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STRATEGIE INTEGRATE PER AFFRONTARE LE SFIDE CLIMATICHE E AGRONOMICHE NELLA GESTIONE DEI SISTEMI AGROALIMENTARI

INTEGRATED STRATEGIES FOR AGRO-ECOSYSTEM MANAGEMENT TO ADDRESS CLIMATE CHANGE CHALLENGES

MILANO
12 - 14 SETTEMBRE 2017

A CURA DI
FRANCESCA VENTURA
GIOVANNA SEDDAIU
GABRIELE COLA

DIPARTIMENTO DI SCIENZE AGRARIE - UNIVERSITÀ DI BOLOGNA

AIAM SIA MILANO 2017

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Strategie integrate per affrontare le sfide climatiche e agronomiche nella gestione dei sistemi agroalimentari

Integrated strategies for agro-ecosystem management to address climate change challenges

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Giovanna Seddaiu
Gabriele Cola

Dipartimento di Scienze Agrarie
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INDICE

SESSION 1 "AGRO-ENVIRONMENTAL INNOVATIONS TO SUPPORT THE AGRICULTURAL POLICIES"

ORALI

IS IT POSSIBLE TO COMBINE CONTRASTING AGRO-ENVIRONMENTAL OBJECTIVES? THE DILEMMA BETWEEN INCREASING SOIL ORGANIC CARBON AND MITIGATING METHANE EMISSIONS WITH RICE STRAW MANAGEMENT? **1**
Chiara Bertora, Maria Alexandra Cucu, Cristina Lerda, Matteo Peyron, Daniel Said-Pullicino, Roberta Gorra, Laura Bardi, Luisella Celi, Carlo Grignani, Dario Sacco

INNOVATION PARTNERSHIP: INTEGRATED STRATEGIES TO ADDRESS AGRO-ENVIRONMENTAL-CLIMATE CHALLENGES IN THE RDPS 2014-2020 **4**
Maria Valentina Lasorella, Federica Cisilino

SERVICES FOR AGRICULTURE FROM COPERNICUS SPACE COMPONENT. THE SENSAGRI PROJECT **6**
Michele Rinaldi, Angelo Pio De Santis, Salvatore Antonio Colecchia, Carmela Riefolo, Alessandro Vittorio Vonella, Anna Balenzano, Sergio Ruggieri

IMPACT OF AGRO-ENVIRONMENTAL MEASURES IN THE TUSCANY REGION. GEOGRAPHIC MULTI-CRITERIA ANALYSIS **11**
Emanuele Gabbrielli

EFFECT OF ENVIRONMENTAL STRESS AND AGRONOMIC MANAGEMENT ON MORPHOLOGICAL, PHYSIOLOGICAL AND QUALITY TRAITS OF VEGETABLES **16**
Angelica Galieni

EFFECT OF HIGH PLANT DENSITY ON YIELD AND MAIZE KERNEL QUALITY **19**
Giulio Testa, Massimo Blandino, Amedeo Reyneri

POSTER

AGRO-ENVIRONMENTAL-CLIMATE PAYMENT: A KEY MEASURE TO ADDRESS THE CLIMATIC AND AGRONOMIC CHALLENGES IN THE NEW RDPS **23**
Maria Valentina Lasorella, Danilo Marandola, Antonio Papaleo, Alessandro Monteleone

FIRST SUGGESTIONS FOR AN UPGRADED COMPARATIVE EVALUATION OF THE MODIFICATION OF FOUR ALPINE VALLEYS DURING THE LAST CENTURY **26**
Vittorio Ingegnoli, Stefano Bocchi

SESSIONE 2 " STRATEGIE DI PIANIFICAZIONE, GESTIONE E MONITORAGGIO DELL’AGROECOSISTEMA E DELLE FILIERE PRODUTTIVE"

ORALI

MONITORING EROSION IN SLOPING VINEYARDS: EFFECTIVENESS OF GRASS COVERING IN DIFFERENT PERIODS **30**
Giorgia Bagagiolo, Danilo Rabino, Marcella Biddoccu, Eugenio Cavallo

SOIL GHGS EMISSIONS IN A VEGETABLE CROP ROTATION UNDER INTEGRATED, ORGANIC AND CONSERVATION ORGANIC MANAGEMENT **34**
Iride Volpi, Jonatha Trabucco, Daniele Antichi, Christian Frasconi, Cristiano Tozzini, Simona Bosco

A SURVEY ON REGIONAL AGROMETEOROLOGICAL NETWORKS IN ITALY **38**
Flora De Natale, Carmen Beltrano, Stanislao Esposito, Barbara Parisse

A DEGREE DAY MODEL FOR DURUM WHEAT (TRITICUM DURUM, DESF.) ACROSS THE ITALIAN PENINSULA **43**
Arianna Di Paola, Francesca Ventura, Marco Vignudelli, Maurizio Severini

CLIMATE CHANGE IMPACTS ON THE ITALIAN WINE SECTOR: CHALLENGES AND PROSPECTS FOR SANGIOVESE PRODUCTION IN THE ROMAGNA AREA **48**
Eva Merloni, Giulio Malorgio, Luca Camanzi, Luca Mulazzani, Gabriele Antolini, Giovanni Nigro

ENERGY YIELD OF BIOMASS IN SORGHUM GROWN UNDER DEFICIT IRRIGATION **52**
Pasquale Campi, Alejandra Navarro, Francesca Modugno, Marcello Mastrorilli

SPATIAL ANALYSES OF THREE YEARS OF KAMUT® KHORASAN PRODUCTION: YIELD AND GRAIN QUALITY PARAMETERS **55**
Giovanni Dinelli, Alessandro Di Loreto, Valeria Bregola, Ilaria Marotti, Rocco Enrico Sferrazza, Sara Bosi

APPLICATION OF SOD SEEDING TECHNIQUES TO TEMPERATE RICE IN ITALY **58**
Eleonora Cordero, Barbara Moretti, Luisella Celi, Cristina Lerda, Gianluca Beltarre, Daniele Tenni, Marco Romani, Dario Sacco

AN INDICATOR OF CROPPING SYSTEMS ECONOMIC ROBUSTNESS **62**
Alicia Ayerdi Gotor, Elisa Marraccini, Olivier Scheurer, Christine Leclercq

SPATIAL YIELD GAP ANALYSIS ON SPRING BARLEY IN SCOTLAND **66**
Davide Cammarano

CROPPING SYSTEMS FOR CULTIVATION OF VERY EARLY MATURITY MAIZE HYBRIDS **68**
Massimo Blandino, Giulio Testa, Diego Gallinotti, Amedeo Reyneri

ORGANIC RICE PRODUCTION SYSTEMS IN ITALY: A PRELIMINARY ENVIRONMENTAL ASSESSMENT **73**
Jacopo Bacenetti, Francesca Orlando, Stefano Bocchi

CEREAL QUALITY NETWORK PROJECT PLUS - RQC-MAIZE: AIMS, RESULTS AND FUTURE PERSPECTIVES. **75**
Carlotta Balconi, Sabrina Locatelli, Amedeo Reyneri, Paola Battilani, Massimo Blandino, Paola Giorni, Chiara Lanzanova

RECOGNIZING POTENTIAL AGROFORESTRY AREAS: THE APULIA CASE STUDY **80**
Anna Rita Bernadette Cammerino, Giuliana Zita, Angela Libutti, Massimo Monteleone

WHAT DATA ARE AVAILABLE TO DESCRIBE CROPPING SYSTEMS AT THE REGIONAL LEVEL? **83**
Davide Rizzo, Elisa Marraccini, Giuliano Vitali, Philippe Martin

A METHODOLOGY FOR PROBABILISTIC ASSESSMENT OF ADAPTATION STRATEGIES: A CASE STUDY IN THE MEDITERRANEAN AREA **86**
R. Ferrise, M. Ruiz-Ramos, A. Rodríguez, I. J. Lorite, M. Bindi, T.R. Carter, S. Fronzek, T. Palosuo, N. Pirttioja, P. Baranowski, S. Buis, D. Cammarano, Y. Chen, B. Dumont, F. Ewert0, T. Gaiser, P. Hlavinka,, H. Hoffmann0, J.G. Höhn, F. Jurecka,, K.C. Kersebaum, J. Krzyszczak, M. Lana, A. Mechiche-Alami, J. Minet, M. Montesino, C. Nendel,J.R. Porter, F. Ruget, M. A. Semenov, Z. Steinmetz, P. Stratonovitch, I. Supit, F. Tao, M. Trnka,, A. de Wit and R. P. Rötter

THE ROLE OF SOIL ORGANIC MATTER ON GREENHOUSE GAS EMISSIONS FROM DIFFERENT FERTILIZERS **89**
Leonardo Verdi, Marco Napoli, Marco Mancini, Mirjana Ljubojević, Anna Dalla Marta, Simone Orlandini

REGULATORY PROBLEMS IN DEFINITION OF CONTAMINATED SOILS: THE AGRONOMIC APPROACH **92**
Massimo Fagnano, Paola Adamo, Antonio Di Gennaro, Fabio Terribile

EFFECT OF ORGANIC CONSERVATION AGRICULTURE ON N BALANCE: FIRST RESULTS OF THE SMOCA PROJECT **95**
Giacomo Tosti, Daniele Antichi, Paolo Benincasa, Simona Bosco, Christian Frasconi, Luigi Manfrini, Andrea Onofri, Marcello Guiducci

TRICHODERMA INOCULATION CAN IMPROVE YIELD AND QUALITY OF LEAFY VEGETABLES UNDER DIFFERENT N AVAILABILITY CONDITIONS **99**
Nunzio Fiorentino, Youssef Rouphael, Armando De Rosa, Eugenio Cozzolino, Vincenzo Cenvinzo, Maria Giordano, Laura Gioia, Sheridan Woo, Massimo Fagnano

POSTER

PHENOLOGICAL LONG-TERM TREND IN MAIZE IN RESPONSE TO TEMPERATURE CHANGES IN NORTHEAST ITALY **102**
Antonio Berti, Alessandra Bonammano, Carmelo Maucieri, Maurizio Borin

DATAMETEONOW REALTIME STORM TRACK VALIDATION PLATFORM **105**
Michele De Rosa, Gabriele Ghibaudo, Cristian Rendina, Stefania Roà

SNOW AS A WATER RESOURCE AND ITS CLIMATOLOGY (NASA-ESA DATABASE) **110**
Andrea Spisni, Valentina Pavan, Martina Collina, Valentina Ciriello, Vittorio Marletto

BIVARIATE ANALYSIS OF THE DURATION AND SEVERITY OF WATER STRESS IN OLIVE **113**
Lorenzo Vergni, Bruno Di Lena, Enrico Maria Lodolini

A PRELIMINARY STUDY ON THE PHYSIOLOGY OF SOME SANGIOVESE CLONES, IN RELATION TO THE ROOTSTOCK AND THE ENVIRONMENTAL CONDITIONS **116**
Paolo Valentini, Rita Perria

INFLUENCE OF THERMAL GRADIENT ON THE DYNAMICS OF GROWTH AND DEVELOPMENT OF EMMER IN GARFAGNANA **122**
Anna Dalla Marta, Marco Mancini, Stefano Cecchi, Giada Brandani, Gianni Licheri, Simone Orlandini

APPLICATION OF THE DAYCENT BIOGEOCHEMICAL MODEL TO ASSESS GHG-EMISSIONS FROM AN SWISS GRASSLAND **125**
L. Brilli, K. Fuchs, L. Merbold, C. Dibari, G. Argenti, R. Ferrise, M. Moriondo, S. Costafreda-Aumedes, M. Bindi

EFFECT OF AIR TEMPERATURE ON OLIVE PHENOLOGY: PRELIMINARY RESULTS OBSERVED IN VAL D’ORCIA **128**
Ada Baldi, Martina Petralli, Stefano Cecchi, Carolina Fabbri, Giada Brandani, Marco Mancini, Simone Orlandini

COMPARISON BETWEEN OLD AND MODERN WHEAT VARIETIES IN THE CONTEXT OF CLIMATE CHANGE: PRELIMINARY RESULTS FOR A STUDY IN TUSCANY **132**
Gloria Padovan, Roberto Ferrise, Marco Mancini, Camilla Dibari, Lisetta Ghiselli, Marco Bindi

POTENTIAL DISTRIBUTION OF XYLELLA FASTIDIOSA IN MARCHE REGION **136**
Leonesi Stefano, Nardi Sandro, Danilo Tognetti

PHENOLOGICAL MODELLING OF SHRUBS FOR SUPPORTING THE HYDROLOGICAL ASSESSMENT WITHIN THE RAINBO PROJECT **139**
Antonio Volta, Giulia Villani, Vittorio Marletto, Lucio Botarelli, Federico Magnani

STILNOVO: SUSTAINABILITY AND INNOVATION TECHNOLOGY FOR DAIRY SHEEP PRODUCTION, AN INNOVATION TRANSFER PROJECT IN TUSCANY **142**
Alberto Mantino, Iride Volpi, Simona Bosco, Giorgio Ragaglini, Enrico Bonari, Alice Cappucci, Eleonora Bulleri, Arianna Buccioni, Carlo Viti, Fabiola Giannerini, Fabio Villani, Carlo Santarelli, Marcello Mele

F. Ventura, G. Seddaiu, G. Cola (a cura di), Atti del XX Convegno AIAM e XLVI Convegno SIA.
Milano, 12-14 settembre 2017.
DOI 10.6092/unibo/amsacta/5692

SHORT-TERM EFFECT OF COVER-CROPS ON SOIL BIOPHYSICAL PROPERTIES IN A FIG ORCHARD **145**
Roberta Rossi, Francesco Cardone, Giuseppe Landi, Mariana Amato

EVALUATION OF CHIA (SALVIA HISPANICA L.) AS A FORAGE CROP: EFFECTS OF SOWING DENSITY ON YIELD AND QUALITY AND RELATIONSHIPS BETWEEN QUALITY AND CROP BIOMETRY **149**
Roberta Rossi, Rocco Bochicchio, Rosanna Labella, Mariana Amato

RISPOSTA FOTOSINTETICA A LIVELLO FOGLIARE DEL SORGO DA BIOMASSA ALL’AUMENTO DELLA CONCENTRAZIONE DI CO2 **154**
Michele Rinaldi, Carmen Maddaluno, Pasquale Garofalo, Laura D’Andrea

PHYSIOLOGICAL RESPONSES OF PROCESSING TOMATO SEEDLINGS INOCULATED WITH ARBUSCULAR MYCORRHIZAL FUNGI DURING DROUGHT STRESS **156**
Federica Caradonia, Domenico Ronga, Leonardo Setti, Luca Laviano, Enrico Francia, Caterina Morcia, Roberta Ghizzoni, Franz-W. Badeck, Fulvia Rizza, Valeria Terzi

AGRONOMIC TRAITS ASSOCIATED TO YIELD IN OLD AND MODERN PROCESSING TOMATO CULTIVARS **160**
Domenico Ronga, Federica Caradonia, Fulvia Rizza, Franz-W. Badeck, Enrico Francia, Marianna Pasquariello, Giuseppe Montevecchi, Luca Laviano, Justyna Milc, Nicola Pecchioni

MYCOTOXINS MONITORING IN MAIZE AGRONOMIC TRIALS – VARIETALS NETWORK. **164**
Chiara Lanzanova, Francesca Fumagalli, Stefania Mascheroni, Fabrizio Facchinetti, Sabrina Locatelli

OCCURRENCE OF MYCOTOXINS IN ITALIAN MAIZE DURING 2014-2016 **167**
Sabrina Locatelli, Francesca Fumagalli, Stefania Mascheroni, Fabrizio Facchinetti, Chiara Lanzanova

BIOREGIONE: HOW TO PROMOTE SUSTAINABLE LOCAL DEVELOPMENT BY THE TERRITORIAL ORGANIZATION OF SUPPLY AND DEMAND OF FOOD **170**
Stefano Bocchi e Roberto Spigarolo

DIGITAL EARTH: A USE CASE IN URBAN AGRICULTURE GEOSPATIAL DATASET CREATION **173**
Flavio Lupia, G. Pulighe, F. Giarè

EFFECT OF CLIMATE AND OF AGRICULTURAL PRACTICE ON THE VEGETO-PRODUCTIVE RESPONSE OF ANCIENT WHEAT VARIETIES: PRELIMINARY RESULTS **178**
Marco Napoli, Marco Mancini, Giada Brandani, Martina Petralli, Leonardo Verdi, Simone Orlandini, Anna Dalla Marta

F. Ventura, G. Seddaiu, G. Cola (a cura di), Atti del XX Convegno AIAM e XLVI Convegno SIA.
Milano, 12-14 settembre 2017.
DOI 10.6092/unibo/amsacta/5692

AGRONOMIC AND ECONOMIC EVALUATION OF TWO AGRICULTURAL SYSTEMS: CONVENTIONAL TILLAGE AND NO-TILLAGE **181**
Vincenzo Tabaglio, Paolo Caprioli, Roberta Boselli, Andrea Fiorini, Cristina Ganimede, Giovanni Lazzari, Dora Inés Melo Ortiz, Stefano Santelli, Romano Demaldè

N2O EMISSIONS SAVING BY THE REDUCTION OF N-FERTILIZATION IN DURUM WHEAT IN TUSCANY: A SPATIALLY EXPLICIT ASSESSMENT BASED ON DNDC MODEL **185**
Giorgio Ragaglini, Ricardo Villani, Federico Triana, Iride Volpi, Nicoletta Nassi o Di Nasso, Enrico Bonari, Simona Bosco

THE LIFE CYCLE ASSESSMENT OF DURUM WHEAT YIELD IN CONTRASTING MANAGEMENT SYSTEMS IN MEDITERRANEAN ENVIRONMENT **189**
Sergio Saia, Giulio Mario Cappelletti, Carlo Russo, Giuseppe Martino Nicoletti, Michele Carlo Lostorto, Pasquale De Vita

EVALUATION OF GRASS SPECIES FOR ASSISTED PHYTOREMEDIATION OF INDUSTRIAL SOILS AND SOIL WASHING SLUDGES **192**
Donato Visconti, Nunzio Fiorentino, Vincenzo Cenvinzo, Armando De Rosa, Eugenio Cozzolino, Paola Adamo, Massimo Fagnano

BIOAGRONOMIC PERFORMANCE OF SICILIAN ORGANIC DURUM WHEAT “TIMILIA” **195**
Paolo Guarnaccia, Giorgio Testa, Paolo Caruso, Carlo Amato, Salvatore Luciano Cosentino, Umberto Anastasi

RISK ASSESSMENT OF CONTAMINATION OF AGRICULTURAL PRODUCTION **198**
Luigi Giuseppe Duri, Eugenio Cozzolino, Vincenzo Leone, Ida Di Mola, Lucia Ottaiano, Nunzio Fiorentino, Mauro Mori, Massimo Fagnano

ENERGY CONTENT AND ENERGY RETURN ON INVESTMENT OF DIVERSE PERENNIAL GRASSES IN SEMI-ARID MEDITERRANEAN ENVIRONMENT **203**
Danilo Scordia, Giorgio Testa, Venera Copani, Silvio Calcagno, Andrea Corinzia, Santo Virgillito, Sebastiano Scandurra, Cristina Patanè, Salvatore L. Cosentino

BIOMASS YIELD AND WATER USE EFFICIENCY OF DIVERSE PERENNIAL GRASSES IN SEMI-ARID MEDITERRANEAN ENVIRONMENT **200**
Danilo Scordia, Giorgio Testa, Venera Copani, Giovanni Scalici, Sarah Sidella, Giancarlo Patanè, Cristina Patanè, Salvatore L. Cosentino

YIELD OF NEW BURLEY TOBACCO VARIETIES IN DIFFERENT AREAS OF CAMPANIA REGION **205**
Eugenio Cozzolino, Francesco Raimo, Massimo Abet, Mariarosaria Sicignano, Giovanni Scognamiglio, Antonio Mosè, Tommaso Enotrio, Luisa del Piano

THIRTY YEARS OF SOYBEAN CULTIVATION IN NORTH-EAST ITALY: YIELD TREND **208**
Danuso F., Patat I., Signor M. , Valdevit F. , Ceccon P., Baldini M.

F. Ventura, G. Seddaiu, G. Cola (a cura di), Atti del XX Convegno AIAM e XLVI Convegno SIA.
Milano, 12-14 settembre 2017.
DOI 10.6092/unibo/amsacta/5692

MODELLING AUTUMN PRODUCTION OF MEDITERRANEAN PASTURES UNDER VARIABLE RAINFALL REGIMES **211**
Pulina A., Mula L., Seddaiu G., Roggero P.P.

WHICH PROSPECTS FOR LIGNOCELLULOSIC CROPS FOR BIOGAS IN ITALY? **214**
Federico Dragoni, Ricardo Villani, Alberto Mantino, Enrico Bonari, Giorgio Ragaglini

CHARACTERIZING CROPPING SYSTEMS AFFECTED BY FLUORIDE CONTAMINATION IN EASTERN AFRICAN COUNTRIES **219**
Rizzu M., Akuno M.H., Roggero, P.P., Wambu E., Mtei K., Seddaiu G.

LONG TERM EVALUATION OF DURUM WHEAT CROPPING SYSTEMS **222**
Salvatore Luciano Cosentino, Paolo Guarnaccia, Venera Copani, Danilo Scordia, Santo Virgillito, Sebastiano Scandurra, Giorgio Testa

MULTI-METHODOLOGY ANALYSIS OF GLUTEN QUALITY IN OLD AND MODERN DURUM WHEAT GENOTYPES **225**
Michele A. De Santis, Marcella M. Giuliani, Luigia Giuzio, Zina Flagella

OPPORTUNITIES AND CHALLENGES OF CLIMATE CHANGE ADAPTATION ACROSS EUROPE: A CASE STUDY ANALYSIS FROM THE MACSUR KNOWLEDGE HUB **228**
Roggero P.P., Bellocchi G., Bojar W., Cammarano D., Daalgard T., Dono G., Lehtonen H., Øygarden L., Schönhart M., Seddaiu G.

EVALUATION OF HEMP GENOTYPES FOR A DUAL PURPOSE PRODUCTION IN SEMI-ARID MEDITERRANEAN ENVIRONMENT **231**
Paolo Guarnaccia, Giorgio Testa, Silvio Calcagno, Giancarlo Patanè, Danilo Scordia, Salvatore Luciano Cosentino

SOIL DNA METABARCODING: EVALUATING THE EFFICIENCY OF MULTIPLEX PRIMER SETS IN RECOVERING THE SOIL INVERTEBRATE’S COMMUNITY AS SOIL QUALITY INDICATORS **233**
Sumer Alali, Paola Cremonesi, Bessem Chouaia, Valeria Mereghetti, Flavia Pizzi, Matteo Montagna, Stefano Bocchi

DOES SALT STRESS INCREASE WEEDS INVASIVENESS? **237**
Valerio Cirillo, Emilio Di Stasio, Giuseppe Zanin, Albino Maggio

SESSIONE 3 “SOLUZIONI OPERATIVE E NUOVE TECNOLOGIE PER UN USO OTTIMALE DELLE RISORSE”

ORALI

WATER STRESS DETECTION IN SITI4FARMER, THE AGRICULTURE NETWORK **241**
Simone G. Parisi

A NEW INTERACTIVE APPROACH AT TAILORED AGRO WEATHER NEWS **244**
Ivano Valmori, Gabriele Ghibaudo, Cristian Rendina, Stefania Roà

F. Ventura, G. Seddaiu, G. Cola (a cura di), Atti del XX Convegno AIAM e XLVI Convegno SIA.
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ADAPTATION OF IRRIGATED AND RAIN-FED ITALIAN CROP SYSTEMS TO FUTURE CLIMATE: ASSESSING THE POTENTIAL OF INTRA-SPECIFIC BIODIVERSITY **247**
Francesca De Lorenzi, Eugenia Monaco, Maria Riccardi, Silvia Maria Alfieri, Michele Rinaldi, Antonello Bonfante, Angelo Basile, Ileana Mula, Massimo Menenti

MODELIZATION OF MICROMETEOROLOGICAL AND PHYSIOLOGICAL PARAMETERS IN THE PIEDMONTESE VINEYARD ECOSYSTEM **250**
Claudio Cassardo, Valentina Andreoli, Federico Spanna

EFFECTS OF PGPR INOCULATION ON ROOT GROWTH AND NITROGEN ACCUMULATION OF COMMON WHEAT IN CONTROLLED CONDITIONS AND IN OPEN FIELDS **254**
Cristian Dal Cortivo, Barion Giuseppe, Giovanna Visioli, Giuliano Mosca, Teofilo Vamerali

WHEAT SPATIAL VARIATION BASED ON SPECTRAL VEGETATION INDICES AND SOIL ANALYSIS **259**
Lorenzo Barbanti, Josep Adroher, Júnior Melo Damian, Nicola Di Virgilio, Gloria Falsone, Matteo Zucchelli, Roberta Martelli

ASSESSMENT OF CROP RESIDUES MANAGEMENT AS STRATEGY OF ADAPTATION AND MITIGATION TO CLIMATE CHANGE **263**
Domenico Ventrella, Luisa Giglio, Marco Bindi, Bruno Basso, Umberto Bonciarelli, Anna Dallamarta, Francesco Danuso, Luca Doro, Roberto Ferrise, Francesco Fornaro, Pasquale Garofalo, Fabrizio Ginaldi, Ileana Iocola, Paolo Merante, Laura Mula, Andrea Onofri, Simone Orlandini, Massimiliano Pasqui, Rodica Tomozeiu, Giulia Villani, Alessandro Vittorio Vonella, Pier Paolo Roggero

SENTINEL-2 AS NEW TOOL FOR WATER AND NITROGEN MANAGEMENT: THE MAIZE AND TOMATO CASE STUDY **266**
Alessandra Fracasso, Karolina Sakowska, Michele Colauzzi, Massimo Vincini, Stefano Amaducci

COUPLING REMOTE SENSING AND MODELING APPROACH FOR OPTIMIZING INPUT MANAGEMENT IN A TYPICAL MEDITERRANEAN CROPPING SYSTEM **269**
Claudia Di Bene, Silvia Vanino, Pasquale Nino, Melania Migliore, Enrico Anzano, Roberta Farina, Bruno Pennelli, Stefano Fabiani, Guido D'Urso, Alessandro Marchetti, Chiara Piccini, Carlo De Michele, Stefano Canali, Fabio Tittarelli, Rosario Napoli

BIOGAS AND SEQUENTIAL CROPPING: A SUSTAINABLE DEVELOPMENT IN AGRICULTURE **272**
Guido Bezzi, Paolo Mantovi, Lorella Rossi, Ernesto Folli

NITROGEN FERTILIZER REPLACEMENT VALUE AND RESIDUAL EFFECTS OF UNDIGESTED SLURRY AND DIGESTATES APPLIED TO SILAGE MAIZE **276**
Daniele Cavalli, Giovanni Cabassi, Lamberto Borrelli, Luigi Degano, Luca Bechini, Pietro Marino Gallina

APPLICATION OF BIOSTIMULANTS TO IMPROVE THE YIELD AND QUALITY OF CROPS **281**
Roberta Bulgari, Giacomo Cocetta, Giulia Franzoni, Livia Martinetti, Antonio Ferrante

POSTER

OPERATIONALIZING THE INCREASE OF WATER USE EFFICIENCY AND RESILIENCE IN IRRIGATION (OPERA) **283**
Filiberto Altobelli, Marius Heinen, Claire Jacobs, Jochen Froebrich, André Chanzy, Dominique Courault, Willem De Clercq, Sara Muñoz Vallés, Antonio Díaz Espejo, Karolina Smarzynska, Wieslawa Kasperska, Leszek Labedzki, Anna Dalla Marta

ARTIFICIAL WATER BASIN IN EMILIA ROMAGNA GEOGRAPHICAL DATABASE’S UPDATE **286**
Luca Tosi, Giulio Coffa, Andrea Spisni, Luca D. Sapia, Valentina Ciriello, Vittorio Marletto

EVALUATION OF IRRIGATIONAL REQUIREMENTS OF FRUIT-GROWING HILLY AREAS USING CONSORTIUM ARTIFICIAL BASINS’ WATER **289**
Luca Tosi, Luca D. Sapia, Andrea Spisni, Gabriele Minardi, Matteo Verlicchi, Valentina Ciriello, Vittorio Marletto

DECISION SUPPORT SYSTEMS (DSS) TO WATER RESOURCES MANAGEMENT AND PLANNING: IRRINET-IRRIFRAME AS CASE STUDY IN EMILIA-ROMAGNA REGION **292**
Maria Valentina Lasorella, Roberto Genovesi, Gioele Chiari, Carlo Malavolta

AGROMETEOROLOGY IN THE APPLICATION OF NITRATES DIRECTIVE **295**
Gabriele Antolini, Monica Bassanino, Alberto Bonini, Federica Checchetto, Lorenzo Craveri, Irene Delillo, Francesco Domenichini, William Pratizzoli, Carlo Riparbelli

DEVELOPMENT AND ASSESSMENT OF OLIVE ORCHARD GROWTH MODEL **301**
M. Moriondo, L. Brilli, L. Leolini, C. Dibari, R. Tognetti, B. Rapi, P. Battista, G. Caruso, R. Gucci, G. Argenti, S. Costafreda-Aumedes, M. Bindi

A COMPARATIVE STUDY ABOUT THE EFFECT OF BIOCHAR AND HYDROCHAR ON THE WATER BALANCE IN SANDY SOILS **305**
Antonio Volta, Giulia Villani, Gabriele Antolini, Fausto Tomei, William Pratizzoli, Giuseppe Gherardi, Vittorio Marletto, Lucio Botarelli

PREDICTION OF WHEAT YIELD USING RELATIONSHIP BETWEEN VEGETATION INDICES AND PLANT N AND BIOMASS AT HEADING **308**
Pasquale De Vita, Sergio Saia, Salvatore Antonio Colecchia, Ivano Pecorella, Costanza Fiorentino, Bruno Basso

THE NEW SEED-APPLIED FUNGICIDE SEDAXANE IMPROVES DROUGHT TOLERANCE IN EARLY GROWTH STAGES OF MAIZE **311**
Manuel Ferrari, Cristian Dal Cortivo, Giuseppe Barion, Teofilo Vamerali

A BENZIMIDAZOLE PROTON PUMP INHIBITOR IN ANIMALS INCREASES GROWTH AND TOLERANCE TO SALT STRESS IN TOMATO **313**
Michael J. Van Oosten, Silvia Silletti, Gianpiero Guida, Valerio Cirillo, Emilio Di Stasio, Petronia Carillo, Pasqualina Woodrow, Albino Maggio and Giampaolo Raimondi

OLIVE-MILL WASTEWATER AND ORGANO-MINERAL FERTLIZERS APPLICATION FOR THE CONTROL OF PARASITIC WEED PHELIPANCHE RAMOSA (L) POMEL IN TOMATO CROP **316**
Grazia Disciglio, Francesco Lops, Laura Frabboni, Giuseppe Gatta, Emanuele Tarantino

ASSESSING PLANT DENSITY OF ABANDONED OLIVE GROVES: PRELIMINARY RESULTS FROM MONTALBANO CASE STUDY **318**
Camilla Dibari, Marco Moriondo, Sergi Costafreda-Aumedes, Lorenzo Brilli, Andrea Triossi, Marco Bindi

LINKING SOIL STRUCTURE PROPERTIES UNDER CONSERVATION AGRICULTURE MANAGEMENT IN VENETO REGION SILTY SOILS **321**
Ilaria Piccoli, Carlo Camarotto, Lorenzo Furlan, Antonio Berti, Barbara Lazzaro, Francesco Morari

LOW-COST MULTISPECTRAL CAMERA ON BOARD A UAV: ESTIMATION OF MAIZE NITROGEN-RELATED VARIABLES TO SUPPORT NITROGEN FERTILIZATION **323**
Martina Corti, Daniele Cavalli, Giovanni Cabassi, Antonio Vigoni, Lamberto Borrelli, Luca Bechini, Pietro Marino Gallina

BIOCHAR APPLICATION TO PEAT-BASED GROWING MEDIA FOR NURSERY PRODUCTION OF BROCCOLI SEEDLINGS **327**
Angela Libutti, Teresa Incoronata Tisi, Anna Rita Bernadette Cammerino, Massimo Monteleone

EFFECTS OF AGRONOMIC MANAGEMENT ON SOYBEAN BRANCHING: VARIATIONS IN CONCENTRATION OF AUXINS AND ISOFLAVONES **330**
Giuseppe Barion, Cristian Dal Cortivo, Giuliano Mosca, Teofilo Vamerali

INFLUENCE OF PLANT DENSITY AND NITROGEN APPLICATION ON GROWTH, YIELD AND QUALITY OF RADISH (RAPHANUS SATIVUS L.) **332**
Sara D’Egidio, Giancarlo Pagnani, Fabio Stagnari, Angelica Galieni

ASSESSMENT OF WATER STRESS TOLERANCE IN TOMATO: PHYSIOLOGICAL AND YIELD RESPONSE **335**
Federica Carucci, Giuseppe Gatta, Eugenio Nardella, Concetta Lotti, Marcella Michela Giuliani

QUANTITATIVE REVIEW OF ANIMAL MANURE DECOMPOSITION IN SOIL **338**
Daniele Cavalli, Martina Corti, Pietro Marino Gallina, Luca Bechini

PREDICTION OF WHEAT YIELD USING RELATIONSHIP BETWEEN VEGETATION INDICES, PLANT N AND BIOMASS AT HEADING

PREVISIONE DELLA RESA DEL FRUMENTO ATTRAVERSO INDICI IPERSPETTRALI, AZOTO, E BIOMASSA A SPIGATURA

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Abstract

The ability to predict wheat yield in a Mediterranean environment is limited by a number of factors. These include the variability of soil N that is available within a growing season and between years, and the highly variable nature of climatic conditions in this environment. These factors interact to confound the relationship between N inputs and actual N that is available for plants at a given phenological stage or period of the year. We measured passive reflectance by crop with a proximal hyper-spectral sensor and computed 38 indexes related to various canopy traits at heading and related their integration to grain yield. The experiment was conducted over 2 growing seasons for 2 durum wheat cultivars subjected to 6 fertilization strategies and two fungicide treatments at heading. Relatively high coefficients of determination were obtained by modelling yield by the indexes used and some plant traits at heading, including heading date. We conclude that this was due to the reflectance indexes rather than crop biomass, N or heading date. Among predictors, chlorophyll vegetation index (CVI) was frequently included in the models, which could depend on the ability of CVI to capture the variability of biomass and its N concentration. However, since both of the cropping seasons had adequate rainfall and homogeneous rainfall distribution, additional research is still needed to model wheat yield by proximal sensing in environments or years with lower and/or more erratic rainfall.

Keywords: proximal sensing, reflectance, grain yield, quality, yield prevision.
Parole chiave: proximal sensing, riflettanza, resa in granella, qualità, previsione della resa.

Introduction

Climatic conditions in Mediterranean semiarid environments are erratic which results in difficult correlating N inputs and actual N availability for plants at key phenological stages or period of the growing season. Because of this high degree of variability, fertilization strategies such as split application or modulating its amount can help in enhance crop responses to fertilizers (Colecchia et al., 2013). In Mediterranean environment, this prediction is partly allowed by the dependence of the wheat biomass and N uptake at harvest by the corresponding traits at heading (Masoni et al., 2007; Barraclough et al., 2014). However, measuring biomass and N uptake at given phenological stages is costly and time consuming. We investigated the use of proximal hyper-spectral sensing to capture the variability in yield and grain N uptake explained by biomass and its traits at heading. In the present study, data for 38 reflectance-derived indexes, biomass and N content recorded at heading stage were used to forecast wheat yield and grain N uptake of two semi-dwarf durum wheat cultivars under 6 fertilization strategies.

Materials and Methods

The experiment reported here was performed at the CREA-CI of Foggia, Italy in the 2012-13 and 2013-14 on a Typic Chromoxerert as a split-plot (4 replicates) with the following treatments: main plots were cultivar (CV, PR22D89 and Iride) and fertilization strategy (see table 1 for the explanation of the treatments); split-plot was fungicide application; size of the split-plot was 1.5 m × 7.5 m. The crop was sown at 380 viable seeds m^{-2} at 17.5-cm wide rows and an herbicide was used to control weeds. The degree of infection by rust was evaluated at heading time. Reflectance was recorded with a FieldSpec® Hand-Held Pro portable spectroradiometer (Analytical Spectral Device, Boudler, CO, USA) which had a spectral range from 350 to 1100 nm and FOV of 25°. The following indices were derived from proximally-sensed, hyper-spectral reflectance data (psHRDIs): WDVI; GNDVI; TVI; CRM; CVI; CGM; PVI; SAVI; TSAVI; SAVI2; MSAVI1; MSAVI2; EVI; EVI2; eta; GEMI; OSAVI; NDVI; NDRE; NDRE2; MTCI; CARI; TCARI; MCARI; MCARI1; MCARI2; SARVI; MTVI; MTVI2; TCARI/OSAVI; MCARI/OSAVI; MCARI/MTVI; MCARI/MTVI2; NDRE1/NDVI; NDRE2/NDVI; MSAVI; CCCI; CCCI*NDVI. Definitions and formulae for these indices can be found in Basso et al. (2016).

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Tab. 1: Code, timing and amount of fertilizer N (kg N ha^{-1}) applied in the various fertilization strategy treatments.
Tab. 1: Codice, momento di applicazione e quantità (kg N ha^{-1}) di fertilizzante applicato nei diversi trattamenti di fertilizzazione.

code	**pre-sowing**	**early tillering**	**late tillering**	**stem elongation (2nd node)**	**booting**	***total N applied***
T0	0	0	0	0	0	***0***
T1	36	54	0	0	0	***90***
T2	36	64	0	40	0	***140***
T3	36	64	0	30	10	***140***
T4	36	54	54	27	0	***171***
T5	36	27	0	27	10	***100***

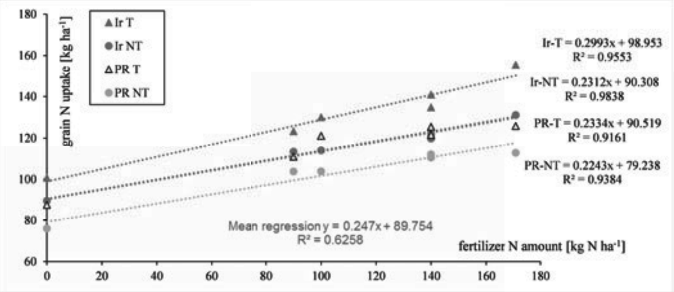
Correlations were calculated at heading stage among psHRDIs and between each psHRDI with biomass and N content using SAS/STAT software (CORR). Grain yield was modelled by means of stepwise regression analyses (REG procedure, with slentry=0.10 slstay=0.05 options), taking into account the collinearity among the predictor used (Collin option), thus retaining only those non-significantly correlated (at a Pearson p statistic higher than F at 5% probability level). Stepwise regression analysis included or not plant biomass, its N content and date of heading (expressed as days from the fist of April). Data on yield, biomass, N contents and grain quality at grain maturity were subjected to analysis of variance (Glimmix procedure) according to the experimental design. Differences among means were compared by applying t-grouping with Tukey-Kramer correction at the 5% probability level to the LSMEANS p-differences. Finally, 3 orthogonal contrasts were computed. The first contrast represents the effect of fertilization and is calculated as (T0) vs (mean of all others). A second contrast represents the increase of N availability and stem elongation and booting calculated as (T1) vs (mean of T2 and T3) and a third contrast represents the increase of N availability at late tillering (T4) vs (mean of T2 and T3)

Results and Discussion

RAINFALL AND TEMPERATURES AND CROP BIOMASS, YIELD AND N CONTENT

Total rainfall, in both cropping seasons, was close to the long-term mean (479 mm year^{-1}) and very well distributed (De Vita et al. 2017). Fall temperatures in both years and winter temperatures in 2013-14 were higher than the long-term mean. Spring temperatures lower than the long-term mean for both years. This likely favoured the expression of the yield potential in both cultivars and for the N treatments as confirmed by the small differences in grain yield among fertilization strategies (4.46 versus 5.42-5.84 t grain ha^{-1} in unfertilized and fertilised treatments, respectively). However, high rainfall and temperatures also favoured rust infection in all treatments (data not shown). Indeed, fungicide treatment increased rain yield by 11.1% with few differences among other treatments. Differences among treatments in N uptake, and thus grain protein concentration (11.1-13.2%) were slightly higher than differences in grain yield. This suggests that N accumulation was limited by N availability and not by fertiliser splitting or other ecological conditions. This likely occurred due to the low N use efficiency achievable when high water availability occurs. In the present work, an apparent N agronomic efficiency analysis suggested that N derived from soil at increasing application rates of fertilisers ranged between 79 and 99 kg N ha^{-1} and apparent fertiliser N uptake efficiency was around 26.2%±3.36% depending on the genotype and fungicide treatment (fig. 1). These results are in agreement with those obtained by applying ^{15}N to trace N movements from soil to plants in other genotypes of the same species (Saia et al., 2014).

Fig. 1: Relationship between fertilizer N applied in the various fertilization scenarios and grain N uptake for the cultivars Iride (Ir) or PR22D89 (PR) treated with a fungicide at heading (T) or not treated (NT). Linear regression equation per treatment and mean are shown.
Fig. 1: Relazione tra quantità di N fornito col fertilizzante nei vari scenari di fertilizzazione azotata e azoto accumulato nella granella delle cultivar Iride (Ir) e PR22D89 (PR) trattate con un fungicida alla spigatura (T) o non trattate (NT). Le regressioni lineari per trattamento e media sono mostrate.



GRAIN YIELD PREDICTION

Prediction of grain yield by the use of psHRDIs, crop traits (biomass and N content and concentration) at heading stage or both resulted in various level of prediction ability. Coefficients of determination (R^2) were relatively high when psHRDIs were included in the modelling phase with R^2 values that ranged from 0.58 to 0.81. Slightly lower R^2 values (0.38 to 0.76) resulted when sole crop traits were used (table 2). These coefficients of regression are higher than those found in other studies that included fewer indices than we used (Raun et al., 2001) and similar to the R^2 values found by data mining reflectance data (Thorp et al., 2017). When psHRDIs and crop traits were at the same time used in the modelling procedure, very few differences were found with the models built with psHRDIs. In particular, only the stepwise regression built for the PR22D89 data (untreated+fungicide treated data pooled) differed in psHRDIs+crop traits compared to psHRDIs only (data not shown). In particular, inclusion of crop traits at heading stage increased R^2 of the model to 0.75, decreased intercept to –11.86 t grain ha^{-1}, and increased NDRE1/NDVI (the most important predictor) beta coefficient to 39.3 t grain unit index^{-1}. Among crop traits, only heading date was retained in this latter analysis, but its contribution to the total regression was negligible (β=0.12 t grain day^{-1}). Despite intecept of the models were never significantly negative (table 2, p not shown), they varied widely among treatments. Similarly the variables taken into account by the modelling procedure varied by the subpopulation of yield data modelled and no common predictor among models was found.

Tab. 2: Beta coefficients, intercepts and R^2 of the stepwise regression models built with all data (Tot, n=192), with data split per genotype [G] (Iride or PR22D89, n=96), or per fungicide treatments [F] (fungicide treated [Fu-TR] or untreated [UnTR]) or G×F interaction (n=48). Negative intercept values were not different than 0 at p<0.05. All beta coefficients were significantly different than 0 at p<0.05.

Tab. 2: Coefficienti angolari, intercette e R^2 dei modelli di regressione stepwise costruiti con tutti i dati (Tot, n=192), per singoli genotipi [G] (Iride o PR22D89, n=96), trattamento fungicida [F] (trattato [Fu-TR] o controllo non trattato [UnTR]) o interazione G×F (n=48). Le intercette negative non erano significativamente diverse da zero a p<0.05. Tutti i coefficienti angolarierano significativi a p<0.05.

	Iride		PR22D89		Iride	PR22D89	UnTR	Fu-TR	Tot
	UnTR	Fu-TR	UnTR	Fu-TR					
beta coefficients of proximally sensed hyperspectral reflectance derived indexes (psHRDIs), only									
Intercept	2.61	3.00	-2.10	4.99	2.77	-1.39	1.23	0.84	0.62
NDRE									
CRM								2.48	1.91
CVI		-0.93	-0.71	-0.51	-0.52	-0.61		-0.93	-0.69
NDRE1/NDVI			24.79			22.50		14.54	13.39
MTCI	1.84	5.06			3.66				
GEMI							2.22		
CCCI				6.47			3.46		
R^2	***0.72***	***0.71***	***0.81***	***0.71***	***0.58***	***0.69***	***0.72***	***0.70***	***0.63***
beta coefficients of crop traits at heading (heading date [HD], biomass [HB] and N [HN]), only									
Intercept	2.19	3.04	-0.42	1.51	2.71	0.29	1.39	2.37	1.88
HD (days from 1st of april)	0.12	0.10	0.20	0.17	0.10	0.19	0.11	0.09	0.10
HB (t ha^{-1}) at heading	0.08				0.10		0.14	0.16	0.15
HN (kg N ha^{-1}) at heading		0.01	0.01			0.00			
R^2	***0.60***	***0.38***	***0.76***	***0.64***	***0.41***	***0.63***	***0.61***	***0.45***	***0.47***

Conclusions

Modelling yield by the psHRDIs and some plant traits at heading stage, including heading date, yielded relatively high coefficients of determination. This agrees with results obtained by Thorp et al. (2017), who found that crop reflectance derived indices at key phenological stages, especially heading, are related to grain yield more than some crop biomass or N traits. This can explain why when we used only psHRDIs or both psHRDIs and crop traits, very few differences in the predictors selected were found. However, since no predictor was constantly retained in all the models, other plant or canopy traits related to yield determinants (e.g. water availability, temperature stress or other genetic traits) should be included as a predictor. Among predictors, chlorophyll vegetation index (CVI) was frequently included in the model, which could depend on its ability to capture the variability of biomass and its N concentration (Vincini et al., 2014). And indeed we found that it correlated with biomass at heading at R=-0.76. Further results are needed, however, to model wheat yield by proximal sensing coupled with a crop simulation model in environments or years different that what than occurred in the study presented here to be able to transfer these results over space and time.

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