Water Wise

INSTITUTE ON THE ENVIRONMENT

UNIVERSITY OF MINNESOTA

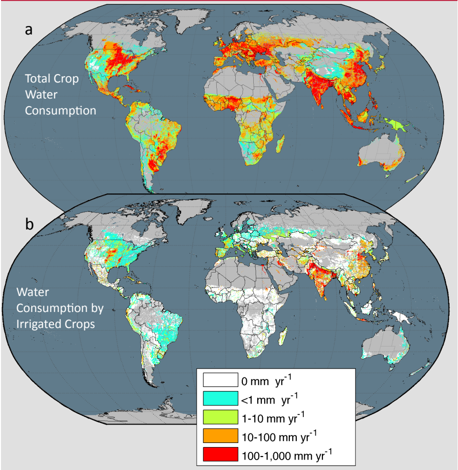
Driven to Discover℠

Are we getting enough crop per drop?

Kate A. Brauman[1], Stefan Siebert[2], Jonathan A. Foley[1]

[1]Institute on the Environment, University of Minnesota, USA [2]Institute of Crop Science and Resource Conservation, University of Bonn, Germany

Annual Water Consumption by Crops



Global distribution of water consumption[1] by 16 staple food crops (a) and water consumption by those crops on irrigated cropland (b). Land that is not cultivated with these crops is shown in gray. The color categories for water consumption are log scaled to illustrate the wide range of water use. Volumes are distributed over 5' grid cells, an area of approximately 8,000 hectares.

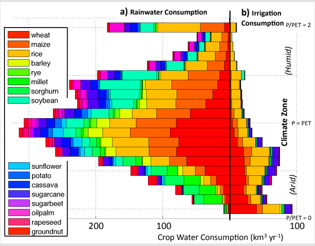
1. Siebert S & Doll P (2010) Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. *Journal Of Hydrology* 384(3-4)

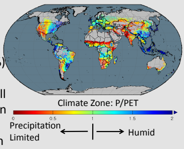
The Key Challenge

Agriculture consumes far more water than any other human activity, linking the challenges of water sustainability and food security.

To evaluate the effectiveness with which water resources are used, we assess water productivity, edible energy produced (kcal) per unit of water evapotranspired (liter).

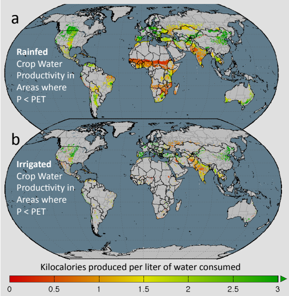
Water Consumption Across Climate Zones





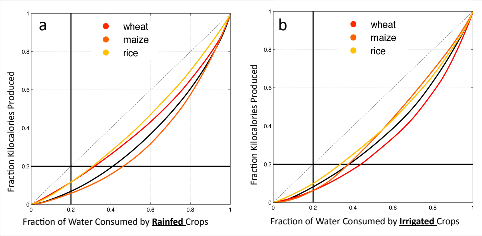
To feed the world, agriculture must be dispersed across climate zones. The majority (83%) of water consumed by crops originates as rainfall on cropland (a). Irrigation water (b) provides only 17% of water, primarily in arid climates. Climate zones, most arid at the bottom and most humid at the top, are based on P/PET (inset map). Climate zones are evenly distributed in climate space.

Water Productivity is Highly Variable



Water productivity, calculated as the sum of all kilocalories produced by 16 crops divided by the sum of water consumed by those crops, is shown for precipitation-limited areas: P < PET. Data for both rainfed (a) and irrigated (b) systems are centered at 1.5 kcal L^{-1}, close to the median water productivity for rainfed (1.1 kcal L^{-1}) and irrigated (1.8 kcal L^{-1}) systems, so that areas of low water productivity are shown in red and areas of high water productivity are shown in green. In climates that are potentially water limited, we find that, among the 16 crops analyzed in this study, median water productivity differs by ~5 kcal L^{-1} among crops.

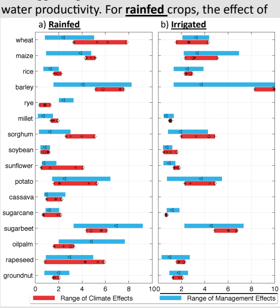
Water Use is Disproportionate



For each crop, the least water productive systems in precipitation-limited regions are disproportionate resource consumers, requiring ~40% of water to produce just 20% of food calories. Fraction of cumulative annual water consumption and cumulative annual kilocalorie production for wheat (red), maize (orange), rice (yellow), and the aggregate of 16 crops (black) for rainfed (a) and irrigated (b) systems in precipitation-limited areas.

Increasing Water Productivity is Possible; The Impacts are Substantial

The range of crop water productivity is driven as much by management and soils as by climate, suggesting that farmers have substantial leeway to improve water productivity. For **rainfed** crops, the effect of climate on water productivity (a) ranges from 2.8 - 4.8 kcal L^{-1} while the effect of management and soil ranges from 1.0 - 4.7 kcal L^{-1}. In **irrigated** systems (b), climate effects range from 2.1 - 3.7 kcal L^{-1} and management effects range from 1.6 - 4.6 kcal L^{-1}



Management ( ) plays a role of equal magnitude to climate ( ) in determining water productivity for both rainfed (a) and irrigated (b) crops. Effects of climate on water use are calculated by comparing maximum rates of water productivity across climate zones for each crop. We calculated these maximum rates in multiple ways. Difference between the high and low 90th percentile water productivity within each zone are marked with an **x**, and differences between the high and low 90th percentile among only high-productivity areas within each zone are marked with a ◊. To control for climate zones with anomalously high or low maximums, we also fit a 2nd degree polynomial to each set of maximums. The difference between the high and low maximums of this curve are marked with a **+** for all areas and * for high-yielding areas. Management illustrates the largest and smallest difference between the 10th and 90th percentile of water productivity within each climate zone. The production–weighted mean value is indicated (▷).

In areas where water is scarce and water productivity is low, increasing water productivity can relax pressure on the system. In contrast, if water is scarce and water productivity is high, increasing sustainability will require structural changes such as decreasing cropland and growing higher value crops, the income from which could then be used to import food from regions with less water scarcity. Our findings indicate substantial potential for increasing agricultural productivity without increasing water use.

Even a modest increase of water productivity to the 20th percentile in precipitation-limited regions could (a) increase caloric output on rainfed cropland by enough to provide food for ~110 million people annually (~120 trillion kilocalories) without increasing water consumption and (b) reduce water consumption on irrigated cropland by enough to meet the annual domestic water demand of 1.4 billion people (~70 km^3).