1 Institut National de la Recherche Agronomique (INRA)

2 Bioversity International, c/o ICARDA, Aleppo, Syria
Email: sikaouilhassane@yahoo.fr

Abstract

Olive groves are important in Morocco, covering approximately 600 000 ha, with 60 million trees (representing half the total area covered by all fruit and nut trees in the country). The main olive variety grown is the 'Picholine Marocaine' . Recent field surveys studying the combination of morphological characterization, AFLP molecular markers and image analysis carried out in the Western High Atlas regions confirmed that this variety contains a number of diverse genotypes. Such diversity is important to mitigate abiotic stress caused by water scarcity. Clonal selection within this variety has led to a number of different cultivars in various areas. Criteria for selection have been: productivity; oil content; fruit size; regularity; and resistance to the disease *Speloceae oleagenum*. The purpose of the present study is to explore diversity within Picholine Marocaine and select genotypes that use water more efficiently. These water-use efficient genotypes may then be grown in areas where rainfall does not exceed 300 mm a year. Carbon Isotopic Discrimination (CID) techniques, using the stable carbon isotope ratio ($\delta^{13}C$) as an indicator of water use efficiency (WUE), were adopted and a trial on the study of rooting was also set up. Cuttings taken from the various survey sites were grown in greenhouse conditions, along with controls known for drought tolerance. Parameters studied were the rate of rooting, the speed of rooting (emission, issue) and the vigour of penetration of roots through a porous film. The results relative to the $\delta^{13}C$ showed a highly significant difference within and between surveyed sites. Subsequent studies will be carried out to define traits associated with WUE, in particular CID and root features to select water-use genotypes of olives for arid areas in Morocco.

Key words: Olive diversity, carbon isotope discrimination, rooting capacity

Introduction

Olive occupies an area of more than 600 000 ha in Morocco and this area is expanding, making it the major crop grown. The cultivated area is predicted to grow to over a million hectares by the year 2010 (Berrichi 2004). This increase will occur while water is becoming increasingly scarce, which will have an impact on new plantations, necessitating new measures to be undertaken in terms of water use. Olive is a particularly important source of income in rural areas. The main olive variety grown locally is 'Picholine Marocaine'. Recent field surveys studying the combination of morphological characterization, AFLP molecular markers and image analysis carried out in the Western High Atlas regions, confirmed that this cultivar in reality comprises a number of different genotypes (Boulouha et al. 2004; Sikaoui et al. 2005). Such diversity is important to mitigate abiotic stress caused by water scarcity.

As a result of clonal selection undertaken within this commonly grown, old cultivar, several new cultivars have been successfully selected by INRA Morocco for various areas of the country. The selection criteria were productivity, oil content, size of fruit, and regularity and resistance to *Speloceae oleagenum* disease.

The purpose of the present study is to explore diversity within Picholine Marocaine and select genotypes that use water more efficiently. These water-use efficient genotypes can then be grown in areas where rainfall does not exceed 300 mm a year. The work depends on adding water-use efficiency (WUE) criteria to the selection process of the olive programme, and successful breeding.

Methodology

Sampling was carried out along a transect on the south-eastern Atlas Mountains at an altitudinal range of 300 to 1300 m above mean sea level (Table 1). The sites and orchards sampled were those where previous studies had been conducted to examine the extent of diversity in the area (Boulouha et al. 2004).

Table 1. Survey area and number of samples per site.

Province	Site no.	Location	Water supply
Chichaoua	3	Sidi El Moukhtar	Irrigated
	15	Mzouda	Irrigated
	14	Boulaawane	Irrigated
Haouz	4	Tnine Ourika	Irrigated
	7	Imegdal	rain-fed
	8	Mouldighte	rain-fed
	6	Touama	Irrigated
	5	Amezmiz	Flood water
Essaouira	2	Meskala	Irrigated
	1	Oued Tyout	Irrigated
	11	Aglif	rain-fed
	10	Tidrine	rain-fed
	12	Tmanar	rain-fed
Agadir	9	Boudirhamain	rain-fed
	13	Assifigue	Irrigated
	99	Atlas mountains wild	Wild (rain-fed)

Leaves were collected from the trees and dry frozen for several days before grinding. Determination of abundance of $\delta^{13}C$ was based on 'standards' from Isotope Services Lab (Isotope Services Inc., Los Alamos, NM, USA). 'Standards' of varying weights were interspersed among the samples whenever a run was made for $\delta^{13}C$. At the end of the run, the $\delta^{13}C$ values were plotted. All samples were corrected to get their 'intercept' value and the corrected Delta value.

$\delta^{13}C$ was determined, based on Equation 1 below:

$$\delta^{13}C = \left[\left(R_{sample} / R_{s\tan dard}\right) - 1\right] \times 1000 \qquad \text{(Eq. 1)}$$

which is expressed in per thousand units (‰).

The discrimination, Δ, value of each sample of olive leaf was then calculated as per Equation 2, as defined by Fraquhar et al. (1989) below:

$$\Delta = \left(\delta_a - \delta_p\right) \Big/ \left(1 + \frac{\delta_p}{1000}\right) \qquad \text{(Eq. 2)}$$

where δa is the carbon isotopic composition of the source air and δp is the carbon isotopic composition of the olive tree sampled.

The $^{13}C/^{12}C$ ratio of plant biomass is used as a natural indicator of photosynthetic WUE, expressed as Δ, to measure the variation of $^{13}C/^{12}C$ in plant tissue relative to the atmospheric source of carbon during growth (Xu et al. 2004). C3 plant species discriminate against ^{13}C, relative to the more abundant ^{12}C in the atmosphere during photosynthetic carbon capture. Genetic variation in transpiration efficiency has been found to be negatively correlated in C3 species (Xu et al. 2004).

Carbon Isotopic Discrimination (CID) techniques, which use the stable carbon isotope ratio ($\delta^{13}C$) as an indicator of WUE, were used on trees *in situ*. A trial on the study of rooting was also set up. Cuttings taken from the trees of the surveyed sites, having different Δ, were grown in greenhouse conditions, together with controls known for their drought tolerance. The parameters studied were the rate of rooting, the speed of rooting (emission, issue) and the vigour of penetration of roots through a porous film.

Results and discussion

The results of the parameters recorded to measure both WUE and associated traits were compiled in a spreadsheet. The summary tables of the data, along with the analysis (including an analysis of variance) are show in Tables 2 and 3. Statistical analysis showed that the carbon ratio (P=0.408 with df=29) was not significantly different between sampled trees. However the difference was highly significant for Δ (P<0.001 with df=29).

Table 2. Mean value of carbon ratio and Δ per orchard or site sampled.

Site	Tree code	Δ	Carbon ratio
1	A1, A2	-26.470	50.410
2	A3	-25.390	49.910
5	A4	-24.930	48.200
6	A5, A6	-23.330	49.930
7	A7, A8	-26.380	49.740
8	A9, A10	-24.910	49.880
9	A20, A26	-25.580	49.570
10	A11, A12, A13, A23	-24.000	49.480
11	A14, A15, A24, A27	-25.440	50.190
12	A 16, A28	-24.790	49.000
13	A17, A18, A22, A29	-25.610	48.460
14	A19	-24.410	49.210
15	A21, A30	-25.500	44.590
Forest	A25	-26.345	49.230

Table 3. ANOVA within and between olive orchards.

Factor	Carbon		Delta	
	Df	*P*	*df*	*P*
Tree	29	0.408	29	<0.001
Site	13	0.259	13	<0.001

Similarly, there was no difference between sites for the carbon ratio ($P=0.259$ with $df=13$), but the difference for Δ was highly significant ($P<0.001$ with $df=13$).

At least one of the sites was very different from the rest. Based on the Newman and Keuls test, there were three distinct groups of sites (Table 4). Sites 1 and 7, where the wild olive was collected, form a group with the highest value for Δ. These sites harbour the genotypes or ecotypes that are probably more efficient in terms of their water uptake.

Table 4. Groups based on the Newman and Keuls Test using Δ .

Site	Groups		
	I	II	III
1*	-26.4725		
7*	-26.3750		
99*	-26.3450		
13	-25.6113	-25.6113	
9	-25.5750	-25.5750	
15	-25.4975	-25.4975	
11	-25.4400	-25.4400	
2	-25.3900	-25.3900	
5	-24.9300	-24.9300	-24.9300
8	-24.9100	-24.9100	-24.9100
12	-24.7875	-24.7875	-24.7875
14	-24.4100	-24.4100	-24.4100
10		-23.9975	-23.9975
6			-23.3325
Significance	0.052	0.212	0.105

Note: * indicates the sites that potentially harbour trees with high water-use efficiency.

These results are yet to be verified, however, since a correlation has also been found between Δ and elevation: the highest Δ values being recorded at lower elevation (Table 5; Figure 1). This is probably due to the differences in rainfall between the sites (Moore et al. 1999). Similar patterns have been found in previous studies on other species (Sparks and Ehleringer 1997).

Table 5. Correlation between Δ and elevation.

Pearson correlation	1.000	0.385**
P	0.000	0.002
Df (N)	60	60

Note: ** Significant correlation

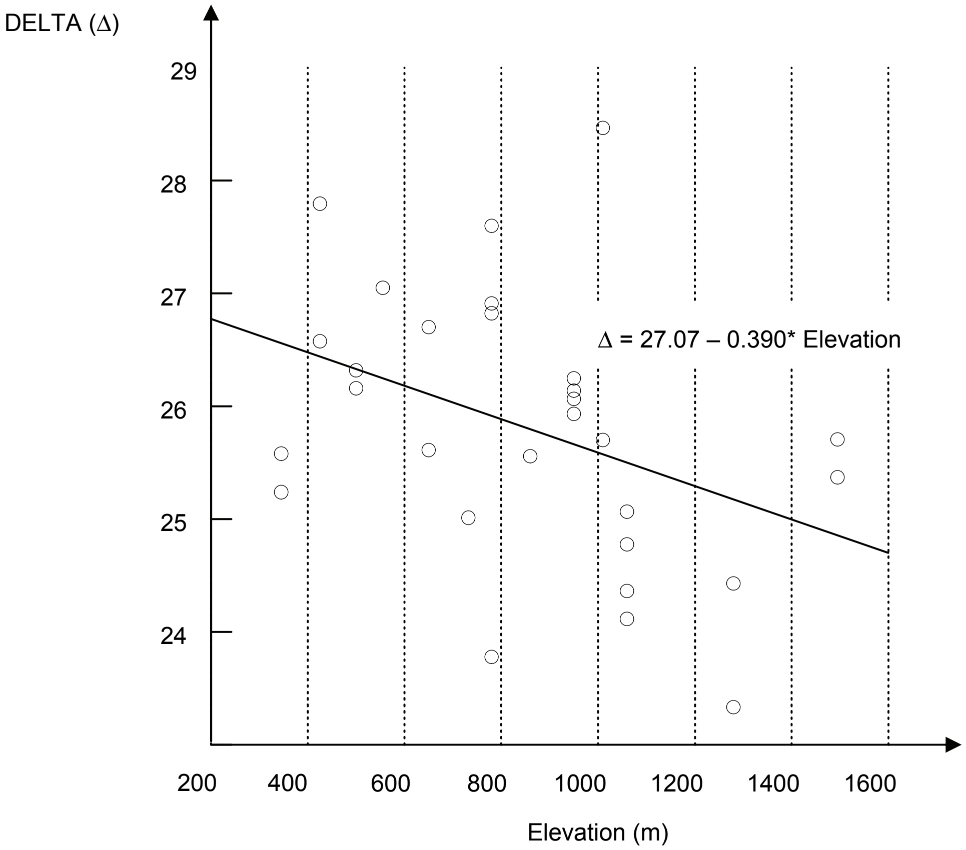


Figure 1. The relationship between olive leaf carbon isotope discrimination (Δ) and elevation (m).

Rooting study

Since the root system has also been found to be linked to WUE, a study was conducted on a sample of 17 trees representing the different sites to see whether any correlation could be found between rooting data and Δ. Cuttings from the trees were grown under mist at the INRA Marrakech station during February 2005. Prior to planting, the cuttings had been submersed in indol butyric acid (IBA) at a concentration of 4000 ppm for a few seconds, then planted in sand. Thirty cuttings were used from each tree.

The trial was a randomized design. Three blocks were used, with each consisting of 20 cuttings per tree. The root parameters measured after 45 days of planting were rooting percentage, number of roots and their length. The cuttings with roots were then transplanted into pots containing sand, with a mesh to measure the root penetration through the mesh after 30 days of transplantation. The results are detailed in Table 6.

Rooting percentage is an important parameter as it is tightly linked to the genotypes and commonly used in the selection of cultivars. Table 6 demonstrates that the % of rooting capacity varies between 8% (hard to root) to 70% (easy to root). However, analysis of variance shows that the difference is not significant for this particular trait. In contrast, the difference in number of roots was highly significant, with $p<0.001$ and 16 df. In fact, tree A5 from the Touama site under rain-fed conditions was highly distinct, with 25 roots on average (Table 7).

There were no significant differences for the other parameters (root length (P=0.07 with df= 16) and number of roots that penetrate the mesh (P=0.148 with df =16)).

Table 6. Rooting capacity of 17 trees.

Tree	Site	Rooting capacity (%)	Root emission		Branching	
			Observation	No. of emissions	Average length	No. of roots penetrating
A1	1	8.3	4	8.75	1.7575	0.50
A2	1	26.7	16	12.94	1.8338	0.38
A3	2	70.0	42	8.55	2.3598	1.71
A4	5	40.0	24	11.46	2.5688	3.67
A5	6	30.0	18	23.39	2.5572	2.67
A6	6	20.0	8	11.13	1.7363	3.13
A7	7	13.3	7	7.00	2.6029	0.00
A8	7	53.3	32	10.22	2.6528	3.28
A9	8	31.7	19	14.26	2.4616	3.21
A10	8	23.3	14	9.21	1.9221	3.86
A11	10	33.3	20	10.15	1.6990	3.55
A12	10	18.0	8	8.63	2.2087	3.63
A13	10	53.3	32	13.22	2.0672	2.34
A14	11	15.0	9	8.00	2.3011	1.44
A15	11	21.7	13	10.15	1.5923	1.08
A16	12	31.7	19	7.16	1.6900	0.21
A17	13	16.7	10	7.40	2.6760	2.30

Table 7. Number of emitted roots and groups based on Student Newman and Keuls.

Tree	Number of observations	Sub-group (cluster)	
		1	2
A7	7	7.00	
A16	19	7.16	
A17	10	7.40	
A14	9	8.00	
A3	42	8.55	
A12	8	8.63	
A1	4	8.75	
A10	14	9.21	
A11	20	10.15	
A15	13	10.15	
A8	32	10.22	
A6	8	11.13	
A4	24	11.46	
A2	16	12.94	
A13	32	13.22	
A9	19	14.26	
A5	18		23.39
Significance		0.773	1.000

When both Δ data and root data were contrasted, there was no correlation (R^2=0.181). We observed, however, that the A5 tree from site 6, which is distinct in terms of root characteristics, had a high Delta value, which is the opposite of that expected in this study. Subsequent research activities should further examine this result.

Future work

This study was a preliminary exercise to assess olive diversity for WUE, which has contributed to identifying potential traits associated with WUE, in particular CID and root features. Work will continue in subsequent studies to further define these traits, which should facilitate a more efficient and strategic selection of water-use efficient genotypes of olives for use in arid areas of Morocco.

References

Berrichi M. 2004 . Filière oléicole. Situation actuelle et perspective d'avenir. Journées oléa - Marrakech: Mai 2004.

Boulouha, B., Sikaoui, L., Bari, A., Elouafi, I. Nachti, M., El Heirech, A. & Mathur, P. 2004. Etude de la diversité de l'olivier au Maroc: Caractérisation par traitement d'images et analyse moléculaire. The 1st International Seminar on "Olive Biotechnology and the quality of the end products in the Mediterranean Basin" (OLIVEBIOTEQ-2004). Errachidia, Morocco, 22–24 November 2004. See: http://www.olivebioteq.ird.fr/

Fraquhar, G.D., Ehleringer J.R., Hubick K.T. 1989. Carbon isotope discrimination and photosynthesis. Annual *Review of Plant Physiology and Plant Molecular Biology,* 40:503-537.

Moore, D.J., Nowak, S.R. & Taush, R.J. 1999. Gas exchange and carbon isotope discrimination of *Juniperus osteosperma* and *Juniperus occidentalis* across environmental gradients in the Great Basin of western North America. *Tree Physiology,* 19: 421–433.

Sikaoui, L., Boulouha, B., Dahhan, R. & Bari, A. 2005. Patterns of carbon isotope discrimination in olives (*Olea europaea* L.) in southwest of Morocco. 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production Under Drought Stress. Rome, Italy.

Sparks, J.P. & Ehleringer, J.R. 1997. Leaf carbon isotope discrimination and nitrogen content for riparian trees along elevational transects. *Oecologia,* 109: 362–367.

Xu, Y., Coburn, J.R., Gollands, B.E., Pausch, R.C., Fleet, C.F., McCouch, S.R., Comstock, J.P. 2004. Mapping quantitative trait loci for water use efficiency in rice. Plant & Animal Genomes XII Conference. Town & Country Convention Center, San Diego, CA, USA, 10–14 January 2004.

Exploration of genetic variation of almond: new attempts

M. Ibnou Ali El Alaoui,[1] A. Bari[2] And A. Oukabli[1]

1 INRA, Centre Régional de Meknès, BP578 VN Meknès, Morocco

2 Bioversity International, Via dei Tre Denari 472/a, 00057 Maccarese (Fiumicino), Rome, Italy

Abstract

Most of the land in Morocco is arid to semi-arid, with a trend in recent years towards increasing aridity. Drought is becoming more frequent and is considered the most important limiting factor in crop production in the country. In recent times, consecutive years of drought have adversely affected horticultural production; once-thriving almond (*Prunus amygdalus* L.) orchards have been abandoned, for example. Farmers have witnessed their resources collapse and have been forced to leave. The complexity of climatic change and subsequent drought necessitates the development of novel integrated approaches, such as the exploration of local diversity of almond to locate drought-tolerant genotypes. Morocco is considered a centre of diversity for almond, where a large number of different types can still be found. The national collection, in the experimental station of Ain Taoujdate, contains almost 250 cultivars from different sources. This work aims at phenotyping for drought tolerance, using an innovative approach to help in rapid assessment and screening. The present investigation focuses on traits for shell features. The method is based on the transformation of an image of the almond shell (fruit) to numeric values that constitute the basis of the estimation of prospective phenotypic descriptors. These might eventually be associated with variation for drought tolerance, such as fractal dimension (*Db*), eccentricity (e) and the central mathematical moments that characterize the shape and texture of the shell. Sixteen cultivars were randomly chosen from the national collection of almond. Ten shells per cultivar were used to estimate those parameters. The results of the analysis of variance have shown that thirteen variables were found to be potential descriptors, being the most stable and easily discriminated between cultivars. These data on shell features will be compared with other drought traits, particularly physiological traits, to further refine the identified descriptors for drought tolerance.

Key words: Almond diversity, drought-tolerant genotypes, descriptors

Introduction

Most of the land in Morocco is arid to semi-arid, with a trend in recent years towards increasing aridity. Drought is becoming more frequent and considered the most important limiting factor in crop production in the country. The increased frequency of drought years in the last few decades has had a devastating effect on agricultural production, resulting in a demographic crisis forcing farmers from their lands and into the cities (The Washington Times 2000). A number of orchards where almond cultivation once thrived have already been abandoned.

Studies have demonstrated that Morocco is among the countries that are most likely to face more frequent cycles of drought as a result of climatic change (Karrou 2000). The increase in yearly average temperature of 1.5°C to 2.5°C forecast for the period 2021–2050 will be accompanied by a reduction in annual average rainfall (INRA 2002). The complexity of climatic change and subsequent drought necessitates the development of novel integrated approaches, including the exploration of local diversity of almond to locate drought-tolerant genotypes.

Morocco is considered to be a centre of diversity for almond, where a large number of different cultivars can still be found. The national collection in the experimental station of Ain Taoujdate contains nearly 250 cultivars, from various sources.

Phenotyping for drought tolerance in the collection is tedious as drought traits are difficult to measure. This research aims primarily at phenotyping for drought tolerance, using an innovative approach to help in rapid assessment and screening. The approach is based on measuring some plant features, in particular shell features, that might be associated with drought tolerance.

The method is based on the transformation of an image of almond fruit to numeric values that constitute the basis of estimation of different fractal descriptors, e.g. fractal dimension (D_b), eccentricity (e) and the central moments that characterize the shape and the texture of the shell. The advantage of quantitatively measuring shell texture and shape is that values can be entered directly into a model to differentiate between cultivars in terms of their drought response. Some authors have found that fractals as quantitative morphological descriptors are not only precise but also environmentally independent. These descriptors proved to be robust in revealing a cultivar’s identity, and may be similarly useful in describing plant diversity, such as in olive (Bari et al. 2002, 2003). This study tested the use of fractals as a new descriptor of almond diversity in order to locate drought-tolerant genotypes.

Material and methods

Sixteen cultivars (Table 1) were randomly chosen from the national collection of almond grown at the experimental station of Ain Taoujdate, situated in the north-central part of Morocco. Ten shells were taken from each cultivar and the hull removed, in order to prepare the shells for examination. The shells were then scanned and the image saved as a bitmap file. Shell features were then converted to numerical values in order to estimate the fractal dimensions and moments.

The fractal dimension was then calculated by the box-counting (D_b) method (May 1989; Maurer 1994; Bari et al. 2002) by using Benoit Fractal Analysis Software version 1.3.

The box-counting method was based on the equation:

$$N(d) \approx \frac{1}{d^{D_b}}$$

where $N(d)$ is the number of boxes of linear size d necessary to cover a data set of points distributed in a two-dimensional plane.

In order to measure the shape, central moments and eccentricity were calculated from the equation (Awcock and Thomas 1996):

$$m_{\alpha\beta} = \sum_{x} \sum_{y} x^{\alpha} y^{\beta} z_{xy}$$

where the order of the moment is $\alpha+\beta$, x and y are the pixel coordinates, and zxy represents the pixel brightness.

And:

$$\mu_{\alpha\beta} = \sum_{x} \sum_{y} (x - x_c)^{\alpha} (y - y_c)^{\beta} z_{xy}$$

where (xc, yc) are the coordinates of the centroid, which is expressed in terms of moments as:

$$x_c = \frac{m_{10}}{m_{00}} \quad \text{and} \quad y_c = \frac{m_{01}}{m_{00}}$$

The eccentricity is expressed as:

$$\varepsilon = \frac{(\mu_{20} - \mu_{02})^2 + 4\mu_{11}{}^2}{(\mu_{00})}$$

Table 1. Cultivars and descriptor states for their shells, based on conventional descriptors list for almonds (IBPGR 1985).

Cultivar	Shell descriptor state		
	Shape	Surface	
		Outer shell marking	Shell colour intensity
Achak	Broad	Densely pored	Light
AT	Intermediate	Intermediate	Dark
Atocha	Broad	Intermediate	Intermediate
Desmayo Largueta	Broad	Intermediate	Dark
Ferraduel	Extremely broad	Densely pored	Intermediate
Fournat	Broad	Densely pored	Dark
Guarrigues	Extremely broad	Intermediate	Dark
IXL	Extremely broad	Densely pored	Light
Laurane	Broad	Intermediate	Dark
Legrand	Broad	Intermediate	Dark
Marcona	Extremely broad	Intermediate	Dark
Mar x Ard	Extremely broad	Densely pored	Intermediate
Mazzeto	Extremely broad	Densely pored	Dark
Filippo Ceo	Intermediate	Intermediate	Dark
Sultane de Sefrou	Intermediate	Densely pored	Light
Xantini	Extremely broad	Intermediate	Intermediate

Upon completion of calculation of both surface and shape parameters based on fractals and moments, respectively, data have been compiled into a single table. Each cultivar in the table was represented by 10 shells with 10 replicates. For each shell, 13 variables were measured.

An analysis of variance was performed using SYSTAT software, version 8. A classification process was then undertaken for the candidate variables using linear discriminant analysis based on Mahalanobis distance, with the candidate variables (selected through general linear modelling) as predictors. The selection of candidate variables used in the classification was based on analysis of variance of a variable over time. Only those that discriminated between cultivars were selected.

Results and discussion

The thirteen variables estimated (W, L, W/L, Db, m_{00}, m_{01}, m_{10}, m_{11}, m_{20}, m_{02}, μ_{20}, μ_{02} and ε) were found to be potential descriptor variables, as they were the most stable across blocks and were highly discriminant between cultivars. The analysis of variance showed a statistically significant difference between cultivars. Other variables showed no significant differences across blocks for shells of genetically identical trees, with the exception of μ_{20} and L (Table 2)

High values of F correspond to the ability of a descriptor to discriminate better between cultivars. A robust descriptor should also have lower F values among shells within cultivars, as in the case of m_{00} and m_{02}: m_{00} has the highest F value between cultivars and m_{02} has the lowest F value within blocks. Discriminant analysis and Mahalanobis distance have been used to classify cultivars. The results showed that with the two variables m_{00} and m_{02}, one cultivar out of 16 was 100% correctly classified, with an overall result of around 42%. With the nine variables Db, L, W, ε, m_{11}, m_{20}, m_{02}, m_{11} and m_{00}, four out of 16 were 100% correctly classified, with an overall result of some 78% correct. These cultivars are 'Desmayo Largueta', 'Filippo Ceo', 'IXL' and 'Marxard'.

Table 2. Analysis of variance of the most stable and discriminant variables.

Descriptor's effect	Source of variation	*F*-ratio	*P*
Width (*W*)	Cultivar	15.852	0.000***
	Shell	1.725	0.089 (ns)
Length (*L*)	Cultivar	35.683	0.000***
	Shell	2.211	0.025*
Ratio (*W*/*L*)	Cultivar	8.741	0.000***
	Shell	1.741	0.086 (ns)
D_b	Cultivar	33.202	0.000***
	Shell	1.250	0.270 (ns)
m_{00}	Cultivar	40.025	0.000***
	Shell	1.340	0.223 (ns)
m_{10}	Cultivar	34.32	0.000***
	Shell	1.615	0.117 (ns)
m_{01}	Cultivar	24.231	0.000***
	Shell	1.539	0.141 (ns)
m_{20}	Cultivar	29.918	0.000***
	Shell	1.802	0.074 (ns)
m_{02}	Cultivar	17.232	0.000***
	Shell	0.399	0.195 (ns)
m_{11}	Cultivar	24.659	0.000***
	Shell	1.584	0.126 (ns)
μ_{20}	Cultivar	29.637	0.000***
	Shell	2.017	0.042*
μ_{02}	Cultivar	15.367	0.000***
	Shell	0.957	0.479 (ns)
$\varepsilon^{\dagger}$	Cultivar	3.060	0.000***
	Shell	1.439	0.178 (ns)

Notes: † Variable transformed in log (ε). *, *** denotes significant at $P \leq 0.05$ and 0,001 respectively; ns, not significant at $P > 0.05$.

Conclusion and future work

The results of the present study indicate that both fractal dimension and moments proved to be robust in revealing a cultivar's identity and may be similarly useful in describing almond diversity. However, the phenotyping data will be contrasted with the carbon isotope discrimination ($\delta^{13}C$) and gas exchange characteristics to define those traits that can be used to locate drought-tolerant cultivars rapidly and economically, using computer-image analysis. The data on shell features will be contrasted with other drought traits, particularly physiological traits, to further refine the identified descriptors for drought tolerance.

References

Awcock, G.W. & Thomas, R. 1996. Applied Image Processing. International Editions, Singapore.

Bari, A., Martin, A., Barranco, D., Gonzalez-Andujar, J.L., Ayad, G. & Padulosi, S. 2002. Use of fractals to capture and analyze biodiversity in plant morphology. pp. 437–438, *in:* M.M. Novak (editor). Emergent Nature. World Scientific Publishing, Singapore.

Bari, A., Martin, A., Boulouha, B. & Gonzalez-Andujar, J.L. 2003. Characterization and identification of olive genotypes using an image feature extraction approach. pp. 73–76, *in:* Proceedings 9th Spanish Conference on Biometrics, La Coruña, Spain, 2003.

IBPGR [International Board for Plant Genetic Resources, now Bioversity International]. 1985. Almond descriptors. Rome, Italy.

INRA. 2002. Caractérisation du climat et stratégies de lutte contre les effets de la sécheresse au Maroc. Note interne pour le Ministère de l'Agriculture. Département d'Agronomie, INRA, Morocco.

Karrou, M. 2000. Climatic change and drought mitigation, case of Morocco. FAO. www.fao.org/sd/climagrimed/pdf/ws01_38.pdf

Maurer, B.A. 1994. Geographical Population Analysis: Tools for the Analysis of Biodiversity. Blackwell Scientific Publications, Oxford, UK.

May, R.M. 1989. How many species? pp. 61–81, *in:* L.E. Friday and R.A. Laskey (editors). The Fragile Environment. Cambridge University Press, Cambridge, UK.

The Washington Times. 2000. Future of agriculture at stake. The Washington Times, 27 November 2000. See: http://www.internationalspecialreports.com/africa/00/morocco/agriculture; and http://www.internationalspecialreports.com/africa/00/morocco/index.html

Identification of fig genotypes tolerant to drought in Morocco

A. Oukabli,[1] A. Bari,[2] A. Mekkaoui[2] and M. Lahlou[1]

1 INRA, Centre Régional de Meknès, BP578 VN Meknès, Morocco

2 Bioversity International, Via dei Tre Denari 472/a, 00057 Maccarese (Fiumicino), Rome, Italy

Abstract

The Government of Morocco is encouraging farmers to grow fruit and nut trees, as the cultivation of these crops will ease the steady increase in water demand. Present water scarcity is the result of several consecutive years of drought over the last 2 or 3 decades. Variation within crops presents an opportunity to reduce water demand by growing water-use efficient (WUE) genotypes. The objective of this study is to explore the diversity within fig in order to select such WUE genotypes. The study also aims to develop and refine traits associated with WUE, such as root structure. The results may help in tagging molecular markers for WUE traits, with the ultimate goal of developing genotypes with improved water productivity, thereby reducing the need for irrigation, and contributing to water saving.

Key words: Fig diversity, water potential, drought-tolerance, water-use efficiency, root structure

Introduction

The government of Morocco is encouraging farmers to grow fruit and nut trees as the cultivation of these crops will ease the steady increase in water demand. Present water scarcity is the result of several consecutive years of drought over the last 2 or 3 decades.

Fig is a traditional crop in Morocco that can not only ease the demand on water supplies, but also generate income for rural farmers. Genotypic variation in terms of water-use efficiency within crops and species has been reported elsewhere (Comstock and Ehleringer 1992, Tauer et al. 1992, Weyhrich et al. 1995, Nienhuis 1994, Johnson and Rumbaugh 1996, Sun et al. 1996, Novello and de Palma. 1997, Grossnickle et al. 1997, Pennington et al. 1999, Mencuccini et al. 1999, 2000; Gaudillere et al. 2002; Xu et al. 2004; Rowland et al. 2004). The objective is to explore fig diversity, to identify water-use efficient genotypes.

Materials and methods

At total of 30 trees, representing 10 cultivars (Table 1) from different origins, were grown at the INRA station. The Station is located in the middle-north of Morocco (Meknes) at an altitude of 500 m and receives an annual rainfall of 400 mm. Previous trials were conducted under irrigation of 2000 mm/year, but as the aim is to reduce water use and to eliminate irrigation completely, in due course, all trials since 2004 have been conducted under rain-fed conditions only.

The performance of each cultivar under rain-fed conditions was measured, based on plant behaviour. The following parameters (morphological and phenological observations) were measured:

- Vigour, based on measurements taken of trunk width.

- Annual elongation of the shoot, based on measurements of the length of new shoots at the end of each year (December).
- Leaf index/area (LI/LA), measured with a planimeter, based on a random sample of leaves per tree.
- Date of fall of leaves. Senescent and fallen leaves were also recorded as a response to limited water conditions.

Table 1. The 10 cultivars, their type and their origin.

Cultivar	Type*	Origin
Bourjassote	MC	France
Kadota	B and MC	Italy
Truano	MC	Italy
Col de Dame Blanche	MC	Spain
Lerida	MC	Spain
Elquoti Lebied	MC	Morocco
Ournakssi	B and MC	Morocco
Nabout	MC	Morocco
Rhouddane	B and MC	Morocco
Ferqouch Jmel	MC	Morocco

Key: * B= Breba, MC= Main Crop

Shoot measurements were taken of several branches per tree, chosen randomly at approximately 2 m high from soil level soil around the tree canopy.

As the objective is to see whether the change in water regime, from non-limited to limited conditions, will affect the performance of different genotypes, water parameters were also measured, in particular water status. The leaf water potential (Ψf) readings were recorded every 3 to 4 hours from morning (07:00) to evening (18:00) during the month of August, when the balance is mostly negative. During this month, the ET exceeds water availability and thus the plant reacts by changing its water status to lower loss. This mechanism is common among plants to lower their K_c (Bari et al. 2004).

The work has taken a whole-plant approach for identification of fig genotypes tolerant to drought. In this context, the root structure was also investigated, as the work aims to develop and refine such traits associated with WUE. The parameters used were:

- volume and weight (fresh and dried) of roots; and
- root branching, based on fractal geometry.

Results and discussion

Plant growth

There was a significant difference among the genotypes. Growth rates of the two groups of introduced and local germplasm form two distinct groups (Table 2 and Figure 1). One local type was significantly less affected than were the others, with its growth rate being statistically more similar to the introduced group.

Senescence (% of leaf fall)

In terms of senescence, there was also a difference among the cultivars (Table 3). Both groups of cultivars had a wide variation in leaf loss, ranging from 6% to 82%.

Table 2. Growth rate of the different genotypes.

Genotypes	**Length of irrigated shoots** (cm)	**Length of non-irrigated shoots** (cm)	**Growth reduction** (%)
Foreign cultivars			
Bourjassote	26	15	32 cd
Kadota	34	17	50 ab
Truano	35	17	53 a
Col de Dame Blanche	28	13	46 abc
Lerida	34	17	48 ab
Local cultivars			
Elquoti Lebied	25	12	37 abc
Ournakssi	24	14	29 d
Nabout	21	13	31 cd
Rhouddane	21	11	25 d
Ferqouch Jmel	22	12	29 d

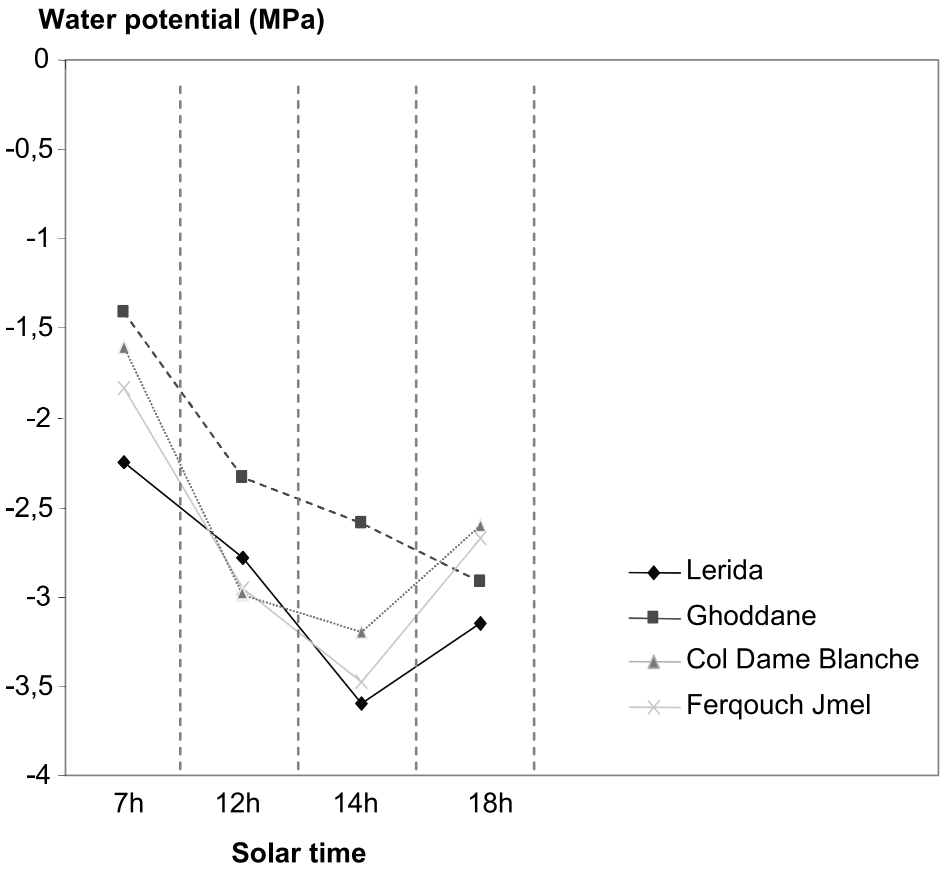


Figure 1. Diurnal variation in leaf water potential of fig cultivar in the first week of August.

Table 3. Senescence (% of falling leaves).

Genotypes	Rate of falling leaves during the 1st week of August
Foreign cultivars	
Bourjassote	67%
Kadota	7%
Truano	37%
Col de Dame Blanche	24%
Lerida	75%
Local cultivars	
Elquoti Lebied	18%
Ournakssi	38%
Nabout	82%
Rhouddane	67%
Ferqouch Jmel	6%

Water status

The difference in water status during August also varied between and within groups of genotypes. There was a rapid reduction in water potential due to high ET (8.5 mm/day). There was also a rapid reduction of Ψ_f until it reached –3.8 Mpa (cvs. Lerida and Ferquouch Jmel). However, a trend towards reversing this reduction was observed in the late evening, reaching –2.5 MPa (cvs. Goldame and Ferquouch Jmel).

Root traits

The root volume of the introduced group of cultivars was higher than the root vuloume of the local cultivars (Table 4). The subsequent work to this will focus on these root aspects to identify the traits that could be associated with water-use efficiency.

Table 4. Root traits characteristics.

Genotypes	Root volume (ml)	Root weigth (g)	Root density (g/ml)
Kadota	190	89	0.47
Lerida	50	59	1.2
Elquoti Lebied	12	26	2.2
Ournakssi	40	52	1.3

Conclusion and future work

In general, there was a reduction in terms of plant growth under limited water conditions. Such reduction was confined mainly to the local cultivars, with the exception – to some extent - of 'Elquoti Lebied'. Hence, appropriate genotypes of fig trees can be used under limited conditions, to utilize limited water and to tolerate drought, as their water potential can reach up to -4 MPa. While this study intends to select drought-tolerant genotypes, the aim is also to better refine and select traits associated with drought tolerance and WUE, such as leaf fall and root structure. Future work is planned to further explore root characteristics in relation to plant growth. This will also help in the refinement and development of root traits associated with WUE, the results of which may help in tagging molecular markers of WUE and in developing genotypes with improved water productivity, thereby reducing the need for irrigation, and contributing to water savings.

References

Bari, A., Ayad, G., Martin, A., Gonzalez-Andujar, J.L., Nachit, M., & Elouafi, I. 2004. Fractals and Water Use Efficiency. pp. 315–316, In: M.M. Novak (editor). Thinking in Patterns. World Scientific, Singapore.

Comstock, J. & Ehleringer, J. 1992. Correlating genetic-variation in carbon isotopic composition with complex climatic gradients. *Proceedings of The National Academy of Sciences of the United States of America, 89(16): 7747–7751.*

Gaudillere, J.P., Leeuwen, C.V. & Ollat, N. 2002. Carbon isotope composition of sugars in grapevine, an integrated indicator of vineyard water status. *Journal of Experimental Botany*, 53(369): 757–763.

Grossnickle, S.C., Fan, S. & Russell, J. Adaptive Physiology of Western Red Cedar. WFGA 1997 Program, Berkeley, California, USA.

Johnson, D.A. & Rumbaugh, M.D. 1996 Genetic variation and inheritance characteristics for carbon isotope discrimination in alfalfa. *Journal of Range Management*, 48: 126–131.

Mencuccini, M. & Comstock, J.P. 1999. Variability in hydraulic architecture and gas exchange of common bean (*Phaseolus vulgaris* L.) cultivars under well-watered conditions: Interactions with leaf size. *Australian Journal of Plant Physiology*, 26: 115–124.

Mencuccini, M., Mambelli, S. & Comstock, J.P. 2000. Stomatal responsiveness to leaf water status in common bean is a function of time of day. *Plant, Cell and Environment*, 23: 1109–1118.

Nienhuis, J., Sills, G.R., Martin, B. & King, G. 1994. Variance for water-use efficiency among ecotypes and recombinant inbred lines of *Arabidopsis thaliana* (Brassicaceae). *American Journal of Botany,* 81: 943–947.

Novello, V. & de Palma, L. 1997. Genotype, rootstock and irrigation influence on water relations, photosynthesis and water use efficiency in grapevine. *Acta Horticulturae (ISHS),* 449: 467–474.

Pennington, R.E., Tischler, C.R., Johnson, H.B. & Polley, H.W. 1999. Genetic variation for carbon isotope composition in honey mesquite (*Prosopis glandulosa*). *Tree Physiology*, 19: 583–589.

Rowland, D., Blankenship, P., Puppala, N., Beasley, J., Burow, M., Gorbet, D., Jordan, D., Melouk, H., Simpson, C. & Bostick, J. 2004. Variation in water-use efficiency of peanut varieties across peanut production regions. The 4th International Crop Science Congress, Brisbane, Australia. See: http://www.cropscience.org.au/icsc2004

Sun, Z.J., Livingston, N.J., Guy, R.D. & Ethier, G.J. 1996. Stable carbon isotopes as indicators of increased water use efficiency and productivity in white spruce (*Picea glauca* (Moench) Voss) seedlings. *Plant, Cell and Environment,* 19(7): 887–894.

Tauer, C.G., Hallgren, S.W. & Martin, B. 1992. Using marker-aided selection to improve tree growth response to abiotic stress. *Canadian Journal of Forest Research*, 22: 1018–1030.

Weyhrich, R.A., Carver, B.F. & Martin, B. 1995. Photosynthesis and water-use efficiency of awned and awnletted near-isogenic lines of hard red winter wheat. *Crop Science*, 35: 172–176.

Xu, Y., Coburn, J.R., Gollands, B.E., Pausch, R.C., Fleet, C.F., McCouch, S.R., Comstock, J.P. 2004. Mapping quantitative trait loci for water use efficiency in rice. Plant & Animal Genomes XII Conference. Town & Country Convention Center, San Diego, CA, USA, 10–14 January 2004.

Bioversity International

ISBN: 978-92-9043-748-2