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The Age of Water Scarcity: In Search of a New Paradigm in Aquatic Weed Control

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ABSTRACT

Over the last decades, in many places in the world weed control has been confronted with an increasing need for environmentally sound and safe practices. The Vision on Water and the Environment presented at the World Water Forum held in The Hague in 2000 predicts water scarcity in more than 50 countries by the year 2025. To meet future food demands 15-20% more water will be used in agriculture. However, agriculture is already responsible for 70% of the worldwide water use. Re-use of agricultural (irrigation) water is a viable alternative, but this is only possible if the water is not too heavily polluted. Therefore, we predict a growing demand for innovative and, in particular, environmentally sound weed control measures in the future, the most promising of which will be integrated weed control, making use of advanced biological knowledge ranging from molecular biology to plant population and ecosystems modeling. Furthermore, weed control practices will become more efficient through institutional reforms in the irrigation sector, although this will depend on the discretion of irrigation and drainage managing agencies to introduce biological weed control systems, which, in turn, will depend on incentives related to cost, quality and reliability of service provision and environmental regulation and policing.

Keywords: World Water Forum, water scarcity, integrated weed control, incentive structures.

INTRODUCTION

This paper will begin by explaining the issue of global water scarcity (Cosgrove and Rijsberman 2000), as stipulated last March by the Second World Water Forum held in The Hague, The Netherlands. Weed control should be seen within this context. With our increasing environmental awareness and expressed urgency for a sustainable water use, the call for a truly integrated weed management approach becomes increasingly acute. This paper will briefly sketch where we feel that future progress could be made in classical aquatic weed ecology in a broader sense. The paper rounds off with an outlook on where major breakthroughs can be made: in the combination of novel ecology-inspired techniques with a well-equipped and trained management dedicated to integrated, preventive sustainable control and an economically effective distribution of water. At the same time we ask how much water we can allocate for the development and use of biological weed control systems? IWMI, the FAO International Water Management Institute, Sri Lanka, indicates the highest levels of water scarcity are in those countries where economic development is low and governance and policing systems are relatively weak. Moreover, these countries are still able to use herbicides that are forbidden in Western Europe and the USA.

THE WORLD WATER FORUM: A NEW PERSPECTIVE

In March 2000 more than 4,500 international water professionals from a wide range of disciplines gathered in The Hague, The Netherlands, to discuss the looming water crisis. The discussions were inspired by and based upon a number of Vision papers prepared by a Vision Unit hosted by UNESCO, Paris. These were written in close consultation with relevant stakeholders from public and private organizations in different regions of the World.

One of conclusions was that due to the globally increasing demand for food, water supplies used in agriculture will have to be augmented by an additional 15 to 20% over the next 25 years, even under favorable assumptions regarding improvements in irrigation efficiency and agronomic potential to meet food requirements. This is equivalent an annual increase of 0.6% to 0.7% (Van Hofwegen and Svendsen 2000).

Some of this additional water can come from increasing harvest of rainfall and further development of small-scale water sources such as shallow aquifers. Better agronomic practices, such as mulching, can also save water, which can be used to improve productivity of rainfed areas and expand irrigated areas.

However, these improvements can only provide a limited quantity of additional water. The Forum concluded that the largest share of an increased water supply for agriculture must come from new practices and investments, which operate on a larger scale. These include improved water management practices both on farms and in delivery systems, comprising new technology, reforms in management institutions, and more rational pricing policies. Development of new storage capacity for use during times of scarcity will also be required, both to replace capacity lost to sedimentation and to save water lost during floods. Reducing waste loads in return flows from both agricultural, municipal and industrial uses can also make an important contribution to improving the available supply of water for all uses, including agriculture.

Furthermore, the Forum observed that the present overall (system) efficiency of water use in irrigated agriculture ranges between 30-50% only. The above estimate of a growing de-

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mand already worked from the assumption that overall water use efficiencies for irrigated agriculture will increase to 60-70%! This means that efficiency gains made by minimizing water losses have to incorporate the reduced water reuse capacity where chemical weed control methods are used.

The overall conclusions from the Forum were:

- water scarcity will prevail in more than 50 countries in the year 2025;
- water management must become more effective, efficient, sustainable and environment-concerned;
- pressure on capacity of water management institutions for support will increase.

We feel that the application of integrated, environmentally sound weed control methods could substantially contribute to these goals because they would allow for water re-use and water saving. This naturally raises the question whether we have progressed enough in the field of aquatic weed research to be ready for this challenge.

PROGRESS IN AQUATIC WEED ECOLOGY

In our estimation, progress in aquatic weed ecology has slowed down since Pieterse and Murphy (1990) published their widely-acclaimed weed handbook. We are all bickering slowly forward in our respective corners, but it appears that the lines have been set. Pieterse and Murphy (1990), as well as numerous management reports, call for *integrated* management (e.g. Hootsmans 1996, Joffe and Cooke 1997, Vermaat and Van der Steen 2000). Nonetheless, well-documented cases of successful implementations are rare (Barker et al. 1996, Gutierrez 1996).

A brief breakdown of the field of aquatic weed ecology would assist us in evaluating progress. Below we discuss recent advance in research on growth ecology, classical weed science, molecular biology, biological control and modeling. We then present an integrated weed control research project in Argentina (Hootsmans 1996) that nicely illustrates the limitations imposed on testing and applying novel findings into the practices of the real world of irrigation schemes.

In *plant ecophysiology*, we have compiled numerous data on P-I curves (Madsen et al. 1991, Hootsmans and Vermaat 1994, Hootsmans et al. 1996), nutrient contents versus requirements (Room 1986, Barko and Smart 1986), inorganic DIC use (Maberly and Spence 1983, Sand-Jensen et al. 1992, Spencer et al. 1994), and drought resistance (e.g. Van Vierssen 1990). All in all, plasticity appears considerable and differences among species, for example in PI curves, are much less than those in architectural growth repertoire (e.g. Spencer et al. 1994). This is particularly true for the likely most problematic submerged weed *Hydrilla verticillata* (L.f.) Royle.

Growth ecology, in our view, links life cycles with the architectural repertoire. The capacity to develop tubers or turions (Spencer 1987, Van Vierssen 1990, Van Vierssen et al. 1994, Spencer et al. 2000) and differences in branching patterns have a strong influence on survival during adverse periods as well as exponential biomass development, which creates undesired obstruction. This was recognized early by Pitlo (1986), who advocated the use of floating-leaved nymphaeids to suppress fully submerged species. We predict that substantial gain is to be achieved in the analysis of meristem distribution over branching patterns and over water and sediment strata.

Classical *weed science*, in our view will only survive when it concentrates and merges with other approaches listed here. Due to environmental concerns, herbicide application will become increasingly restricted. The fact that this congress still includes a session on chemical control suggests that a bright sustainable future has not fully started yet.

In *molecular biology*, excellent work has unraveled the genetic relations among populations of for example the widely spread Hydrilla (*Hydrilla verticillata* (L.f.) Royle, Madeira et al. 1999) and sago pondweed (*Potamogeton pectinatus* L., Mader et al. 1998). In Hydrilla, however, the distinct genetic and morphometric differences between some monoecious and dioecious populations or strains, does not directly translate into difference in photosynthetic behavior and growth (Vermaat and Okungu, unpublished). The pistillate, dioecious strain from Lake Tanganyika, Burundi Africa, for example, produced just as much leaf whorls and biomass as a monoecious strain from Rawalpindi, Pakistan, under most combinations of light availability and alkalinity in a fully factorial experiment. Also, in a pH drift experiment, both strains were able to continue photosynthesis until a pH of 10 (Figure 1).

Harley and Forno (1990) have written a comprehensive review on *biological control.* Progress lies largely in the larger scale application of the various options, and in new ideas based on the foodweb perspective. Despite the fact that Philipp et al. (1983) could find little economic use for harvested water hyacinth (*Eichhornia crassipes* (Mart.) Solms) and were skeptical about biological control, presently the *Neochetina* weevil has clearly demonstrated its effectiveness in biological control (Harley and Forno 1990, Vermaat and Van der Steen 2001). An illustrative example is the explosive spread of water hyacinth in Lake Victoria. Authorities were highly con-

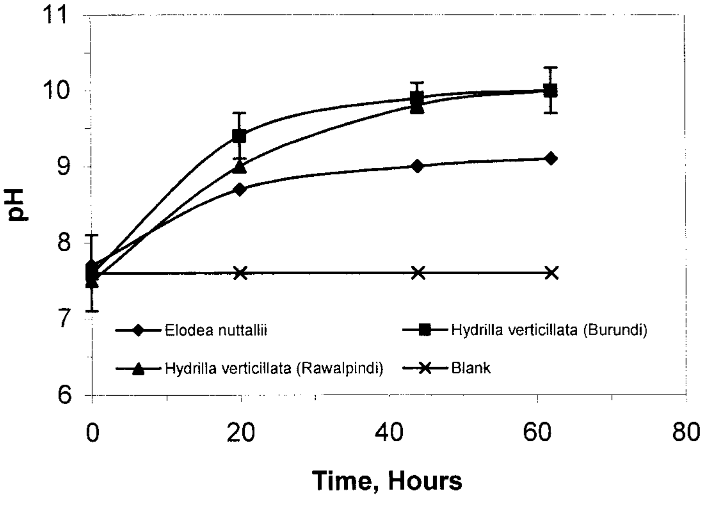

Figure 1. pH increase due to photosynthesis by two strains of *Hydrilla verticillata* (respectively a pistillate, dioecious strain from Lake Tanganyika, Burundi Africa, and a monoecious strain from Rawalpindi Pakistan) and *Elodea nutallii,* as compared to changes in blanks. Replication was 3 times 3, for clarity only 1 set of SE's is shown. Pants were incubated in 300 ml Winkler bottles at 350 µmol PAR m^{-2} s^{-1}. Initial alkalinity varied between 0.5 and 3.0 mM HCO_3-, but converged rapidly.

cerned and seriously considered large-scale application of herbicides, because they had little confidence in these tiny herbivores. However, after some time required to build up sufficiently large populations (numerical response) at present the weevils are widespread and have serious impact (Patrick Denny, pers. comm.). Several papers presented here discuss the use of *Hydrellia pakistanae* as a biological agent for Hydrilla, illustrating the scope for new developments in biological control.

Modeling. Few fully calibrated and verified models for aquatic plant growth exist beyond what is reviewed in Pieterse and Murphy (1990). A notable exception is the growth model developed by Hootsmans (1994) that was applied later in irrigation schemes in Argentina (see case presented below). Although highly useful once calibrated, verified and operational, models of this complexity suffer from extensive data requirements. For weed management purposes, simpler 'mini'-models (e.g. Scheffer 1997) or empirical multiple or logistic regression models (cf Peters 1991) may be equally useful.

In short, we are of the opinion that a substantial amount of knowledge has been accumulated. We foresee creative, new breakthroughs mainly in areas where combinations are made of for example growth ecology (life cycle timing), the foodweb or ecosystem perspective, and modeling.

As a challenge, we suggest that a minimal data set is required to allow prediction of the main nuisance weeds and give advice on their control. These are:

- the correct species names and a rough estimate of their overall abundance in the system;
- some basic water quality data, e.g. turbidity and conductivity ranges in feeders and drains;
- the physical dimensions of the irrigation system: water quantity distributed over area of land, flow regimes, and the local climate.

A CASE STUDY AND EXAMPLE

In the mid-nineties, a number of sustainable biological weed control alternatives were tested in a semi-arid irrigation schedule in SW Argentina (Hootsmans 1996; with recent updates from K. J. Murphy, Glasgow, Scotland). In this multi-partner (CERZOS, Bahia Blanca, Argentina; University of Reading, UK; IHE The Netherlands), EU-funded project the aim was to develop innovative channel management regimes for two irrigation systems (CORFO and IDEVI) near Bahia Blanca. Two types of biological weed control with fish were tested for efficiency and sustainability: one utilized the herbivorous grass carp, the other used benthivorous common carp. The project applied a multilevel (lab and field experiments, full-scale operational trials, modeling) and multidisciplinary approach (aquatic plant ecology, fish biology, ecological modeling). The underlying concepts were: (1) chemical control soon will be no longer acceptable, (2) cutting is expensive, (3) biological control of the two main target pondweed species might be feasible, either through (4) direct herbivory with grass carp, a fish known to control weeds effectively elsewhere, or (5) indirectly through an increase in water turbidity by sediment-stirring common carp.

Both fish species were found to reduce weed growth very well (Figure 2). At the higher densities vegetation was completely removed before the end of the experiment. Carp substantially raised turbidity. The project advised to apply grass carp at a rate of 150 kg ha^{-1} in normal freshwater. Common carp would require similar stocking rates. In the more saline waters of the CORFO system, grass carp would probably have to be stocked at expensive high stocking rates, because foraging reduces substantially at conductivity above 1 mS cm^{-1}. Comparative scenario evaluation with the weed growth model SAGA developed by Hootsmans (1994) revealed that (a) enhanced turbidity by common carp bottom stirring would not critically reduce light availability in most of the shallow irrigation channels (<1 m depth); (b) sustained grass carp herbivory would suffice to keep the maximum seasonal weed biomass below 100 g DW m^{-2}; (c) Combining mowing with increased turbidity by common carp would reduce the mowing frequency from once per year to only once every third or fourth year, even in very shallow canals (50 cm).

Grass carp is presently used at a large scale and with great success. Apparently, the technological and investment needs of initiating and running a grass carp system were felt to be less costly than the potential risks of applying a more novel approach with common carp, despite the fact that the latter species was already introduced in a Buenos Aires park in 1912 and in CORFO in the 1980s.

THE LOCAL CONTEXT: INSTITUTIONAL NEEDS FOR IRRIGATION

Farmers (water users) and Farmer (water user) Organizations

It is now widely recognized that new technologies will only be effective when there is a system of incentives for those in-

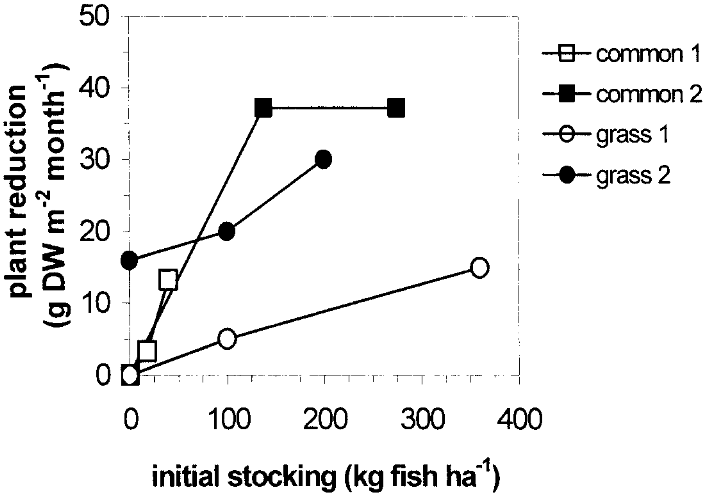

Figure 2. Removal rates of water plant biomass by common carp and grass carp from experimental pond systems in Argentina. Data are presented here from 4 experiments lasting 2-4 months. Common carp was tested in the CORFO scheme, grass carp in IDEVI. For both, the second experiment involved stockings with less but larger individuals. In all experiments, the higher densities led to an almost complete removal of vegetation before the end of the experiment, suggesting starvation for the grass carp.

volved in the implementation of them. In identifying incentive structures for reverting chemical methods, a distinction has to be made between subsistence farmers and commercial farmers as entrepreneurs.

The majority of farmers in the world are subsistence farmers. They usually participate in the manual maintenance activities of irrigation schemes to add to their income through local contractors or through an obligatory labor input contribution for O&M cost sharing. Chemical methods are seldom used.

In commercial farming environments cost effectiveness is a main driving force. Cost effectiveness has to be regarded in the sense of the direct cost to carry out maintenance including weed control, and the indirect cost for the farmers regarding production risks and market quality standards. Here externally imposed standards and procedures are important drivers related to the direct costs. Particularly in such systems, a differentiation has to be made between the maintenance obligations at different levels of the systems

- weed control in infrastructure and adjacent to parcels is usually the responsibility of individual farmers-landowners. Different methods are applied based on affordability and economics. Chemical treatment is often done in conjunction with application of chemical herbicides for crop protection.
- maintenance of communal systems is done by farmer groups within their area of jurisdiction based on consensus among users. Usually small canals and ditches are cleaned before every irrigation season. Drainage canals are often neglected as the direct benefit of these canals is often realized after inundation occurred. Usually mechanical or manual labor methodologies are applied.

Irrigation and Drainage Agencies

Irrigation and drainage authorities do maintenance of main systems. Their motivation to use certain methods is mainly determined by cost effectiveness, socio-economic considerations as employment generation, and their relation with the farmers. Here the degree to what level they are responsible and answerable for the delivery of the irrigation and drainage services is essential. When farmers pay for the services and have a say in defining the services and controlling their costs.

In summary, the incentives for agencies to use or not use different maintenance methods are as follows:

A. Mechanical control:

- Generation of employment through local communities or contractors, labor intensive could become cost intensive if labor cost are high.
- Consideration for more frequent mechanical mowing versus less frequent manual uprooting.
- The opportunity for users to contribute in cost sharing for operation and maintenance of the system.

B. Chemical control:

- Quick and cost-effective but polluting.
- In farmer controlled systems they are likely more sensitive to pollution arguments if there is a crops risk.
- Environmental regulations, policing and sanctioning, and (non-) availability on local market are main incentive controllers

C. Integrated biological control:

- Relatively low or at least comparable costs to other methods. An important limitation could be that fish cannot be maintained in the channels due to irregularity and insecurity of flows (summer-winter season, dry-wet season, rotation, 'on and off' systems) resulting from most efficient water use for crop production.
- Requires relatively much water to sustain fish populations.
- In many developing countries fish is the main protein source and the presence of fish in irrigation canals is a valuable addition to the diet.

CONCLUSIONS AND RECOMMENDATIONS

Based on the above we arrive at the following set of conclusions and recommendations:

- Chemical weed control methods for irrigation and drainage channels are still applied for their convenience and cost effectiveness for farmers and water managing agencies (e.g., irrigation and drainage agencies);
- Reduction of chemical methods will contribute to the reduction of waste loads into water systems and consequently to the making available of more reusable water;
- Joint research is necessary on the application of non-chemical weed control methods, which meet the objectives of increasing productivity of water, water use efficiency and eco-system protection and improvement on scheme and on basin level;
- Integrated weed control, based on generalized plant growth models and implemented in an ecosystem perspective could qualify for this. Such an approach is 'knowledge-intensive' and requires proper guidance and an incentive structure for the local water users;
- Proper incentive structures for water managing agencies and farmers are essential to refrain from use of chemical weed control methods. This includes: (a) raising of awareness and knowledge on the consequences of use of chemical methods; (b) regulation and policing of availability and use of chemicals; (c) provision of feasible weed control alternatives for both farmers and water managing agencies.

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