The water footprint of bioenergy from *Jatropha curcas* L.

The water footprint (WF) of energy crops should be calculated by relating the energy yield of a crop to its actual water use under actual climatic conditions during the growing season. Recently, average precipitation and additional irrigation to satisfy potential crop water requirements were used as input to the WF computation (1). We disagree with this approach because it relates optimized crop water use to actual yields, thereby introducing bias towards inefficient WF for low-yielding crops under suboptimal rain-fed conditions.

In particular, the presented WF of the pan-tropical perennial species *Jatropha curcas* L. deserves correction. A too simplistic computation discards this multi-purpose tree as an inefficient energy source, whereas it may provide a viable alternative in semi-arid areas, contributing to increased resource use efficiency, erosion control, crop diversification, local energy supply, and rural development. *Jatropha* has a range of characteristics for coping with water stress. Its physical constitution changes, and it is suggested to combine C3-/CAM photosynthesis in succulent stems (water storage), with leaves shifting from C3-metabolism to more water-efficient CAM (2). Low water use is supported by field data (3), but claims that combine this trait with high production potentials are unrealistic (4).

Our objections to the presented WF for *jatropha* concern the use of low-yield data (from nonirrigated young plantations) connected to simulated water use of mature plantations under optimal growing conditions, without considering specific characteristics of soils and species. Background information (5) did not supply essential information for sound WF calculations with appropriate values for *jatropha* crop factors to correct reference evaporation.

Furthermore, the remaining press cake of *jatropha* seeds after oil extraction should be considered for energy production. Except for some Central American accessions, all plant parts are toxic and unlike other oil species, its press cake cannot be used for animal feed without detoxification. Roughly, *jatropha* seeds provide 1/3 oil and 2/3 press cake with higher

heating values of 37.7 MJ/kg oil and 17.5 MJ/kg press cake. Considering the division of 33% and 67%, both fractions give similar energy production and double the energy yield, or halve the WF per GJ produced.

In South Africa, nonirrigated unfertilized 4-year-old *jatropha* (4.5×3.0 m; 741 trees/ha) yielded 1,286 kg/ha dry seeds in a growing season of 8.5 months with 652 mm rainfall. With 35% oil, this represents 450 kg/ha oil (or 489 L/ha oil at 0.92 kg/L) and 836 kg/ha press cake, delivering 31.6 GJ/ha. Over the growing season, our water-balance model simulated total transpiration and soil evaporation of 4,052 m³/ha, well in agreement with field observations (3). The concurrent WF is 8,281 L of water per L of oil and 128 m³ of water per GJ; not even 1/3 of the WF of soybean, comparable to the WF of cassava, and only 1/5 of the WF obtained by using potential crop water requirements (1).

ACKNOWLEDGMENTS. We thank Francois du Toit (OSCA farm manager, South African Department of Agriculture) and Mark Gush (CSIR) for availing field data and Stichting Het Groene Woudt & FACT Foundation for their support.

R. E. E. Jongschaap^{a,1}, R. A. R. Blesgraaf^b, T. A. Bogaard^b, E. N. van Loo^a, and H. H. G. Savenije^b

^aWageningen University and Research Centre, Plant Research International, P. O. Box 616, NL-6700AP Wageningen, The Netherlands; and ^bFaculty of Civil Engineering and Geosciences, Department of Water Management, Delft University of Technology, P. O. Box 5048, NL-2600GA Delft, The Netherlands

1. Gerbens-Leenes W, Hoekstra AY, van der Meer TH (2009) The water footprint of bioenergy. *Proc Natl Acad Sci USA* 106:10219–10223.
2. Maes WH, Achten WMJ, Reubens B, Raes D, Samson R, Muys B (2009) Plant–water relationships and growth strategies of *Jatropha curcas* L. seedlings under different levels of drought stress. *J Arid Environ* 73:877–884.
3. Gush MB, Moodley M (2007) Water use assessment of *Jatropha curcas*. *Jatropha curcas in South Africa: An Assessment of Its Water Use and Bio-Physical Potential*, eds Holl M, Gush MB, Hallows J, Versfeld DB. Available at www.ascension-publishing.com/BIZ/JatrophaWater.pdf. Accessed June 24, 2009.
4. Jongschaap REE, Corré WJ, Bindraban PS, Brandenburg WA (2007) Claims and facts on *Jatropha curcas* L. *Global Jatropha curcas Evaluation, Breeding and Propagation Programme, Report 158*. Available at <http://library.wur.nl/way/bestanden/cic/1858843.pdf>. Accessed June 24, 2009.
5. Daey Ouwens K, et al. (2007) *Position Paper on Jatropha curcas. State of the Art, Small and Large Scale Project Development*. (Wageningen Univ, Wageningen, The Netherlands).

Author contributions: T.A.B. designed research; R.A.R.B. performed research; R.E.E.J., R.A.R.B., T.A.B., E.N.v.L., and H.H.G.S. analyzed data; and R.E.E.J. and H.H.G.S. wrote the paper.

The authors declare no conflict of interest.

¹To whom correspondence should be addressed. E-mail: raymond.jongschaap@wur.nl.