An Overall Synthesis of the Symposium

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As a framework for discussion drawing from all the knowledge and ideas presented during the Symposium, an overall synthesis of the Symposium was presented by Caldwell in Session IV. The synthesis is depicted in Figures 1 and 2.

Figure 1 presents water needs and solutions at the global level. Two fundamental forces are producing water needs at the global level. These are shown at the upper left and upper right. At the upper left, global warming (shown in orange) is affecting rainfall and rivers (shown in green), and thereby affecting the natural water supply. Estimates of **water supply** ① on a global grid basis and for specific river basins were given by Dr. Mushiaki. An example of estimates on a smaller scale was given for Sri Lanka by Dr. Shinogi.

At the upper right, the second major force creating water needs is shown: **population** increase ②, also in orange. This means increased demand for water for food production, for living use, and for industry, as shown in data by Dr. Molden. The overall natural water supply ① must be partitioned among these uses and the environment. **Scarcity** ③[a] due to competition between food and living needs, at the upper right, thus also means competition and scarcity in **allocation** of the water supply between overall human needs and environmental needs. This is shown as a double arrow for competition and scarcity in orange superimposed on the green and blue lines flowing downward from the global water supply.

Competition and scarcity were quantified by Dr. Molden. Over the next 25 years, to meet increased demand for food using current technology, irrigation would need to be increased by 12-27%. This means increasing the blue line of water supply to rice and other irrigated crops through large-scale irrigation. Yet, to maintain the environment, irrigation should instead be reduced by 8%, in favor of the green line from global water supply that benefits the **environment** ③[b]. To maintain rice self-sufficiency, the legacy of the Green Revolution, while simultaneously reducing water to irrigation for the benefit of the environment, means that a 60% increase in irrigated crop **productivity** is required. Likewise, in rainfed agriculture, fed by the green line of water from global water supply down to the bottom right, productivity must be increased by 35%.

How can these productivity increases be achieved? Dr. Kaida suggested that the answers will be quite different from the large scale engineering approach of the Green Revolution. Through numerous examples illustrated by on-site photographs, he presented a range of small-scale **landscape formation** ④ technologies. These may include canals and small-scale irrigation, built on an individualized or community, rather than national or state, basis. These are termed **regionalized ecotechnologies**. The examples given later by Dr. Shinogi of the cascade system in Sri Lanka, Dr. Ito and Dr. Pichai of small-scale ponds in Thailand, and Dr. Nishimaki of sisal fencing water harvesting in Kenya, were all examples of landscape formation and regionalized ecotechnologies.

In each case, as Dr. Molden pointed out, we evaluate and address three types of scarcity: economic scarcity through development (D), utilization scarcity through management (U), and physical scarcity through allocation (A). Combined as DUA, these are scarcity indicators that can guide our work. The relative

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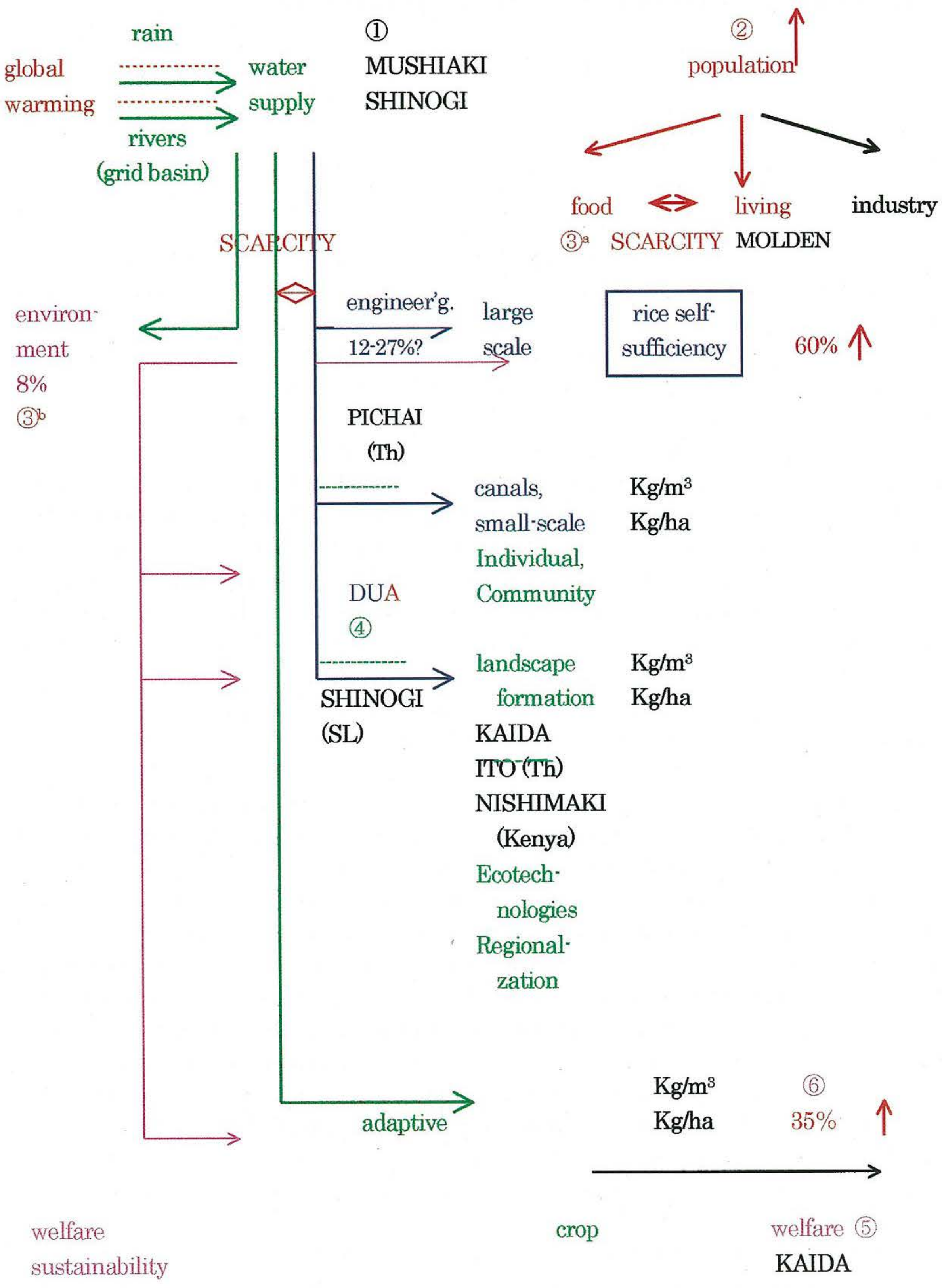

Fig. 1 Water Needs and Solutions, Global Level.

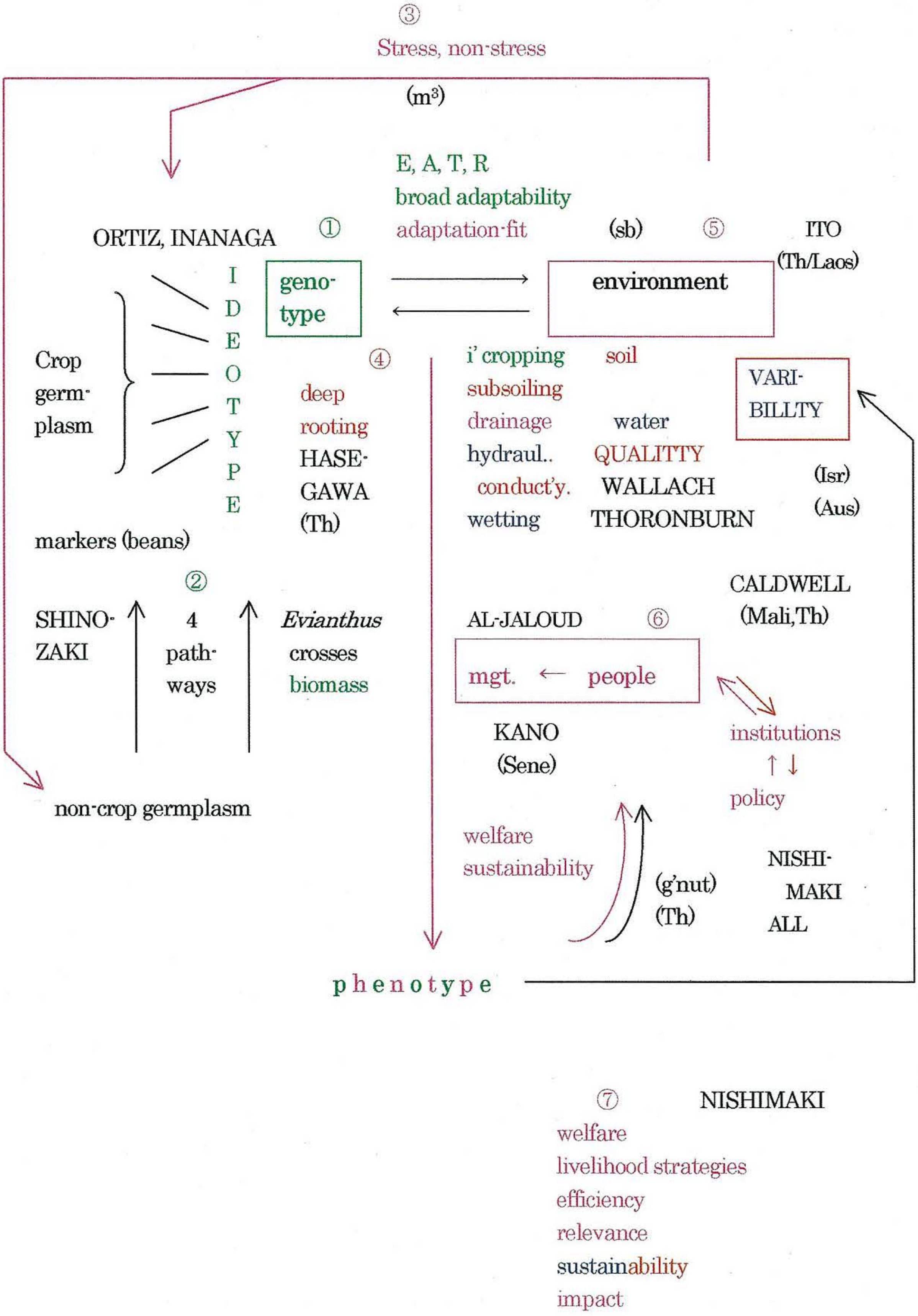

Fig. 2 Water Needs and Solutions, Field, Farm, and Regional/National Level.

emphasis on each varies among countries and regions, with D most important in sub-Saharan Africa, U a key issue in Southeast and South Asia, and A critical in diverse locations, including South Africa, North Africa, the Punjab, and Northern China.

In rainfed areas, landscape formation is more difficult, and more answers will come from better **adaptation** ⑥ of crops to the environment. Breeding and selection are powerful tools for this purpose.

In all this work, our immediate objective is more **crop** for every drop, shown at the bottom center right and in the column above. More crop for every scarce drop may be expressed as kg / ha, but most fundamentally it is kg / m^3 water. But Dr. Kaida challenged us to remember that it is people who both produce crops and manage the environment, and their objective is their welfare and the sustainability of their lives. So ultimately, our measure of success is more human **welfare** ⑤ for every scarce drop.

Figure 2 presents water needs and solutions at the field, farm, regional, and national levels. This figure integrates the different solutions, actual and potential, offered during the two days of the symposium. The fundamental framework is based on an expanded **genotype** (upper left box in green) - **environment** (upper right box in pink) - **phenotype** (lower center word in alternating green and pink letters) model offered by Dr. Ortiz. As the alternating colors of phenotype suggest, phenotype is a product of the interaction of genotype and environment. But Dr. Ortiz' model recognizes that this interaction does not occur spontaneously. Rather, it is an interaction mediated and created by **management by people** (center right box in pink).

Session I of the Symposium focused on the **genotype** ① side of the model (left box in green). Dr. Ortiz and Dr. Inanaga presented examples of work using traditional breeding techniques based on combining characteristics from **crop germplasm** into new **ideotypes**. Even with traditional breeding techniques, new techniques from advances in molecular genetic understanding, such as use of markers for beans, can help accelerate this work.

Advances in molecular genetic understanding through the identification of **4 pathways**②, presented by Dr. Shinogi, are opening up new prospects for the incorporation of **non-crop germplasm** into better ideotypes. In the future, as these techniques are adapted and applied to economic crops, it may be possible, for example, to develop biomass producing crop plants from *Erianthus* spp., relatives of sugarcane well-adapted to drier environments. This can create the potential for more crop for every drop, more kg / m^3, and through the introduction of new options for diversification in rainfed cropping systems, more welfare for every drop.

In both traditional and molecular biology-based breeding, the objective is to enable the crop to produce well under both **stress and non-stress** ③ conditions. Dr. Ortiz explained how this involves not just seeking broad adaptability to the environment, in the traditional framework, but also increasingly, **adaptation fit** to specific environments. For example, genotypes of soybean (sb) have been identified with season-specific adaptability. The framework for breeding today is knowledge-based in the local as well as the basic science sense, and it is increasingly decentralized, involving partnerships between breeders and holders of local knowledge, farmers.

Achievement of adaptation fit involves different mechanisms for different crops and environments. Dr. Iwanaga presented four key **mechanisms for adaptation** to water stress: escape (E), avoidance (A), tolerance (T), and recovery (R). They may apply at the phenological, morphological, or physiological levels, singly or in combinations.

From here, the Symposium shifted to the **environment** part of Figure 2. Dr. Hasegawa, working in Thailand, presented techniques to promote the **deep rooting** ④ of crops, by reducing soil impedance of root penetration through hardpan fracture and organic amendments in trenches. This is modifying the crop environment to enable the crop genotype to express itself phenotypically with longer roots deeper in the soil, thereby tapping more scarce water. Here was a concrete example of how to get more crop (root, but ultimately yield) for every scarce drop.

Other techniques for modifying the soils (in orange) and water (in blue) of the crop environment to enable crops to express phenotypes more positively included intercropping, subsoiling, and improved drainage. Dr. Wallach, from Isreal, and Dr. Thoronburn, from Australia, presented results that provide new understanding of hydraulic conductivity and wetting patterns, and tools based on this understanding for better management of soils and water. Paralleling the shift in breeding from broad adaptability to more site-specific adaptation fit, their results indicate a need for a shift from traditional broad criteria such as moisture content and soil texture, to site- and soil type-specific properties. This in turn means a large increase in the number of soil type categories to consider. Their results highlighted the importance of variability, and again showed how knowledge-based research involves site-specific knowledge as well as knowledge from basic science.

The last session of presentations looked more broadly at not only interactions between a crop and soil and water as components of the environment, but also complex multiple **crop-environment interactions** ⑤. In Thailand and Laos, a new rainfed agriculture project presented by Dr. Ito will look at micro-environments across toposequences in small watersheds, involving physical and biological interactions among several types of crops, including rice, vegetables, and industrial and forage vegetable crops. Similar interactions between crops and upland and lowland micro-environments in Mali, West Africa, were compared with Thailand by Dr. Caldwell.

Presentations by Dr. Al-Jaloud, from Saudi Arabia, Dr. Kano, working in Senegal, and Dr. Nishimaki, working in Kenya, showed how institutions and policy affect **management by people** ⑥ of the environment, and thereby enable plants, trees (in the Senegal case) as well as crops, to achieve more of their genotypic potential. Achievement of this potential in turn provides **feedback** in the overall genotype - environment - human management - phenotype system. When research results on genotype and environmental management are supported by policies and institutional arrangements that increase **welfare** and **sustainability** of users, the system will function most effectively.

A series of **indicators** ⑦ offered by Dr. Nishimaki can help us monitor this feedback and assess how well research on each part of the genotype - environment - human management - phenotype system is contributing to overall system functioning. These indicators are: welfare, livelihood strategies, efficiency, relevance, sustainability, and impact. While water may be the most important component, solutions to water needs are not total solutions. Water is the key link, but it is one link in a system with many links. Solutions to water needs become effective only when the whole system functions effectively. Our real target is not water alone, nor even the crop-water-soil complex alone, but the crop-water-soil-human management system that supports its users, people, and their natural environment. This is the meaning for research of the concluding call of the Symposium, "more crop and more welfare from every scarce drop."