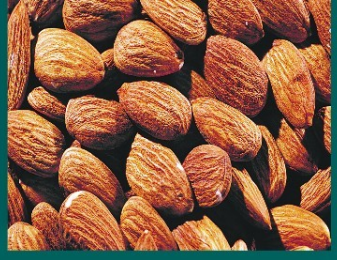
Eric Lichtfouse
Marjolaine Hamelin
Mireille Navarrete
Philippe Debaeke
Editors



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Eric Lichtfouse • Marjolaine Hamelin
Mireille Navarrete • Philippe Debaeke
Editors

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Editors
Eric Lichtfouse
INRA-CMSE-PME
rue Sully 17
21000 Dijon
France
eric.lichtfouse@dijon.inra.fr

Mireille Navarrete
INRA-SAD
Unite d′Écodéveloppement
Avignon CX 09
France
navarret@avignon.inra.fr

Marjolaine Hamelin
French National Institute for Agriculture
LBE
Avenue des étangs
11100 Narbonne
France
marjolaine.hamelin@supagro.inra.fr

Philippe Debaeke
INRA
UMR AGIR
PO Box 52627
31326 Toulouse CX
France
debaeke@toulouse.inra.fr

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Contents

Contributors

Majid Afyuni Department of Soil Science, Isfahan University of Technology, 84154, Isfahan, Iran

Ishita Ahuja Department of Biology, Norwegian University of Science and Technology, Realfagbygget, NO-7491 Trondheim, Norway, atle.bones@bio.ntnu.no

O.C. Ajayi World Agroforestry Centre (ICRAF), Southern Africa Regional Programme, PO Box 30798, Lilongwe, Malawi

T. Akar Central Research Institute for Field Crops, PO Box 226, 06042 Ulus-Ankara, Turkey

Festus K. Akinnifesi World Agroforestry Centre (ICRAF), Southern Africa Regional Programme, PO Box 30798, Lilongwe, Malawi, fakinnifesi@africa-online.net

C. Alcaraz-López Plant Nutrition Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain

Lionel Alletto Université de Toulouse - École d'ingénieurs de Purpan, Agronomy Department, 75 voie du TOEC, BP 57611, 31076 Toulouse Cedex 3, France, lionel.alletto@purpan.fr

Merlina N. Andalecio Institute of Fisheries Policy and Development Studies, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miag-ao, Iloilo 5023, Philippines, merlina_andalecio@yahoo.com

Frèdèrique Angevin INRA, UAR1240 Eco-Innov, BP 01, 78850 Thiverval Grignon, France

Tesfay Araya Ghent University, Department of Soil Management, 9000 Gent, Belgium
and
Mekelle University, Department of Crop and Horticultural Science, Mekelle, Ethiopia

Dominique Arrouays INRA Orléans - US 1106, Unité INFOSOL, avenue de la Pomme de Pin, BP 20619, Ardon, 45166 Olivet Cedex, France

Muzaffer Avci Central Research Institute Field Crops (CRIFC), Agronomy Department, PO Box 226, Ankara, Turkey, muzafavci@yahoo.com

John A. Baddeley Crop and Soil Systems Research Group, Scottish Agricultural College, Craibstone Estate, Aberdeen, AB21 9YA, UK

Bruce C. Ball Crop and Soil Systems Research Group, SAC, West Mains Road, Edinburgh EH9 3JG, UK

J.P. Baresel Technical University of Munich, Chair of Organic Farming, Alte Akademie 12, 85350 Freising, Germany

Enrique Barriuso UMR 1091 INRA/AgroParisTech Environment and Arable Crops, Institut National de la Recherche Agronomique/Institut National des Sciences et Industries du Vivant et de l'Environnement, 78850 Thiverval-Grignon, France

D.A. Barry Institute for Environmental Engineering, École Polytechnique Fédérale de Lausanne, Station 2, 1015, Lausanne, Switzerland, andrew.barry@epfl.ch

Ruth Bartel-Kratochvil BOKU – University of Natural Resources and Applied Life Sciences, Vienna, Feistmantelstr. 4, 1180 Vienna, Austria

E. Bastías Departamento de Producción Agrícola, Facultad de Ciencias Agronómicas, Universidad de Tarapacá, Casilla 6-D, Arica, Chile

J. Batlle-Aguilar School of the Environment, National Centre for Groundwater Research and Training (NCGRT), Flinders University, GPO Box 2100, Adelaide, SA-5001, Australia, jordi.batlleaguilar@flinders.edu.au

Hans Bauer Mekelle University, Department of Land Resources Management and Environmental Protection, Mekelle, Ethiopia
and
K.U. Leuven, Department of Earth and Environmental Sciences, 3001 Heverlee, Belgium

P.J. Bebeli Department of Plant Breeding and Biometry, Agricultural University of Athens, Iera Odos 75, Athens 11855, Greece

Gianni Bellocchi Grassland Ecosystem Research Unit, French National Institute for Agricultural Research, 234 Avenue du Brézet, 63100 Clermont-Ferrand, France, gianni.bellocchi@clermont.inra.fr, giannibellocchi@yahoo.com

Stéphane Bellon UR 0767 Ecodéveloppement, INRA, 84914 Avignon Cedex 9, France

Gero Benckiser Department of Applied Microbiology, Justus-Liebig University, Giessen, Heinrich Buff-Ring 26-32, Germany,
gero.benckiser@umwelt.uni-giessen.de

Jürgen Bender Institute of Biodiversity, Johann Heinrich von Thünen-Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig, Germany, juergen.bender@vti.bund.de

Pierre Benoit UMR 1091 INRA/AgroParisTech Environment and Arable Crops, Institut National de la Recherche Agronomique/Institut National des Sciences et Industries du Vivant et de l'Environnement, 78850 Thiverval-Grignon, France

Cécile Bessou INRA Environment and Agricultural Crop Research Unit, 78850 Thiverval-Grignon, France, cecile.bessou@cirad.fr

E. Bettencourt Genetic Resources, Ecophysiology and Plant Bredding Unit, Instituto Nacional dos Recursos Biológicos, I.P. (INRB, I.P.), Quinta do Marquês, 2784-505 Oeiras, Portugal

Anne Biarnès IRD, UMR1221 LISAH, 2 place Viala, 34060 Montpellier, France

K.V. Bladenopoulos NAGREF –Cereal Institute 57001, Thermi, Thessaloniki, Greece

D. Blancard UMR Santé Végétale 1065, INRA, ENITA de Bordeaux, Université de Bordeaux, 33175 Gradignan, France

Atle Magnar Bones Department of Biology, Norwegian University of Science and Technology, Realfagbygget, NO-7491 Trondheim, Norway, atle.bones@bio.ntnu.no

Nicolas Chemidlin-Prévost Bouré INRA-Université de Bourgogne, UMR Microbiologie du Sol et de l'Environnement, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France
and
Platform GenoSol, INRA-Université de Bourgogne, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France

Jean-Charles Bouvier INRA, PSH Domaine St Paul, Agroparc, 84914 Avignon Cédex, France, jean-charles.bouvier@avignon.inra.fr

M. Brancourt-Hulmel INRA, USTL UMR 1281, 80203 Estrees-Mons, Peronne, France, brancour@mons.inra.fr

A. Brovelli Institute for Environmental Engineering, École Polytechnique Fédérale de Lausanne, Station 2, 1015, Lausanne, Switzerland

Roland J. Buresh Crop and Environmental Sciences Division, International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines

Yingfan Cai College of Bioinformation, Chongqing University of Posts and Telecommunications, Chongqing, 400065, China, caiyf3000@yahoo.com.cn

M. Carvajal Plant Nutrition Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain, mcarvaja@cebas.csic.es

Shikha Chandel Department of Botany, Panjab University, Chandigarh – 160014, India

Rufus L. Chaney USDA-Agricultural Research Service, Environmental Management and Byproduct Utilization Laboratory, Building 007, BARC-West, Beltsville, MD 20705, USA

Jonas N. Chianu TSBF-CIAT, c/o World Agroforestry Centre (ICRAF), UN Avenue, Gigiri, PO Box 30677, Nairobi, Kenya, j.chianu@cgiar.org

P.W. Chirwa Pretoria University, South Africa

S.-U. Chon EFARINET Co. Ltd., BI Center, Chosun University, Gwangju 501-759, South Korea, chonsu4100@yahoo.co.kr

K.V. Christensen Department of Chemical Engineering, Biotechnology and Environmental Technology, Faculty of Engineering, University of Southern Denmark, Niels Bohrs Allé 1, 5220 Odense, Denmark, kvc@kbm.sdu.dk

M.L. Christensen Department of Biotechnology, Chemistry and Environmental Engineering, Aalborg University, Sohngaardsholmsvej 57, 9000 Aalborg, Denmark, mlc@bio.aau.dk

Jean-Bernard Cliquet UMR INRA 950 Ecophysiologie Végétale Agronomie INRA/Université de Caen, 14032 Caen Cedex, France

Nathalie Colbach INRA, UMR1210 Biologie et Gestion des Adventices, 17 rue Sully, BP 86510, 21065 Dijon Cedex, France

Yves Coquet UMR 1091 INRA/AgroParisTech Environment and Arable Crops, Institut National de la Recherche Agronomique/Institut National des Sciences et Industries du Vivant et de l'Environnement, 78850 Thiverval-Grignon, France

Wim M. Cornelis Ghent University, Department of Soil Management, 9000 Gent, Belgium

Kehui Cui Crop Physiology and Production Center, MOA Key Laboratory of Huazhong Crop Physiology, Ecology and Production, Huazhong Agricultural University, Wuhan, Hubei 430070, China

J.H. Czembor Plant Breeding and Acclimatization Institute – IHAR Radzikow, 05-870 Blonie, Poland

Bahareh Daneshbakhsh Department of Soil Science, Isfahan University of Technology, 84154, Isfahan, Iran

Ika Darnhofer BOKU – University of Natural Resources and Applied Life Sciences, Vienna, Feistmantelstr. 4, 1180 Vienna, Austria
and
Department of Economic and Social Sciences, University of Natural Resources and Applied Life Sciences Vienna, Feistmantelstr. 4, 1180 Vienna, Austria, ika.darnhofer@boku.ac.at

C. David ISARA, Department of Agroecosystems, Environment and Production, 23 rue Jean Baldassini, 69364 Lyon Cedex 07, France

Philippe Debaeke INRA, UMR AGIR, BP 52627, 31326 Toulouse Cedex, France

Jean-François Debras INRA, PSH Domaine St Paul, Agroparc, 84914 AVIGNON Cédex, France, jean-francois.debras@avignon.inra.fr

Jozef Deckers K.U. Leuven, Department of Earth and Environmental Sciences, 3001 Heverlee, Belgium

Benoît Dedieu UMR 1273 Metafort, INRA, Theix, 63122 Saint-Genès Champanelle, France

F. Déniel Université Européenne de Bretagne, France
and
Université de Brest, EA3882 Laboratoire Universitaire de Biodiversité et Écologie Microbienne, IFR148 ScInBioS, ESMISAB, Technopôle Brest-Iroise, 29280 Plouzané, France

Samuel Dequiedt INRA-Université de Bourgogne, UMR Microbiologie du Sol et de l'Environnement, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France
and
Platform GenoSol, INRA-Université de Bourgogne, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France

Mariangela Diacono CRA- Research Unit for Cropping Systems in Dry Environments, Bari - Italy

Achim Dobermann Crop and Environmental Sciences Division, International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines

R. Dominguez-Perles Food Science and Technology Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain

Marcello Donatelli Agriculture Research Council, via di Corticella 133, 40128 Bologna, Italy

T. Doré AgroParisTech, UMR 211 INRA/AgroParisTech, BP 01, 78850 Thiverval-Grignon, France

T.M.M. Dos Santos ISOPlexis Banco de Germoplasma, BGR, CEM, Universidade da Madeira, 9000-390 Funchal, Portugal

Jean-Louis Durand INRA, Unité de Recherche Pluridisciplinaire sur les prairies et les plantes fourragères, BP 6, 86600 Lusignan, France

Frank Eulenstein Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) Müncheberg, Eberswalder Straße 84, 15374 Müncheberg, Germany

Saliou Fall Équipe "Génomique Microbienne Environnementale" (Environmental Microbial Genomics Group), UMR CNRS 5005, Laboratoire Ampère, École Centrale de Lyon, 36 avenue Guy de Collongue, 69134 Ecully Cedex, France

D.A. Fasoula Agricultural Research Institute, P.O.Box 22016, 1516 Nicosia, Cyprus

Fabien Ferchaud INRA, US1158 Agro-Impact, 02 007 Laon-Mons, France

J.L. Fiorelli SOLPHY, La Grennery, 73670 Entremont-le-Vieux, France

Aysha Fleming Tasmanian Institute of Agricultural Research, University of Tasmania, Private Bag 54, Hobart TAS 7001, Australia, Aysha.Fleming@utas.edu.au

C. Francis University of Nebraska-Lincoln, Department of Agronomy and Horticulture, 279 Plant Science Hall, Lincoln, Nebraska 68583-0915, USA

Joëlle Fustec LUNAM University, Groupe ESA, UR Laboratoire d'Ecophysiologie Végétale et Agroécologie, 55 rue Rabelais, 49007 Angers Cedex 01, France, j.fustec@groupe-esa.com

Benoît Gabrielle INRA, US1158 Agro-Impact, 02 007 Laon-Mons, France

C. García-Viguera Food Science and Technology Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain

Neera Garg Department of Botany, Panjab University, Chandigarh – 160014, India, garg_neera@yahoo.com

François Gastal INRA, Unité de Recherche Pluridisciplinaire sur les prairies et les plantes fourragères, BP 6, 86600 Lusignan, France

Victoria Gonzalez-Dugo IAS-CSIC, Instituto de Agricultura Sostenible, Consejo Superior de Investigaciones Científicas, Alameda del Obispo, s/n, 14004, Córdoba, Spain
and
INRA, Unité de Recherche Pluridisciplinaire sur les prairies et les plantes fourragères, BP 6, 86600 Lusignan, France, victoria.gonzalez@ias.csic.es

Bram Govaerts International Maize and Wheat Improvement Centre (CIMMYT), México D.F. 06600, Mexico

T. Graham Shepherd BioAgriNomics Ltd., 6 Parata Street, Palmerston North 4410, New Zealand

L. Guérin-Dubrana UMR Santé Végétale 1065, INRA, ENITA de Bordeaux, Université de Bordeaux, 33175 Gradignan, France

Mitiku Haile Mekelle University, Department of Crop and Horticultural Science, Mekelle, Ethiopia

Marjolaine Hamelin INRA, UA1267, Agronomy for Sustainable Development, UR 50, Laboratoire de Biotechnologie de lŠEnvironnement, avenue des Étangs, 11100 Narbonne, France

Jérome Harmand INRA-INRIA MERE research project, UMR ASB, place Pierre Viala, 34060 Montpellier Cedex, France
and
LBE-INRA, UR050, avenue des étangs, 11100 Narbonne, France

Djilali Heddadj Chambres d'agriculture de Bretagne, Recherche appliquée - Pôle agronomie, avenue du Général Borgnis Desbordes, BP 398, 56009 Vannes Cedex, France

Jaakko Heikkilä MTT Economic Research, Latokartanonkaari 9, 00790 Helsinki, Finland, jaakko.heikkila@mtt.fi

Katharina Helming Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) Müncheberg, Eberswalder Straße 84, 15374 Müncheberg, Germany

Agnès Henri EDP Sciences, Parc dŠActivités de Courtaboeuf, BP 112, 17 avenue du Hoggar, 91944 Les Ulis Cedex A, France

Maibritt Hjorth Department of Biosystems Engineering, Faculty of Agricultural Sciences, Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark

Amir Hossein Khoshgoftarmanesh Department of Soil Science, Isfahan University of Technology, 84154 Isfahan, Iran, amirhkhosh@cc.iut.ac.ir

Ruifa Hu Centre for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences, Beijing 100101, China

Jianliang Huang Crop Physiology and Production Center, MOA Key Laboratory of Huazhong Crop Physiology, Ecology and Production, Huazhong Agricultural University, Wuhan, Hubei 430070, China

Richard Joffre UMR 5175 CNRS, Équipe DREAM - Centre d'Écologie Fonctionnelle et Évolutive, 1919 route de Mende, 34293 Montpellier Cedex 5, France

Claudy Jolivet INRA Orléans - US 1106, Unité INFOSOL, avenue de la Pomme de Pin, BP 20619, Ardon, 45166 Olivet Cedex, France

Henning Kage Institute of Crop Science and Plant Breeding, Christian-Albrechts-University, Hermann-Rodewald-Str. 9, 24118 Kiel, Germany

A. Katsiotis Department of Plant Breeding and Biometry, Agricultural University of Athens, Iera Odos 75, Athens 11855, Greece

K. Koutis Laboratory of Genetics and Plant Breeding, Faculty of Agriculture, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

M. Koutsika-Sotiriou Department of Genetic Resources and Organic Plant Breeding, Agricultural Research Institute of the Hungarian Academy of Sciences, Brunszvik u. 2., Martonvasar, 2462, Hungary

G. Kovacs Department of Genetic Resources and Organic Plant Breeding, Agricultural Research Institute of the Hungarian Academy of Sciences, Brunszvik u. 2., Martonvasar, 2462, Hungary

Sudesh Kumar Yadav Biotechnology Division, Institute of Himalayan Bioresource Technology, CSIR, Palampur-176061 (HP), India,
skyt@rediffmail.com; sudeshkumar@ihbt.res.in

Denis Lairon INRA, UMR 1260, Nutriments Lipidiques et Prévention des Maladies Métaboliques, U476, Univ. Aix-Marseille 1, Univ. Aix-Marseille 2, Faculté de Médecine, 13385 Marseille, France, denis.lairon@univmed.fr

H. Larsson Swedish University of Agricultural Sciences, Box 104, SE-23053 Alnarp, Sweden

G. Le Floch Université Européenne de Bretagne, France
and
Université de Brest, EA3882 Laboratoire Universitaire de Biodiversité et Écologie Microbienne, IFR148 ScInBioS, ESMISAB, Technopôle Brest-Iroise, 29280 Plouzané, France

Delphine Leenhardt INRA, UMR1248 – AGIR (Agrosystèmes et développement territorial), BP 52627, 31326 Castanet Tolosan Cedex, France, Delphine.Burger-Leenhardt@toulouse.inra.fr

Philippe Lemanceau INRA-Université de Bourgogne, UMR Microbiologie du Sol et de l'Environnement, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France
and
Platform GenoSol, INRA-Université de Bourgogne, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France

Fabien Lesuffleur UMR INRA 950 Ecophysiologie Végétale Agronomie INRA/Université de Caen, 14032 Caen Cedex, France

Eric Lichtfouse INRA, UA1267, Agronomy for Sustainable Development, INRA-CMSE-PME, 17 rue Sully, 21000 Dijon, France, eric.lichtfouse@dijon.inra.fr

Thomas Lindenthal BOKU – University of Natural Resources and Applied Life Sciences, Vienna, Feistmantelstr. 4, 1180 Vienna, Austria

Jinggao Liu Southern Plains Agricultural Research Center, United States Department of Agriculture, Texas, College Station, Texas, 77845, USA

Yanyan Liu College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China
and
Crop and Soil Systems Research Group, Scottish Agricultural College, Craibstone Estate, Aberdeen, AB21 9YA, UK, yanyan.liu@cau.edu.cn

Yuanying Liu College of Resources and Environmental Sciences, Northeast Agricultural University, Harbin, Heilongjiang 150030, China

Patrice Loisel INRA-INRIA MERE research project, UMR ASB, place Pierre Viala, 34060 Montpellier Cedex, France

F.S. Mairura TSBF-CIAT, c/o World Agroforestry Centre (ICRAF), UN Avenue, Gigiri, PO Box 30677, Nairobi, Kenya

Pierre-Alain Maron INRA-Université de Bourgogne, UMR Microbiologie du Sol et de l'Environnement, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France
and
Platform GenoSol, INRA-Université de Bourgogne, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France

Stéphanie Mahieu LUNAM University, Groupe ESA, UR Laboratoire d'Ecophysiologie Végétale et Agroécologie, 55 rue Rabelais, 49007 Angers Cedex 01, France

David A.C. Manning School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne, NE1 7RU UK, David.Manning@newcastle.ac.uk

M.C. Martínez-Ballesta Plant Nutrition Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain

Manuel P. Martin INRA Orléans - US 1106, Unité INFOSOL, avenue de la Pomme de Pin, BP 20619, Ardon, 45166 Olivet Cedex, France

Bruno Mary INRA, US1158 Agro-Impact, 02 007 Laon-Mons, France

Keith Matthews Macaulay Institute, Craigiebuckler AB15 8QH, Aberdeen, UK

Rebecka Milestad Dept. of Urban and Rural Studies, Swedish University of Agricultural Sciences, 75007 Uppsala, Sweden

Wilfried Mirschel Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) Müncheberg, Eberswalder Straße 84, 15374 Müncheberg, Germany

Catherine Mignolet INRA, UR55 SAD-Mirecourt, 662 avenue Louis Buffet, 88500 Mirecourt, France

Francesco Montemurro CRA – Research Unit for the Study of Cropping Systems – Metaponto (MT), Italy, francesco.montemurro@entecra.it

D.A. Moreno Food Science and Technology Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain

Christophe Mougel INRA-Université de Bourgogne, UMR Microbiologie du Sol et de l'Environnement, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France and
Platform GenoSol, INRA-Université de Bourgogne, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France

Lothar Mueller Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) Müncheberg, Eberswalder Straße 84, 15374 Müncheberg, Germany, mueller@zalf.de

B. Muries Plant Nutrition Department, CEBAS-CSIC, PO Box 164, Espinardo, 30100, Murcia, Spain

Mireille Navarrete INRA, UR 767, Écodéveloppement, 84914 Avignon Cedex 09, France

C.J. Nelson Department of Agronomy, University of Missouri, Columbia, MO 65211, USA

A.C. Newton SCRI, Invergowrie, Dundee DD2 5DA, Scotland, UK, adrian.newton@scri.ac.uk

E.M. Nkonya International Food Policy Research Institute (IFPRI), (202) 862-5600, 2033 K St NW, #400, Washington DC, USA

S.M. Novak INRA, Unité Expérimentale Fourrages et Environnement, F-86600 Lusignan, France, sandra.novak@lusignan.inra.fr

Jan Nyssen Department of Geography, Ghent University, 9000 Gent, Belgium, jan.nyssen@ugent.be

Shaobing Peng Crop and Environmental Sciences Division, International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines, s.peng@cgiar.org

M.A.A. Pinheiro de Carvalho ISOPlexis Banco de Germoplasma, BGR, CEM, Universidade da Madeira, 9000-390 Funchal, Portugal

A. Porporato Institute for Environmental Engineering, École Polytechnique Fédérale de Lausanne, Station 2, 1015, Lausanne, Switzerland
and
Permanent address: Civil and Environmental Engineering Department, Duke University, Durham, NC 27708, USA

Lionel Ranjard INRA-Université de Bourgogne, UMR Microbiologie du Sol et de l'Environnement, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France
and
Platform GenoSol, INRA-Université de Bourgogne, CMSE, 17 rue Sully, B.V. 86510, 21065 Dijon Cedex, France, ranjard@dijon.inra.fr

Alain Rapaport INRA-INRIA MERE research project, UMR ASB, place Pierre Viala, 34060 Montpellier Cedex, France

P. Rey UMR Santé Végétale 1065, INRA, ENITA de Bordeaux, Université de Bordeaux, 33175 Gradignan, France, prey@bordeaux.inra.fr

Mike Rivington Macaulay Institute, Craigiebuckler AB15 8QH, Aberdeen, UK

Alan S. Robinson Entomology Unit, FAO/IAEA Agriculture and Biotechnology Laboratory, Joint FAO/IAEA Programme, Vienna, Austria

Jutta Rogasik Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen (JKI), Institut für Pflanzenbau und Bodenkunde, Bundesallee 50, 38116 Braunschweig, Germany

Jens Rohloff Department of Biology, Norwegian University of Science and Technology, Realfagbygget, NO-7491 Trondheim, Norway

D. Rubiales Institute for Sustainable Agriculture, CSIC, Alameda del Obispo s/n, Apdo. 4084, 14080 Cordoba, Spain

J. Russell SCRI, Invergowrie, Dundee DD2 5DA, Scotland, UK

Nicolas P.A. Saby INRA Orléans - US 1106, Unité INFOSOL, avenue de la Pomme de Pin, BP 20619, Ardon, 45166 Olivet Cedex, France

Benoît Sauphanor INRA, PSH Domaine St Paul, Agroparc, 84914 AVIGNON Cédex 9, France, benoit.sauphanor@avignon.inra.fr

Ken Sayre International Maize and Wheat Improvement Centre (CIMMYT), México D.F. 06600, Mexico

Uwe Schindler Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) Müncheberg, Eberswalder Straße 84, 15374 Müncheberg, Germany

Rainer Schulin Institutes of Terrestrial Ecology, ETH Zurich, Universitaetstr. 16, 8092 Zurich, Switzerland

Klaus Sieling Institute of Crop Science and Plant Breeding, Christian-Albrechts-University, Hermann-Rodewald-Str. 9, 24118 Kiel, Germany, sieling@pflanzenbau.uni-kiel.de

Gilbert C. Sigua Research Soil Scientist, United States Department of Agriculture-Agricultural Research Service Subtropical Agricultural Research Station, Brooksville, FL, 34601, USA, gilbert.sigua@ars.usda.gov

G. Sileshi World Agroforestry Centre (ICRAF), Southern Africa Regional Programme, PO Box 30798, Lilongwe, Malawi

Sylvaine Simon INRA, UERI, Gotheron, 26320 Saint-Marcel-lès-Valence, France, sylvaine.simon@avignon.inra.fr

Pascal Simonet Équipe "Génomique Microbienne Environnementale" (Environmental Microbial Genomics Group), UMR CNRS 5005, Laboratoire Ampère, École Centrale de Lyon, 36 avenue Guy de Collongue, 69134 Ecully Cedex, France

S.G. Sommer Department of Biosystems Engineering, Faculty of Agricultural Sciences, Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark, sgs@kbm.sdu.dk

Qiyuan Tang Crop Physiology, Ecology, and Production Center, Hunan Agricultural University, Changsha, Hunan 410128, China

Jean Thioulouse Université de Lyon, 69000 Lyon, France; Université Lyon 1, CNRS, UMR 5558, Laboratoire de Biométrie et Biologie Évolutive, 69622 Villeurbanne, France

Benoît Toutain INRA Orléans - US 1106, Unité INFOSOL, avenue de la Pomme de Pin, BP 20619, Ardon, 45166 Olivet Cedex, France

J. Vallance Université Européenne de Bretagne, France
and
Université de Brest, EA3882 Laboratoire Universitaire de Biodiversité et Écologie Microbienne, IFR148 ScInBioS, ESMISAB, Technopôle Brest-Iroise, 29280 Plouzané, France
and
UMR Santé Végétale 1065, INRA, ENITA de Bordeaux, Université de Bordeaux, 33175 Gradignan, France

D. Vallod ISARA, Department of Agroecosystems, Environment and Production, 23 rue Jean Baldassini, 69364 Lyon Cedex 07, France

Frank Vanclay Faculty of Spatial Sciences, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands, Frank.Vanclay@rug.nl

M.C. Vaz Patto Instituto de Tecnologia Química e Biológica, Apto. 127, 2781-901 Oeiras, Portugal

Marc J.B. Vreysen Insect Pest Control Laboratory, FAO/IAEA Agriculture and Biotechnology Laboratories, Joint FAO/IAEA Programme, Vienna, Austria, M.Vreysen@iaea.org

Guanghuo Wang College of Environmental and Natural Resources Sciences, Zhejiang University, Hangzhou, Zhejiang 310029, China

Christine A. Watson Crop and Soil Systems Research Group, Scottish Agricultural College, Craibstone Estate, Aberdeen, AB21 9YA, UK

Hans-Joachim Weigel Institute of Biodiversity, Johann Heinrich von Thünen-Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig, Germany

A. Wezel ISARA, Department of Agroecosystems, Environment and Production, 23 rue Jean Baldassini, 69364 Lyon Cedex 07, France, wezel@isara.fr

Hubert Wiggering Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) Müncheberg, Eberswalder Straße 84, 15374 Müncheberg, Germany

Lianhai Wu Crop and Soil Systems Research Group, Scottish Agricultural College, Craibstone Estate, Aberdeen, AB21 9YA, UK
and
North Wyke Research, Okehampton, Devon EX20 2SB, UK

Yongfang Xie College of Bioinformation, Chongqing University of Posts and Telecommunications, Chongqing, 400065, China

Jianchang Yang Agronomy Department, Agricultural College, Yangzhou University, Yangzhou, Jiangsu 225009, China

Fusuo Zhang College of Resources and Environmental Sciences, China Agricultural University, Beijing 100094, China

Xuhua Zhong Rice Research Institute, Guangdong Academy of Agricultural Science, Guangzhou, Guangdong 510640, China

Werner Zollitsch BOKU – University of Natural Resources and Applied Life Sciences, Vienna, Feistmantelstr. 4, 1180 Vienna, Austria

Yingbin Zou Crop Physiology, Ecology, and Production Center, Hunan Agricultural University, Changsha, Hunan 410128, China

H.W. Zub INRA, USTL UMR 1281, 80203 Estrees-Mons, Peronne, France, brancour@mons.inra.fr

Part I
Novel Concepts

Emerging Agroscience

Eric Lichtfouse, Marjolaine Hamelin, Mireille Navarrete, Philippe Debaeke, and Agnès Henri

Contents

Abstract Climate change and the recent financial crisis clearly show that humans have entered the anthropocene, an unprecedented era of fast and possibly dangerous changes. Unprecedented changes call for unprecedented thinking. Indeed, agricultural research has been for too long driven solely by the need for higher yields using classical agrosciences, whatever the adverse ecological effects. Agricultural research needs the input of other sciences such as ecological, economic, social and political sciences. These social sciences emerged in agricultural research a few decades ago, but there are currently no precise trends and data on the speed of emergence of specific topics. Therefore, here we report: (1) an analysis of the emergence of topics in the journal *Agronomy for Sustainable Development*, and (2) a review of selected articles published in 2009. First, to analyse topic emergence we studied three data sets: most-cited articles from 1999 to 2009, topic hits in article text from 1999 to 2009, and most-downloaded articles in 2009. We found the following major points. Most-cited articles show that transgenic plants and biofuels are clearly emerging topics from 2007, whereas soil carbon and climate change are the major mainstream topics of the last 10 years. Topic hits analysis allows one to rank topics by mean emergence date, e.g. 2008.3 for 'genetically modified' and 2005.3 for 'irrigation'. Accordingly, the 10 most emerging topics over 1999–2009 are biofuels, genetically modified, conservation agriculture, urban agriculture, sociology, organic farming, carbon sequestration, phytoremediation, mulch and biodiversity. Analysis of most-downloaded articles in 2009 shows the predominance of topics such as carbon, climate, biodiversity, biofuels, pollutants, beneficial microbes, transgenic plants and organic farming. Second,

E. Lichtfouse (✉)
INRA, UA1267, Agronomy for Sustainable Development, INRA-CMSE-PME, 17 rue Sully, 21000 Dijon, France
e-mail: eric.lichtfouse@dijon.inra.fr

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we reviewed selected articles published in 2009 with emphasis on emerging topics. We find that sociology is clearly bringing novel and unexpected findings to designing sustainable agriculture. Transgenic crops are highly innovative but show many unknowns that need to be carefully studied using various disciplines. Climate change has many scientifically proven effects on terrestrial ecosystems and agriculture. Here, soil carbon loss should be of particular attention because it rules the long-term fate of many factors such as atmospheric CO_2, erosion, and water and nutrient supply. Biodiversity loss due to industrial monocropping is leading scientists to disclose alternative, more diverse cropping systems that optimise biodiversity, pest control and yield.

Keywords Agriculture • Climate change • Biofuel • Transgenic plants • Biodiversity • Sociology • Organic farming • Conservation agriculture • Urban agriculture • Industrial agriculture • Carbon sequestration • Soil carbon • Crop rotation • No tillage • Beneficial microbes • Citation analysis • Topic emergence analysis • Most-cited articles • Most-downloaded articles

1 Introduction

Climate change and the recent financial crisis clearly show that humans have entered an unprecedented era of fast and possibly dangerous changes. This era is the anthropocene, a term that was coined in 2000 by the Nobel Prize-winning atmospheric chemist Paul Crutzen to point out that human activities now have a global impact on climate and ecosystems. Crutzen has explained, "I was at a conference where someone said something about the Holocene. I suddenly thought this was wrong. The world has changed too much. So I said: 'No, we are in the anthropocene'. I just made up the word on the spur of the moment. Everyone was shocked. But it seems to have stuck".

Unprecedented changes call for unprecedented adaptation. Unprecedented adaptation calls for unprecedented thinking. For instance, a major issue is that agricultural research has been for too long driven solely by the need for *higher yields* using monoculture, whatever the adverse ecological effects, such as food and drinking water pollution, biodiversity loss, and pest resistance. Mainstream goals such as higher yields should be challenged and rethought to take into account other factors. Those factors should not be solely defined by classical agrosciences, e.g. plant and soil sciences, but should also include all other sciences that really rule agriculture; for instance, ecological, economic, social and political sciences (De Bon et al., 2009; Wezel et al., 2009; Fleming and Vanclay, 2009; Lamine and Bellon, 2009; Lichtfouse et al., 2009a, b; Veldkamp et al., 2009). In other words, agronomy should not be reduced to a science that improves crop yields but should answer all society's issues because agriculture is both the foundation and the future of society. Agronomists should rethink the role of agriculture in our society. For instance, studies of farming systems should also include food systems (Gliessman, 2007).

Previous works have attempted to define the core issues of the industrial agricultural society: technology without wisdom; and the tragedy of the global commons: soil, water and air (Lal, 2009a, b); artificialisation and painkiller solutions; climate change and outdated society structures; and society dependence and sustainable agriculture (Lichtfouse, 2009a–c). In the book *Sustainable Agriculture* we have gathered 53 review articles that cover major advances in agrosciences (Lichtfouse et al., 2009a). Four recent books also report major contributions in emerging agrosciences (Lichtfouse et al., 2009d–g). Here, we analyse recent topical trends in the journal *Agronomy for Sustainable Development*. Topical trends are assessed using three indicators: (1) most-cited articles 1999–2009, (2) topic hits on the journal website over 1999–2009, and (3) most-downloaded articles in 2009. We then briefly review selected journal articles published in 2009.

2 Most-Cited Articles 1999–2009

A first means to assess topics in the journal is to look at most-cited articles in the *Journal Citation Reports*. Table 1 shows yearly top-cited articles in the journal *Agronomy for Sustainable Development* from 1999 to 2009. The results indicate that major recent topics are transgenic plants, agroindicators, alternative crop management, beneficial microbes, and topics related to climate change such as biofuels and soil carbon. Whereas

Table 1 Top 3 yearly most cited articles in the journal *Agronomy for Sustainable Development*. Number of citing articles, named cites, are from ISI-thompson on October 22, 2009. The top 5 highest cites are printed in bold. Full references are given in the reference list

Most-Cited Articles			
Year	Cites	Topics	First author - Title
2008	5	Transgenic plants	BONNY. Genetically modified glyphosate-tolerant soybean in the USA...
	5	Transgenic plants	DEVOS. Feasibility of isolation perimeters for genetically modified maize
	4	Agroindicators, N, pesticides	BOCKSTALLER. Agri-environmental indicators to assess cropping and farming...
2007	16	Transgenic plants	DEVOS. Implementing isolation perimeters around genetically modified...
	11	Alternative fertilisation, beneficial microbes	GARG. Symbiotic nitrogen fixation in legume nodules: process and signaling.
	10	Biofuels, climate, carbon	HILL. Environmental costs and benefits of transportation biofuel production...
2006	17	Alternative management, soil, carbon	BERNOUX. Cropping systems, carbon sequestration and erosion in Brazil.
	17	Alternative fertilisation, soil, carbon	HACHICHA. Compost of poultry manure and olive mill wastes as an alternative...
	8	Pollutants, food	GROVA. Effect of oral exposure to polycyclic aromatic hydrocarbons...
2005	19	Alternative management, soil, pesticides	LACAS. Using grassed strips to limit pesticide transfer to surface water.
	18	Agroindicators, biodiversity	CLERGUE. Biodiversity: function and assessment in agricultural areas.
	13	Transgenic plants	COLBACH. Spatial aspects of gene flow between rapeseed varieties and volunteers.
2004	25	Alternative management, biodiversity	MARRIOTT. Long-term impacts of extensification of grassland management...
	21	Alternative management, soil, erosion	LE BISSONNAIS. Grass strip effects on runoff and soil loss.
	17	Soil, carbon, compost	AMIR. Elemental analysis, FTIR and C-13-NMR of humic acids from sewage...
2003	**98**	Soil, carbon, roots	NGUYEN. Rhizodeposition of organic C by plants: mechanisms and controls.
	26	Soil, carbon, fungi	CASARIN. Quantification of oxalate ions and protons released by ectomycorrhizal...
	23	Pollutants, toxicity	ROUT. Effect of metal toxicity on plant growth and metabolism: I. Zinc.
2002	**146**	Alternative management, soil, carbon	SIX. Soil organic matter, biota and aggregation in temperate and tropical soils...
	50	Agroindicators, climate, soil	BRISSON. STICS: a generic model for simulating crops and their water...
	33	Climate, greenhouse	REICHRATH. Using CFD to model the internal climate of greenhouses...
2001	51	Climate, carbon, salt stress	DORAI. Influence of electric conductivity management on greenhouse tomato...
	35	Alternative control	EHRET. Disinfestation of recirculating nutrient solutions in greenhouse horticulture.
	32	Carbon, growth	GUICHARD. Tomato fruit quality in relation to water and carbon fluxes.
2000	**72**	Climate, canopy	WEISS. Investigation of a model inversion technique to estimate canopy...
	52	Alternative control, intercropping	FINCKH. Cereal variety and species mixtures in practice...
	37	Beneficial microbes	BOSSIS. The taxonomy of Pseudomonas fluorescens and Pseudomonas putida...
1999	**73**	Climate, remote sensing	CEROVIC. Ultraviolet-induced fluorescence for plant monitoring...
	44	Climate, canopy	FOURNIER. ADEL-maize: an L-system based model for the integration of growth...
	40	Plant architecture, model	GODIN. Exploration of a plant architecture database with the AMAPmod...

transgenic plants and biofuels are clearly emerging topics from 2007, soil carbon and climate are strikingly apparent as major topics through the whole 1999–2009 period. Soil carbon and climate are also topics of the 4 most-cited articles from 1999 to 2009. Other most-cited topics include agroindicators; alternative crop management, pest control and fertilisation; biodiversity; and pollutants and pesticides. We conclude that transgenic plants and biofuels are clearly emerging topics, whereas soil carbon and climate are the major mainstream topics of the last 10 years.

3 Journal Website Hits

We also studied topics by counting hits over 1999–2009 using the search engine of the journal website (Table 2). As topics refer to queries found in the whole article text, topics do not necessarily represent article topic. We ranked topics by decreasing order of emergence using the mean emergence date calculated by averaging dates weighted by hits. Figures 1 and 2 show examples of the evolution of topic hits with time. Four evolution types were identified: (1) A *plateau*; for

Table 2 Mean emergence date (MED) of topics in articles from the journal *Agronomy for Sustainable Development*. Topics were searched in all article text, and thus do not necessarily reflect the article topic. Topics that showed highest hits in 2009 are printed in bold. Hits in percent refer to the number of articles containing topics measured using the journal website search engine on October 22–23, 2009, versus total yearly published articles. Mean emergence date was calculated as the average of years weighed by hits: $\sum$(Hits.year)/$\sum$Hits, thus allowing to sort topics by order of emergence in the journal. Most recent topics have thus most recent date (see Fig. 1). For queries having several words, e.g. genetically modified, we used double quotes operators ("...") to retrieve only answers from words appearing together. AD: Anno Domini

TOPICS	MED AD	2009 %	2008 %	2007 %	2006 %	2005 %	2004 %	2003 %	2002 %	2001 %	2000 %	1999 %
Biofuels	2008.29	5.48	3.39	2.27	0	0	0	0	0	0	0	0
Genetically modified	2008.25	5.48	5.08	2.27	0	0	0	0	0	0	0	0
Conservation agriculture	2007.54	13.70	1.69	0	9.09	0	1.92	0	0	0	0	0
Urban agriculture	2007.22	2.74	1.69	0	0	0	1.92	0	0	0	0	0
Sociology	2007.11	10.96	0	2.27	0	1.59	3.85	1.27	0	0	0	0
Organic farming	2007.05	**38.36**	20.34	22.73	9.09	7.94	0	3.80	5.13	1.43	2.50	0
Carbon sequestration	2006.92	16.44	11.86	6.82	9.09	4.76	3.85	0	3.85	0	0	0
Phytoremediation	2006.87	1.37	6.78	2.27	0	3.17	0	1.27	0	0	0	0
Mulch	2006.62	21.92	28.81	15.91	15.15	3.17	9.62	1.27	5.13	1.43	1.25	1.79
Biodiversity	2006.55	**54.79**	25.42	25	12.12	12.7	7.69	5.06	6.41	5.71	2.50	5.36
Climate change	2006.54	31.51	18.64	9.09	9.09	6.35	9.62	2.53	5.13	2.86	1.25	1.79
Integrated pest management	2006.50	9.59	10.17	11.36	6.06	4.76	0	3.8	0	1.43	0	1.79
Allelopathy	2006.41	5.48	6.78	4.55	3.03	1.59	0	2.53	0	2.86	0	0
Soil erosion	2006.19	21.92	16.95	20.45	15.15	6.35	9.62	1.27	7.69	0	2.50	3.57
Crop rotation	2006.17	**49.32**	30.51	31.82	18.18	12.70	11.54	6.33	12.82	10	2.50	5.36
Transgenic	2006.15	13.70	13.56	13.64	0	4.76	1.92	6.33	0	0	1.25	5.36
Grass strips	2005.92	5.48	3.39	2.27	6.06	1.59	1.92	0	0	1.43	2.50	0
Biocontrol	2005.87	5.48	8.47	4.55	12.12	3.17	3.85	6.33	0	2.86	0	0
Cover crops	2005.76	17.81	16.95	15.91	6.06	9.52	7.69	3.80	14.1	2.86	1.25	1.79
Biological control	2005.70	10.96	10.17	18.18	12.12	7.94	7.69	7.59	0	7.14	2.50	0
No tillage	2005.59	**42.47**	35.59	34.09	18.18	20.63	28.85	18.99	20.51	5.71	3.75	8.93
Weed control	2005.35	27.40	27.12	18.18	24.24	20.63	19.23	13.92	8.97	14.29	2.50	7.14
Intercropping	2005.34	16.44	13.56	18.18	9.09	4.76	5.77	3.80	8.97	4.29	3.75	7.14
Irrigation	2005.21	**39.73**	42.37	43.18	39.39	39.68	51.92	37.97	32.05	28.57	0	0
Biological nitrogen fixation	2005.00	6.85	6.78	11.36	0	0	1.92	3.80	1.28	14.29	0	0
Agroforestry	2004.88	10.96	6.78	6.82	3.03	1.59	1.92	0	3.85	2.86	3.75	7.14
Decision support systems	2004.74	8.22	8.47	6.82	3.03	0	13.46	3.80	6.41	5.71	1.25	3.57
Precision agriculture	2004.06	4.11	3.39	2.27	0	1.59	9.62	1.27	6.41	2.86	0	3.57
Drought stress	2004.01	12.33	5.08	13.64	0	6.35	11.54	10.13	7.69	10	2.5	12.5

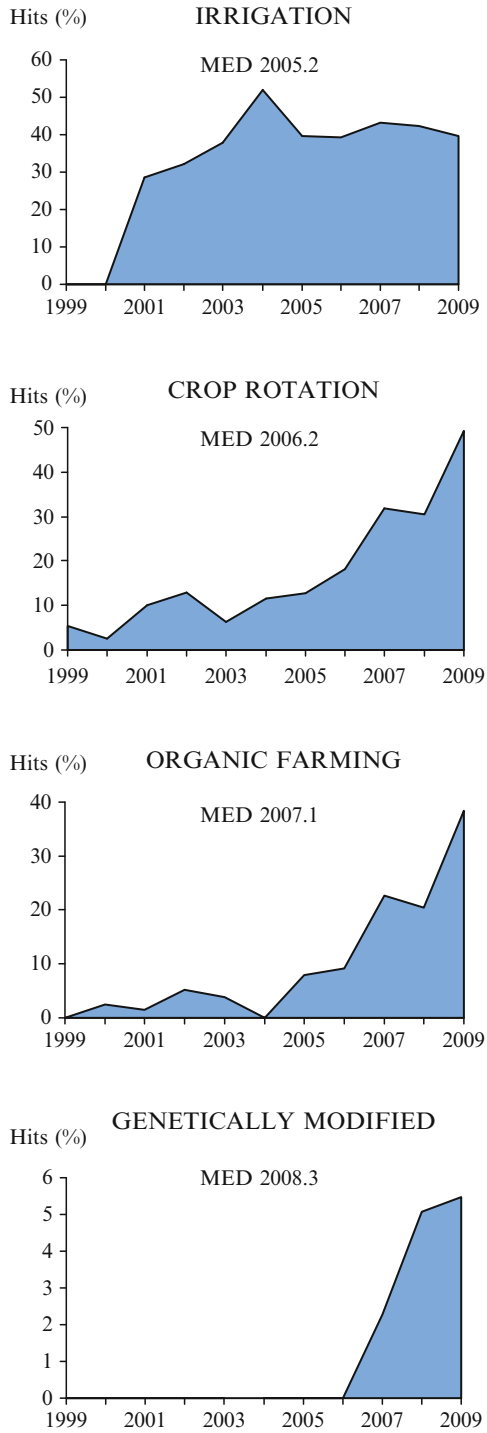

Fig. 1 Emergence of topics in article text from the journal *Agronomy for Sustainable Development*. Note the shift to the right of most emerging topics in the journal. MED refers to mean emergence date (see Table 3 caption). Hits in percent refer to the number of articles containing topics measured using the journal website search engine (see Table 3 caption)

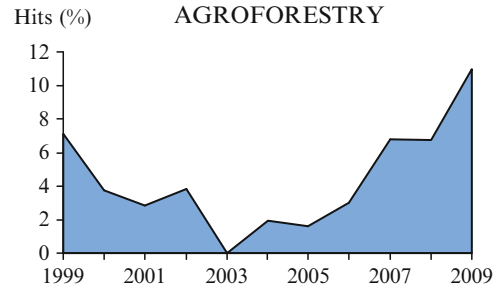

Fig. 2 Evolution of the topic Agroforestry in article text from the journal *Agronomy for Sustainable Development*. Note the decrease until 2003 followed by an increase, suggesting a renewed interest. Hits in percent refer to the number of articles containing topics measured u sing the journal website search engine (see Table 3 caption)

instance, 'irrigation' data shows a plateau with a mean emergence date of 2005.2. (2) A *regular increase* such as that for 'crop rotation' since 2003. 'Crop rotation' has thus a younger mean emergence date of 2006.2. (3) A *sharp increase* such as that for 'organic farming' after 2004. 'Organic farming' has thus an even younger mean emergence date of 2007.1. 'Genetically modified' exhibits the youngest mean emergence date of 2008.3. (4) A *dive-rise* such as that for 'agroforestry', showing a decrease from 1999 to 2003 followed by an increase from 2003 to 2009, suggesting a renewed interest in this topic.

Table 2 shows that according to the mean emergence date the 10 most emerging topics are biofuels, genetically modified, conservation agriculture, urban agriculture, sociology, organic farming, carbon sequestration, phytoremediation, mulch and biodiversity. This finding confirms biofuels and transgenic plants as emerging topics from citation data (Table 1). The predominance of soil carbon and climate is also apparent in most emerging topics.

Urban agriculture, ranking 3 in emergence, and sociology, ranking 4, are of special interest because those topics represent a clear change of thinking. Urban agriculture is challenging the common belief that crops should be cultivated in rural areas. Here, the idea of producing food close to consumers to decrease transportation pollution and costs is clearly elegant and apposite to fight climate change. The emergence of sociology can be explained both by increased interest from agronomists and by the shift in journal topics from 2004 (Lichtfouse et al., 2004). Table 2 also shows printed in bold the 5 top topics according

to hits in 2009. Here, biodiversity is found in 55% of articles, crop rotation 49%, no tillage 43%, irrigation 40% and organic farming 38%. These data from one single year cannot be interpreted in terms of evolution, but they probably represent the major concerns of authors in 2009.

To conclude, the 10 most emerging topics according to mean emergence date are biofuels, genetically modified organisms, conservation agriculture, urban agriculture, sociology, organic farming, carbon sequestration, phytoremediation, mulch and biodiversity. Those topics can be roughly classified into two streams of research aiming at a more sustainable agriculture. First, an *analytical stream* that develops technological innovations in plant science such as transgenic plants and biofuels. Second, a *systemic stream* that develops innovative farming practices such as organic farming and urban agriculture. Concepts of the systemic stream are given by Hill and MacRae (1996), Vandermeer et al. (1998), Papy (2001), Dalgaard et al. (2003), Lichtfouse et al. (2009b), and references therein.

4 Most-Downloaded Articles in 2009

Topics of interest for readers of the journal can be evaluated by topics of the most-downloaded articles on the journal website (Table 3). We observe three major categories of topics: (1) topics related to climate change, e.g. biofuels, drought and salt stress, biodiversity, and carbon sequestration in soils; (2) topics related to alternative management, e.g. agroindicators, fertilisation, beneficial microbes, intercropping and organic farming, and (3) topics related to food security, e.g. pollutants, alternative fertilisation and control, and organic farming. The predominance of topics such as carbon, climate, biodiversity, biofuels, pollutants, beneficial microbes, transgenic plants and organic farming agrees with our previous results.

5 Review of Selected 2009 Articles

Here, we review selected articles published in 2009 in the journal *Agronomy for Sustainable Development*. The fast emergence of new disciplines such as social and economic sciences in agronomic research is underlined by Wezel et al. (2009), Lamine and Bellon (2009), and Lichtfouse et al. (2009b). Wezel et al. (2009) reconstruct the historical rise of agroecology following the decline of industrial agriculture. It is noteworthy that these authors observe that the meaning of agroecology changes from one country to another. For instance, in Germany agroecology is mainly a science, whereas in France and in Brazil agroecology is also a green movement that is run by citizens.

5.1 Sociology

Sociology emergence in the journal *Agronomy for Sustainable Development* is highlighted well by Veldkamp et al. (2009), who designed an innovative Dutch project that takes into account the opinion of all stakeholders. The authors develop their ideas on the alternative principle that sustainable development requires a better balance of the triple P values – people, planet and prosperity. Another tantalising example of bridging sociology and agronomy is given by Fleming and Vanclay (2009), who analyse the impact of climate change on farmer discourses. The core issue is nicely underlined by a farmer interview: "What's sustainable? You've got to look at our world as we know it. We're not in a sustainable position at the moment. That's why I say 'what's sustainable?' – I don't know". The authors found that farmers have four main discourses that guide their decision: money, earth, human responsibility and questioning. Disclosing which discourses are at work in a specific farming system is clearly needed because, to put it simply, farmers will not follow scientists' advice if they are not convinced that this advice agrees with their discourses. De Bon et al. (2009) show the social benefits of urban agriculture in developing countries. Lamine and Bellon (2009) review the conversion from intensive to organic farming using viewpoints from both agronomists and social scientists. They found that most publications report conversion effects and motivations, whereas few publications study transitions and trajectories. To conclude, the use of sociological tools to study farming systems is bringing unexpected findings to designing sustainable agriculture.

Table 3 Top 30 most downloaded articles from the website of the journal *Agronomy for Sustainable Development*

Most-Downloaded Articles 2009*			
Year	PDF	Topics	First author - Title
2009	1975	Climate, drought stress	FAROOQ. Plant drought stress: effects, mechanisms and management.
2007	1421	Alternative fertilisation, beneficial microbes	KHAN. Role of phosphate-solubilizing microorganisms...
2009	1260	Agroecology	LICHTFOUSE. Agronomy for sustainable agriculture.
2003	970	Pollutants, toxicity	ROUT. Effect of metal toxicity on plant growth...
2006	931	Alternative fertilisation, beneficial microbes	HAFEEZ. Plant growth-promoting bacteria as biofertilizer
2009	786	Alternative management, intercropping	MALEZIEUX. Mixing plant species in cropping systems...
2007	647	Biofuel, climate, carbon	HILL. Environmental costs and benefits of transportation biofuel...
2001	641	Alternative fertilisation, beneficial microbes	IGUAL. Phosphate-solubilizing bacteria as inoculants...
2009	639	Soil, food security	LAL. Soils and food sufficiency.
2009	629	Alternative management, soil	LAL. Laws of sustainable soil management.
2009	628	Climate, biodiversity	FEEHAN. Climate change in Europe. 1. Impact on terrestrial...
2009	609	Climate, carbon, sequestration	BENBI. A 25-year record of carbon sequestration...
2001	522	Climate, carbon, salt stress	DORAI. Influence of electric conductivity management...
2009	497	Transgenic plants	DEVOS. Coexistence of genetically modified...
E-first	495	Organic farming, food security	LAIRON. Nutritional quality and safety of organic food.
2009	493	Organic farming, sociology	LAMINE. Conversion to organic farming...
2009	492	Agroindicators	BOCKSTALLER. Comparison of methods to assess the sustainability...
2009	473	Climate, agriculture	LAVALLE. Climate change in Europe. 3. Impact on agriculture...
2005	446	Climate, drought stress	SAMARAH. Effects of drought stress on growth and yield of barley.
2003	437	Climate, salt stress	BEN KHALED. Effet du stress salin en milieu hydroponique...
2009	436	Climate, soil	JONES. Climate change in Europe. 2. Impact on soil.
2008	427	Alternative control	DORDAS. Role of nutrients in controlling plant diseases...
2009	423	Agroecology	WEZEL. Agroecology as a science, a movement and a practice.
2007	422	Alternative fertilisation, beneficial microbes	GARG. Symbiotic nitrogen fixation in legume nodules...
2009	411	Alternative fertilisation, intercropping	ZUO. Iron and zinc biofortification strategies in dicot plants...
2003	392	Soil, carbon, roots	NGUYEN. Rhizodeposition of organic C by plants...
E-first	391	Alternative fertilisation, food security	SPIERTZ. Nitrogen, sustainable agriculture and food security.
E-first	366	Alternative management, urban agriculture	DE BON. Sustainable urban agriculture in developing countries.
2003	364	Pollutants, beneficial microbes	JONER. Phytoremediation of organic pollutants using mycorrhizal...
2003	341	Beneficial microbes, methods	GAMALERO. Methods for studying root colonization...

* Counts from January 1, 2009 to October 27, 2009. Year refers to year of publication. PDF refers to number of articles downloaded. PDF: portable document format. Full references are given in the reference list. E-first refers to articles online published but not yet issue published; those articles will be published in 2010

5.2 Transgenic Crops

Transgenic crops is typically an emerging topic that has escaped the science sphere to be now a major social, economical and political issue. As a consequence, transgenic crops is therefore a well-suited research topic for agronomists that use sociology and economics. Like all major scientific breakthroughs, e.g. nitro-glycerine and nuclear energy, there are many arguments in favour of genetically modified organisms and many arguments against their use. Devos et al. (2009) analyse policies ruling the coexistence of transgenic and non-transgenic maize in European nations. They found that current isolation distances are excessive, difficult to implement, and not economically viable. Very interestingly, they conclude that 'other scientific issues must be at play'. Such an unknown may indeed be disclosed by the discourse approach of Fleming and Vanclay (2009).

Graef (2009) reviews possible adverse effects of introducing transgenic oilseed rape into Europe. He found that possible adverse effects to be monitored are persistence and spread of herbicide-tolerant oilseed rape, transfer of tolerance to wild relatives, development of herbicide tolerance of weeds, decrease in biodiversity, herbicide pollution, and adverse impact on field organisms and biogeochemical cycles. Hart et al. (2009) demonstrate for the first time the persistence of transgenic crop DNA residues within a soil food web. They found the transgene for glyphosate tolerance in soil arthropods, nematodes and earthworms from a transgenic corn field. The potential of transgene flow from transgenic crops' wild relatives is addressed by Loureiro et al. (2009), who found that hybrids of wheat and its wild relative *Aegilops biuncialis* are formed easily with 9–75% hybridisation rates. To conclude, transgenic crops are highly innovative but show both benefits and drawbacks that need to be carefully studied using various disciplines.

5.3 Climate Change

Climate change effects in Europe are reviewed in three reprints from an European report. First, Feehan et al. (2009) analyse major effects on terrestrial ecosystems and biodiversity. Key trends include northward and uphill shift of plants, birds and mammals; and earlier seasonal events such as flowering, bird nesting and frog spawning. Second, Jones et al. (2009) report major effects of climate change on soils. Key observations include a decrease in soil C over the last 25 years, a higher risk of erosion and projected increases in CO_2 release in the atmosphere. It should be noted that there is much less evidence from soil studies because soil research is usually more difficult and needs more time - and funds - because most soil changes occur very slowly. Here, the major issue is that once adverse changes have occurred, e.g. soil carbon depletion, they cannot be healed fast. Therefore, management options that favour carbon sequestration and soil preservation should be applied (Doumbia et al., 2009; Benbi and Brar, 2009; Hazarika et al., 2009; Pleguezuelo et al., 2009; Tuttobene et al., 2009). Principles for sustainable soil management are given by Lal (2009c, d).

Third, Lavalle et al. (2009) review major effects of climate change on agriculture and forestry. Key trends include the shortening of the growing season in the south with higher risk of frost damage; flowering and maturity of crops occurring now about 2–3 weeks earlier; a higher yield variability due to extreme climate events such as the 2003 summer heat and the 2007 spring drought; a high increase of 50–70% in the water demand in Mediterranean areas; a faster forest growth; and a higher risk of forest fires. Tingem et al. (2009) simulate future crop yield in response to climate change in Cameroon. They found that developing later-maturing cultivars could greatly increase yields of maize, sorghum and bambara groundnut. Farooq et al. (2009) review effects of drought stress on plants. They also propose several solutions to counteract drought stress. To conclude, there are many scientific proofs of the effects of climate change on terrestrial ecosystems. Adverse, long-term effects such as soil carbon loss and erosion should be paid particular attention by agronomists.

5.4 Biodiversity

Biodiversity loss due to adverse effects of industrial agriculture is a major threat to sustainable agriculture. A well-known example is the decrease in bees. Indeed, bees and other insects carry pollen and thus are essential to the reproduction of some crops such as blueberries. Higher biodiversity is also a means to control crop