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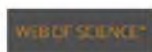
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## CONTENT

<b>Sergey Tyutrin</b> IMPROVING RELIABILITY OF PARTS OF MOUNTED MOWER ACCORDING TO MONITORING RESULTS BY FATIGUE GAUGES FROM TIN FOIL.....	22
<b>Mikhail Erokhin, Alexander Pastukhov, Sergey Kazantsev</b> OPERABILITY ASSESSMENT OF DRIVE SHAFTS OF JOHN DEERE TRACTORS IN OPERATIONAL PARAMETERS.....	28
<b>Gheorghe Stroescu, Anisoara Paun, Carmen Bracacescu, Mihai Olan</b> STREAMLINING ORGANIG SEED PRODUCTION TECHNOLOGIES FOR VEGETABLE SPECIES BY MAKING SEED CONDITIONING MODULE .....	34
<b>Maris Mangalis, Juris Priekulis, Mara Mangale</b> POSSIBILITIES TO IMPROVE ROTARY PARLOUR MILKING EQUIPMENT EFFICIENCY .....	39
<b>Vladimir Shakhov, Semjons Ivanovs, Pavel Uchkin, Yury Ushakov</b> STUDIES IN COATINGS FOR WORKING BODIES OF DEEP-RIPPERS RECOVERED BY PLASMA SURFACING.....	44
<b>Mikhail Romanchenko, Alexander Pastukhov</b> DETERMINATION OF SPECIFIC POWER PARAMETERS AND COEFFICIENT OF SLIPPING OF TRACTOR WHEEL.....	50
<b>Konstantin Salamandra</b> GEAR RATIOS CALCULATION FOR PLANETARY-LAYSHAFT TRANSMISSIONS WITH THREE POWER-FLOWS .....	57
<b>Maksim Simonov, Aleksandr Burkov, Valentin Mokiyev</b> OPTIMISATION DESIGN AND TECHNOLOGICAL PARAMETERS OF CLOVER THRESHER K-0.3 .....	66
<b>Alessandro Lezier, Alberto Cadei, Omar Mologni, Luca Marchi, Stefano Grigolato</b> DEVELOPMENT OF DEVICE BASED ON OPEN-SOURCE ELECTRONICS PLATFORM FOR MONITORING OF CABLE-LOGGING OPERATIONS .....	72
<b>Laima Berzina, Juris Priekulis, Aivars Aboltins, Olga Frolova</b> GREENHOUSE GAS EMISSIONS CAUSED BY FARM MANURE MANAGEMENT IN LATVIA.....	78
<b>Juris Priekulis, Armins Laurs, Ligita Melece</b> AMMONIA EMISSION REDUCTION MEASURES IN DAIRY CATTLE FARMING.....	83
<b>Algirdas Janulevicius, Antanas Juostas, Gediminas Pupinis</b> ESTIMATION OF TRACTOR WHEEL SLIPPAGE WITH DIFFERENT TIRE PRESSURES FOR 4WD AND 2WD DRIVING SYSTEMS.....	88
<b>Costin Mircea, Dragos Manea, Eugen Marin, Marinela Mateescu</b> EXPERIMENTAL RESEARCH IN IRRIGATION BY CONDENSATION IN SOLARIUM .....	94
<b>Nikolay Aldoshin, Otari Didmanidze, Nikolay Lylin, Maxim Mosyakov</b> WORK IMPROVEMENT OF AIR-AND-SCREEN CLEANER OF COMBINE HARVESTER.....	100
<b>Artem Kliuchnikov</b> DEVELOPMENT OF NEW METHOD OF DRYING AT ENERGY-SAVING UNIVERSAL DRYER TO IMPROVE QUALITY OF CROPS USED IN FODDER PRODUCTION .....	105
<b>Pavel Kic</b> DRYING OF INSHELL WALNUTS AND WALNUT KERNELS UNDER DIFFERENT CONVECTION CONDITIONS.....	112

<b>Elena Yanzina, Vladimir Yanzin, Oksana Mamai, Velta Parsova</b> IMPROVING EFFICIENCY OF AGRICULTURAL MACHINERY EXPLOITATION AS FACTOR OF OPTIMIZATION USE OF AGRICULTURAL LAND.....	117
<b>Peter Savinyh, Vladimir Kazakov, Alexander Moshonkin, Semjons Ivanovs</b> INVESTIGATIONS IN FEEDING DEVICE OF GRAIN CRUSHER.....	123
<b>Volodymyr Bulgakov, Semjons Ivanovs, Francesco Santoro, Alexandros Sotirios Anifantis</b> AMMONIA CONCENTRATION IN COW BARN UNDER LIMITED AIR EXCHANGE.....	129
<b>Volodymyr Bulgakov, Volodymyr Nadykto, Semjons Ivanovs, Janusz Nowak</b> RESEARCH OF VARIANTS TO IMPROVE STEERABILITY OF MOVEMENT OF TRAILED ASYMMETRIC HARVESTING AGGREGATE .....	136
<b>Volodymyr Bulgakov, Simone Pascuzzi, Semjons Ivanovs, Volodymyr Volskyi</b> EXPERIMENTAL INVESTIGATIONS IN DRAFT RESISTANCE OF SPHERICAL WORKING TOOL OF DISK HARROW .....	144
<b>Arpad Papp-Vary, Judit Grotte, Shyhrete Muriqi, Zsolt Baranyai</b> DRIVERS OF MACHINERY SHARING ARRANGEMENTS – EXPERIENCES OF EMPIRICAL SURVEY IN HUNGARIAN AGRICULTURE.....	153
<b>Marco Bietresato, Matteo Malavasi, Fabrizio Mazzetto</b> SET-UP OF INTEGRATED SYSTEM FOR REAL-TIME DETECTION AND RECORDING OF MANY ENGINE PARAMETERS OF AGRICULTURAL MACHINES DURING DYNO TESTS .....	160
<b>Guido F. Botta, Diogenes L. Antille, Fernando Bienvenido, David Rivero, EnriqueE. Contessotto</b> ENERGY REQUIREMENTS FOR ALLEVIATION OF SUBSOIL COMPACTION AND EFFECT OF DEEP TILLAGE ON SUNFLOWER ( <i>HELIANTHUS ANNUS L.</i> ) YIELD IN WESTERN REGION OF ARGENTINA'S ROLLING PAMPA .....	174
<b>Juri Olt, Risto Ilves, Arne Kuut</b> OVERVIEW OF DEVELOPMENTS OF CEREAL HARVESTER FLEET IN ESTONIA .....	179
<b>Yury Ushakov, Vladimir Shakhov, Evgeniy Asmankin, Denis Naumov</b> THEORETICAL STUDY RESULTS OF PRODUCT FLOW MANAGEMENT PROCESS IN HAMMER-TYPE SHREDDER WORKING CHAMBER .....	185
<b>Aslan Apazhev, Viktor Smelik, Yuri Shekikhachev, Liuan Hazhmetov</b> COMBINED UNIT FOR PREPARATION OF SOIL FOR SOWING GRAIN CROPS.....	192
<b>Georgiy Pisarenko, Oleksandr Voinalovych, Ivan Rogovskii, Myhailo Motrich</b> PROBABILITY OF BOUNDARY EXHAUSTION OF RESOURCES AS FACTOR OF OPERATIONAL SAFETY FOR AGRICULTURAL AGGREGATES .....	199
<b>Alexandr Belinsky, Bulat Ziganshin, Ayrat Valiev, Damir Haliullin, Ilgiz Galiev, Nail Adigamov</b> THEORETICAL INVESTIGATION OF INCREASING EFFICIENCY OF COMBINE HARVESTER OPERATION ON SLOPES .....	206
<b>Simone Pascuzzi, Alexandros Sotirios Anifantis, Francesco Santoro, Vincenzo Cimino</b> CORRELATION ANALYSIS BETWEEN VEGETATION INDEX (NDVI) AND CANOPY COVERAGE (TOC) BASED ON REMOTE SENSING BY USING UAV .....	214
<b>Vidas Damanauskas</b> DEPENDENCE OF FUEL CONSUMPTION ON WINTER RAPE STUBBLE TILLAGE QUALITY IN CLAY LOAM SOIL.....	221
<b>Dagnija Lazdina, Karlis Dumins, Timo Saksa, Kristaps Makovskis</b> EVALUATION OF FOREST TREE PLANTING MACHINE EFFECTIVENESS.....	227
<b>Alexandru Zaica, Alexandra Visan, Ana Zaica, Mihai Olan, George Bunduchi</b> COATING PROCESS OF CORN GRAINS USING TREATMENT MACHINE WITH BRUSH SCREW CONVEYOR.....	233
<b>Nikolai Skuryatin, Alexander Novitsky, Anatoly Zhiltsov, Evgeniy Soloviev</b> DEVELOPMENT OF CONSTRUCTIVE-TECHNOLOGICAL SCHEME OF PARKING FOR AGRICULTURAL MACHINERY .....	239

<b>Valentyna Krutyakova, Volodymyr Bulgakov, Volodymyr Belchenko, Adolfs Rucins</b> INVESTIGATION OF MECHANICAL METHOD OF TRICHOGRAM DISPERSAL .....	247
<b>Volodymyr Bulgakov, Valerii Adamchuk, Semjons Ivanovs, Hryhorij Kaletnik</b> EXPERIMENTAL INVESTIGATION OF TECHNICAL AND OPERATIONAL INDICES OF ASYMMETRIC SWATH REAPER MACHINE-AND-TRACTOR AGGREGATE.....	256
<b>Ivan Holovach</b> DEVELOPMENT OF MATHEMATICAL MODEL OF CUT HAULM MOVEMENT ALONG WORKING TOOL OF LOADING MECHANISM.....	264
<b>Oldrich Latal, Petr Novak, Petr Sarec, Martin Brtnicky</b> ACTIVATORS OF BIOLOGICAL TRANSFORMATION AND THEIR EFFECT ON PIG MANURE QUALITY AND BARN CONDITION AGGREGATE .....	272
<b>Valentina Krutiakova, Igor Bepalov, Volodymyr Bulgakov, Dainis Viesturs</b> ENGINEERING DESIGN OF INDUSTRIAL PRODUCTION OF GOLDEN-EYED LACEWINGS ( <i>CHRYSOPERLA CARNEA STEPH L.</i> ) IN PROGRAMS OF BIOLOGICAL PROTECTION OF PLANTS.....	278
<b>Gheorghe Voicu, Gabriel-Alexandru Constantin, Petru Cardei, Ion Cristian Poenaru</b> THEORETICAL AND EXPERIMENTAL RESEARCH IN FUEL CONSUMPTION AT MISCANTHUS RHIZOMES PLANTING .....	284
<b>Ivan Rogovskii, Liudmyla Titova, Andriy Novitskii, Victor Rebenko</b> RESEARCH OF VIBROACOUSTIC DIAGNOSTICS OF FUEL SYSTEM OF ENGINES OF COMBINE HARVESTERS.....	291
<b>Vasyl Khmelovskiy, Svitlana Rogach, Oksana Tonkha, Yuriy Rosamaha</b> QUALITY EVALUATION OF MIXING FODDER BY MOBILE COMBINED UNITS.....	299
<b>Janis Ivanovs, Raitis Melniks, Jelena Stola, Olga Frolova</b> PRELIMINARY ASSESSMENT OF IMPACT OF ROUNDWOOD FORWARDING ON SOIL WATER PERMEABILITY AND WATER TABLE LEVEL IN COMMERCIAL THINNINGS ON MINERAL SOILS .....	305
<b>Ayrat Valiev, Ilshat Mukhametshin, Farzutdin Muhamadyarov, Fanis Yarullin, Gennady Pikmullin</b> THEORETICAL SUBSTANTIATION OF PARAMETERS OF ROTARY SUBSOIL LOOSENER .....	312
<b>Bogusława Jaskiewicz</b> CHEMICAL COMPOSITION OF WINTER TRITICALE GRAIN DEPENDING ON TYPE OF TILLAGE IN CROP ROTATION .....	319
<b>Ivars Lūsis, Armins Laurs, Vita Antane</b> VISCOSITY METHOD IN ROBOTIC MILKING SYSTEM FOR DETECTION OF SOMATIC CELL COUNT IN MILK .....	324
<b>Andrey Novikov, Anton Poddubsky, Sergey Grigorov, Maksim Ratanov, Maksim Filimonov, Olga Poddubskaya</b> MODELING AND IMPROVING SPRINKLING PROCESS WITH EJECTION NOZZLES .....	330
<b>Elena Pismennaya, Vladimir Stucalo, Irina Volters, Lyudmila Kipa, Margarita Azarova</b> ANIMAL HUSBANDRY OF SOUTH OF RUSSIA: CURRENT STATE AND PROSPECTS OF DEVELOPMENT.....	337
<b>Regina Gurina, Vladimir Nikitchenko, Dmitriy Nikitchenko, Anton Poddubsky, Vadim Plyushchikov</b> EVALUATION OF ECONOMIC EFFICIENCY OF KEEPING AND RAISING YOUNG CATTLE IN RUSSIA .....	343
<b>Vasiliy Kaliuga, Alexey Trifanov, Valentin Bazykin</b> JUSTIFICATION OF CHOICE OF STRESS-FREE PIG HOUSING METHOD ON SMALL-SCALE FARMS AT DESIGNING STAGE .....	349
<b>Alexey Trifanov, Ilya Plaksin, Sergei Plaksin</b> STUDY RESULTS OF THE AIR VELOCITY INSIDE THE TECHNOLOGICAL MODULE FOR BROILER CHICKENS FATTENING.....	355

<b>Iuliana Gageanu, Catalin Persu, Dan Cujbescu, Gabriel Gheorghe, Gheorghe Voicu</b> INFLUENCE OF USING ADDITIVES ON QUALITY OF PELLETIZED FODDER .....	362
<b>Basil Kvashennikov, Andrey Kozlovstev, Vladimir Shakhov, Eugene Kochkin</b> SUBSTANTIATION AND DEVELOPMENT OF NATURAL COLD ACCUMULATOR FOR MILKING AREAS OF REMOTE SUMMER FARM CAMPS .....	368
<b>Evgeny Golosnoy, Maxim Sigida, Alexander Esaulko, Sergey Korostylev, Yuliya Grechishkina</b> IMPACT OF AGRICULTURAL MACHINERY ON INCREASING EFFICIENCY OF NITROGEN FERTILIZERS USED IN TOP-DRESSING OF WINTER WHEAT GROWN WITH NO-TILL TECHNOLOGY .....	374
<b>Sergey Korostylev, Alexander Esaulko, Alena Ozheredova, Natalya Gromova, Yuliya Grechishkina</b> INFLUENCE OF TILLAGE METHODS ON OPTIMIZATION OF NUTRITION, YIELD AND FILLING GRAIN OF WINTER WHEAT ON LEACHED CHERNOZEM.....	379
<b>Evgeny Golosnoy, Alexander Esaulko, Alla Belovolova, Alena Ozhdorova</b> INFLUENCE OF METHODS AND TECHNOLOGY OF NITROGEN FERTILIZER APPLICATION IN EARLY SPRING FERTILIZATION ON WINTER WHEAT PRODUCTIVITY IN ARID ZONE OF SOUTH OF RUSSIA .....	386
<b>Alexander Esaulko, Maxim Sigida, Evgeny Golosnoy, Sergey Antonov, Olga Lobankova</b> CONDITION MONITORING AND ANALYSIS OF DEVELOPMENT IN WINTER CROPS OF WATER EROSION PROCESSES USING REMOTE SENSING TECHNOLOGIES .....	391
<b>Andrey Novikov, Anton Poddubsky, Evgenii Dugin, Olga Poddubskaya, Maksim Filimonov, Regina Gurina</b> WASTEWATER TREATMENT AND DISPOSAL OF INDIVIDUAL RESIDENTIAL BUILDINGS IN AGRICULTURE .....	397
<b>Nikolay Buryakov, Maria Buryakova, Evgeniy Prokhorov, Dmitriy Aleshin</b> EFFICIENCY OF WHITE LUPIN GRAIN IN COMPOSITION OF FEED FOR DAIRY CATTLE .....	407
<b>Vladislav Gordeev, Tatiana Mironova, Victor Khazanov, Viacheslav Mironov</b> MODELS TO MINIMIZE OUTPUT OF MANURE-BEARING WASTEWATER FROM MILKING PARLOURS AT CONCEPTUAL DESIGNING STAGE OF DAIRY FARMS .....	413
<b>Vladimir Trukhachev, Alexander Esaulko, Maxim Sigida, Sergey Korostylev, Valentin Ageev</b> INFLUENCE OF SOIL TREATMENT METHODS AND FERTILIZER SYSTEMS ON PRODUCTIVITY OF GRAIN-GRAND TREATMENT IN CONDITIONS OF THE CENTRAL CISCAUCASIA.....	420
<b>Vera Perederieva, Olga Vlasova, Irina Wolters, Anna Shutko</b> INFLUENCE OF PRE-CROPS ON WEEDY COMPONENT OF AGROPHYTOCENOSIS IN CULTIVATION OF WINTER WHEAT UNDER NO- TILLAGE TECHNOLOGY.....	426
<b>Olga Sycheva, Sergei Shlykov, Ruslan Omarov, Elena Skorbina</b> STUDYING EFFECT OF ELECTROMAGNETIC TREATMENT ON MILK TECHNOLOGICAL PROPERTIES.....	430
<b>Vladimir Trukhachev, Sergei Oliinyk, Tatyana Lesnyak, Irina Kartavtseva</b> PROSPECTS FOR USE OF AEROSPACE MONITORING FOR ACCELERATED DEVELOPMENT OF LIVESTOCK GRAZING .....	436
<b>Vladimir Trukhachev, Serhii Oliinyk, Ilya Mikhailenko, Valeriy Timoshin, Tatyana Lesnyak</b> ESTIMATION OF CONDITION OF CULTIVATED PASTURES UNDER REMOTE SENSING OF EARTH .....	442
<b>Vladimir Trukhachev, Serhii Oliinyk, Tatyana Lesnyak, Vitaly Morozov, Sergey Sklyarov</b> DEVELOPMENT OF METHODS FOR REMOTE MONITORING OF ALLOCATION OF LOCAL AREAS OF OPPRESSED VEGETATION ON CULTIVATED PASTURE UNDER INFLUENCE OF VARIOUS NEGATIVE FACTORS.....	450

<b>Petr Novak, Petr Sarec, Oldrich Latal, Michal Brtnicky, Jiri Masek</b> INFLUENCE OF MANURE WITH ACTIVATORS OF ORGANIC MATTER ON PHYSICAL PROPERTIES OF SOIL .....	457
<b>Marina Chkalova, Vladimir Shahov, Victoria Pavlidis</b> EFFECTIVENESS ANALYSIS OF WAYS ORGANIZING PRODUCTION OF COMBINED FEEDS.....	462
<b>Mikhail Erohin, Oleg Leonov, Uriy Kataev, Ulia Vergazova</b> CALCULATION OF FITS FOR CYLINDRICAL CONNECTIONS WITH KEY FOR REDUCERS IN AGRICULTURAL MACHINERY .....	469
<b>Agris Zimelis, Santa Kaleja, Modris Okmanis</b> COMPLEX FOREST MANAGEMENT SYSTEM BASED ON SMALL SIZE FOREST MACHINES .....	475
<b>Dmitriy Bakharev, Alexander Pastukhov, Sergey Volvak, Olga Sharaya</b> SUBSTANTIATION OF DECK PARAMETERS OF ROTARY THRESHING DEVICE.....	481
<b>Aleksandr Kolesnikov, Alexander Pastukhov, Nataliia Vodolazskaya, Alexan Minasyan</b> RESEARCH IN PARAMETERS OF WORKING PROCESS OF INTERFUSING IN BATCHER MIXER.....	487
<b>Evgeniy Ivanov, Nikita Kokorin</b> MANIFESTATION OF INFORMATION PROPERTIES OF WATER SUFFERED CAVITATION IN AFTEREFFECT VIA EXAMPLES "MEMORIES OF SOILS".....	493
<b>Vladimir Masan, Patrik Burg, Pavla Bukovska, Jakub Sikora</b> EXAMINATION OF THERMAL BALANCE OF VERTICAL GREEN MOBILE WALL .....	501
<b>Mariya Nosevich</b> DEVELOPMENT OF INNOVATIVE MACHINE TECHNOLOGY FOR FIBER FLAX GROWING IN CONDITIONS OF NORTH-WEST REGION .....	507
<b>Igor Vorotnikov, Maxim Mastepanenko, Shaliko Gabrielyan, Anna Shunina</b> ENERGY ESTIMATION OF PARAMETERS OF REACTIVE POWER COMPENSATOR FOR NONLINEAR LOADS IN STEADY MODE .....	515
<b>Margarita Kochneva, Leonid Butusov, Sergey Bindukov, Vasiliy Ivlev</b> SOXHLET-RANDALL METHOD MODIFICATION FOR RAPID LIPID EXTRACTION ON EXAMPLE OF RAINBOW TROUT.....	521
<b>Daiva Nemeiksyte, Vitalijs Osadcuks</b> RESEARCH IN CONTROLLED MOVES OF ROBOTIC MANIPULATORS FOR BIOLOGICAL OBJECT PROCESSING.....	526
<b>Aleksandr Levshin, Irina Gasparyan, Boris Bitsoev, Sergey Shchigolev</b> CONSTRUCTIVE FEATURES OF DEVICE TO REMOVE APICAL SHOOTS OF POTATOES.....	532
<b>Roman Uvarov, Natalia Oblomkova, Ivan Freidkin</b> SLURRY ACIDIFICATION TECHNIQUES: FRST STEPS TOWARDS COMPREHENSIVE STUDY IN RUSSIAN CONDITIONS.....	538
<b>Alexander Briukhanov, Ekaterina Shalavina, Pavel Gridnev, Tatyana Gridneva</b> CHOICE OF CATTLE MANURE REMOVAL SYSTEM DEPENDING ON MANURE PHYSICAL PROPERTIES .....	543
<b>Sergey Strebkov, Alexey Slobodyuk, Andrey Bondarev, Andrey Sakhnov</b> STRENGTHENING OF CULTIVATOR PAWS WITH ELECTROSPARK DOPING .....	549
<b>Rais Sabirov, Ayrat Valiev, Lylia Karimova, Andrey Dmitriev, Damir Khaliullin</b> INFLUENCE OF PHYSICAL FACTORS ON VIABILITY OF MICROORGANISMS FOR PLANT PROTECTION.....	555



<b>Oleksandr Voinalovych, Oleg Hnatiuk, Ivan Rogovskii, Oleksandr Pokutnii</b> PROBABILITY OF TRAUMATIC SITUATIONS IN MECHANIZED PROCESSES IN AGRICULTURE USING MATHEMATICAL APPARATUS OF MARKOV CHAIN METHOD.....	563
<b>Pavel Zemanek, Vladimir Masan, Patrik Burg, Bozena Gladyszewska</b> EVALUATION OF SELECTED PARAMETERS OF MECHANICAL AND PNEUMATIC PRESS DURING GRAPE PRESSING .....	570
<b>Patrik Burg, Vladimir Masan, Alice Cizkova, Barbora Badalikova</b> IMPACT OF COMPOST APPLICATION IN VINEYARDS ON CHANGES OF PHYSICAL PROPERTIES OF SOIL.....	576
<b>Marta Wyzinska, Jerzy Grabinski</b> PRODUCTIVITY AND TECHNOLOGICAL VALUE OF SPRING WHEAT IN CONDITIONS OF AUTUMN SOWING DATE .....	583
<b>Marta Wyzinska, Bozena Smreczak</b> INFLUENCE OF TYPE AND RATE OF BIOCHAR ON PRODUCTIVITY OF WINTER WHEAT.....	594
<b>Alicja Sulek, Marta Wyzinska, Grazyna Cacak-Pietrzak</b> IMPACT OF TILLAGE ON YIELD AND QUALITY TRAITS OF GRAINS OF SPRING WHEAT CULTIVARS .....	600
<b>Alexander Lysakov, Yaroslav Tarasov</b> EFFECT OF MAGNETIC FIELD OF NEODYMIUM (NDFEB) MAGNET ON STORAGE QUALITY OF POTATOES .....	607
<b>Alexander Ivashina, Andrey Adoshev, Valery Zhdanov, Vitaly Shemyakin</b> STUDYING THE ELECTRICAL CHARACTERISTICS OF GRAIN UNDER VIBRATION ACTION.....	613
<b>Ariel Langowski, Roman Rolbiecki, Stanislaw Rolbiecki, Wieslaw Ptach, Paulina Wrobel</b> EFFECT OF SPRINKLER IRRIGATION ON GROWTH OF PAULOWNIA SHAN TONG TREES AT FIRST TWO YEARS OF CULTIVATION IN LIGHT SOIL .....	619
<b>Egle Jotautiene, Antanas Juostas, Algirdas Janulevicius, Aivars Aboltins</b> EVALUATION OF BEARING RELIABILITY OF COMBINE HARVESTER STRAW CHOPPER.....	625
<b>Alexander Lysakov, Vitaly Grinchenko, Anatoly Molchanov, Igor Devederkin</b> EFFECT OF ULTRA-BRIGHT LED LIGHT FOR LOCUST PLAGUE CONTROL .....	630
<b>Ramunas Mieldazys, Egle Jotautiene, Raimonda Zinkeviciene, Algirdas Jasinskas</b> MANURE PROCESSING INTO GRANULAR FERTILIZERS USING ADDITIONAL ADDITIVES .....	635
<b>Augustina Pruteanu</b> RESEARCHES IN QUALITY OF DRIED AND CHOPPED CHICORY HERB SORTING PROCESS.....	641
<b>Ileana Dugaescu, Lucretia Popa, Stefan Moise Iulian, Victor Moise, Vasilica Stefan, Alexandra Rotaru</b> KINEMATIC ANALYSIS OF MONO-MOBILE MECHANICAL SYSTEM ACTUATED BY MOTOR TETRAD RRR-T <sub>A</sub> -RRR.....	648
<b>Popa Lucretia, Stefan Moise Iulian, Vasilica Stefan, Liviu-Marian Ungureanu, Luciana Dudici</b> STRUCTURAL AND KINEMATIC ANALYSIS OF LIFTING AND FOLDING MECHANISM OF MOBILE SHUTTER.....	655
<b>Jurii Belenkii, Aleksandr Andronov, Boris Martynov, Anna Khakhina</b> TRENDS OF TECHNICAL CHARACTERISTICS OF WHEELED SKIDDING MACHINERY.....	662
<b>Tomasz Hebda, Beata Brzychezkyk, Boguslawa Lapczynska-Kordon, Jakub Styks</b> INFLUENCE OF PRE-TREATMENT AND DRYING METHODS ON PROCESS OF REHYDRATION OF DRIED APPLE .....	669

<b>Marco Benetti, Francesco Saltarin, Stefano Zanon, Michele Zucal</b> SINGLE VERSUS MULTIPLE HORTICULTURAL OPERATIONS WITH GNSS ASSISTED STEERING .....	677
<b>Daina Vasilevska, Baiba Rivza, Peteris Rivza</b> IMPACT OF DIGITAL INNOVATION ON DEVELOPMENT OF AGRICULTURE IN LATVIA .....	682
<b>Nikolay Bogatyrev, Sergej Morgun, Mikhail Poteshin, Dmitrij Semernin</b> NEW TECHNOLOGIES AND MECHANISMS FOR GREENHOUSES .....	688
<b>Asnate Kirse-Ozolina, Sandra Muizniece-Brasava, Evalds Raitis, Zanda Kruma</b> EFFECT OF STERILIZATION PARAMETERS ON QUALITY OF COMMERCIALY-PREPARED INSTANT SOUPS.....	695
<b>Vitaly Krupenin, George Nerubenko, Pavel Kolomier</b> MODELING AND CALCULATION OF AMPHIBIOUS ALL-TERRAIN VEHICLE EQUIPPED BY VIBRATION ENERGY HARVESTING DAMPERS.....	705
<b>Vitaly Krupenin, George Nerubenko, Dmytriy Gurevych</b> IMPROVED PERFORMANCE OF BELT CONVEYOR-FEEDER .....	712
<b>Mihails Urbans, Jelena Malahova, Vladimirs Jemeljanovs</b> IDENTIFYING POTENTIAL RISKS CREATED BY STATE JOINT-STOCK COMPANY LATVIJAS DZELZCEĻŠ JELGAVA STATION AND EVALUATING THEIR IMPACT ON ENVIRONMENT, INHABITANTS AND INFRASTRUCTURE .....	718
<b>Rostislav Li, Aleksandr Odintsov, Sandra Sidenko</b> OPTMIZING HEAT TRANSFERING SURFACE SHAPE OF BRAZED PLATE HEATEXCHANGER.....	726
<b>Rostislav Li, Aleksandr Odintsov, Sandra Sidenko</b> EXPERIMENTAL RESEARCH IN BRAZED PLATE-TYPE HEAT EXCHANGERS .....	733
<b>Adriana Istudor, Gheorghe Voicu, Gheorghe Muscalu, Mariana Munteanu</b> POWER CONSUMPTION OPTIMIZATION FOR BREAD DOUGH PROVER .....	739
<b>Kristina Lebedeva, Galina Kashkarova, Andrejs Snegirjovs, Peteris Shipkovs, Martins Vanags</b> TRANSLUCENT COMPONENT TO PROVIDE THERMAL ENERGY SAVING IN BUILDINGS.....	745
<b>Alina Syp, Dariusz Osuch</b> DAIRY FARMERS' VIEWS ON ENVIRONMENT, RESULTS OF QUESTIONNAIRE SURVEY FROM REGIONS OF MAZOWSZE AND PODLASIE IN POLAND.....	751
<b>Boguslawa Jaskiewicz</b> SPRING TRITICALE TECHNOLOGY DEPENDING ON CROP ROTATION.....	758
<b>Valentina Avdeeva, Galina Starodubtseva, Julia Bezgina, Elena Zorina, Alexander Lysakov</b> OZONE EFFECTS ON TOXICITY OF WHEAT GRAIN AND GRAIN MIXTURES.....	764
<b>Yury Mazhayskiy, Inna Davydova</b> CONCEPTUAL MODELING OF INVESTMENT RISK IN HEAVY METAL CONTAMINATION OF AGRICULTURAL LAND SOILS IN RYAZAN REGION .....	768
<b>Anastasiya Kondolskaya, Dariya Vasilieva, Velta Parsova, Dmitry Antropov</b> PROBLEMS OF CONSERVATION AND USE OF AGRICULTURAL LAND IN URBAN AGGLOMERATIONS.....	774
<b>Andrey Adoshev, Sergey Antonov, Alexander Ivashina, Sergey Yastrebov</b> INVESTIGATION OF ELECTROMAGNETIC CHARACTERISTICS OF FERRO- VORTEX APPARATUS.....	780
<b>Ludmila Kalinnikova, Jelena Saplavaska, Aleksey Zavodilov</b> NEGATIVE PERSONALITY TRAITS AND SELF-MONITORING AMONG SALES MANAGERS.....	786
<b>Sergey Antonov, Gennady Nikitenko, Andrey Adoshev, Igor Devederkin, Sergey Dorozhko</b> SIMULATION OF MAGNETIC SYSTEM OF APPARATUS OF MAGNETIC WATER TREATMENT FOR BOILER GREENHOUSE PRODUCTION .....	793

<b>Velta Parsova, Nataliia Stoiko, Roman Kuryltsiv, Nadiia Kryshenyk</b> DIFFERENTIATION OF LAND COVER DEGRADATION IN UKRAINE AND LATVIA .....	798
<b>Sergey Antonov, Gennady Nikitenko</b> LINEAR ELECTRIC MOTOR FOR HANDHELD ELECTRIFIED TOOLS USED IN GARDENING .....	804
<b>Sergey Antonov</b> DEVELOPMENT OF HIGH VOLTAGE SOURCE FOR SPRAYING PLANTS WITH IONIZED AEROSOL .....	808
<b>Daniels Levickis, Maris Gailis, Janis Rudzitis, Juris Kreicbergs</b> EVALUATION OF METHODOLOGY FOR DETERMINATION OF MECHANICAL EFFICIENCY OF SPARK IGNITION ENGINE .....	814
<b>Regina Gurina, Nadiya Khairova, Dmitriy Kucher, Lyutsiya Idrisova</b> COMPLEX ECOLOGICAL AND ENGINEERING ASSESSMENT OF AGRICULTURAL ACTIVITIES PROJECTS.....	822
<b>Matiss Erins, Olesja Minejeva, Raivis Kivlenieks, Juris Lauznis</b> FEASIBILITY STUDY OF PHYSIOLOGICAL PARAMETER REGISTRATION SENSORS FOR NON-INTRUSIVE HUMAN FATIGUE DETECTION SYSTEM .....	827
<b>Rims Janeliukstis</b> REVIEW ON TIME-FREQUENCY-BASED MACHINE LEARNING FOR STRUCTURAL DAMAGE ASSESSMENT AND CONDITION MONITORING .....	833
<b>Egle Jotautiene, Inga Bernotiene, Jurate Liebuviene, Almantas Bernotas</b> QUANTITATIVE STUDY OF ENVIRONMENTAL NOISE ON DOVILU VILLAGE POPULATION.....	839
<b>Antanas Pocius, Sigute Savickiene, Tytas Savickas, Jurate Vaitekoniene</b> INVESTIGATION OF IMPACT OF TECHNOLOGICAL PARAMETERS OF COMPRESION ON RELATIVE DENSITY AND MECHANICAL RESISTANCE OF GRANULATED ORGANIC COMPOST FERTILIZERS .....	844
<b>Janis Gulbis, Janis Viba, Martins Irbe, Kristaps Spade</b> EXPERIMENTAL OPTIMIZATION OF ANNEALING OF CYLINDRICAL BRASS CASINGS .....	852
<b>Mailis Polma, Tonu Leemet, Marten Madissoo</b> STUDY OF SURFACE INTEGRITY BASED ON MILLING OF MATERIAL AISI 316L .....	858
<b>Dainis Berjoza, Inara Jurgena, Vilnis Pirs</b> RESEARCH IN PARAMETERS OF ACCELERATION OF ELECTRIC VEHICLE DEPENDING ON TRANSMISSION GEAR RATIO.....	866
<b>Aivars Rubenis, Dainis Tropins, Leslie R. Adrian</b> OPPORTUNITIES FOR ELECTRIC VEHICLE FAST CHARGING NETWORKS IN NORTHERN REGIONS USING SMART CHARGING.....	872
<b>Aivars Rubenis, Dainis Tropins, Andra Zvirbule</b> DEVELOPMENT OF MODEL FOR INCREASING ELECTRIC VEHICLE CHARGING CAPACITY WITH LIMITED AVAILABLE GRID POWER .....	878
<b>Svetla Stoilova</b> METHODOLOGY FOR CLASSIFICATION SECTIONS OF RAILWAY NETWORK USING CLUSTER ANALYSIS .....	886
<b>Svetla Stoilova</b> APPLICATION OF SIMUS METHOD FOR ASSESSMENT ALTERNATIVE TRANSPORT POLICIES FOR CONTAINER CARRIAGE.....	898
<b>Rahim Zainetdinov, Irina Belinskaia, Viktor Smelik, Mihail Novikov</b> ENTROPY ESTIMATION METHOD USING HEAT IN PISTON ENGINES WITH NON-EQUILIBRIUM OF INSIDE-CYLINDER PROCESSES .....	907

<b>Muhtar Kerinov, Irina Belinskaia, Galina Bulgakova</b> IMPROVEMENT OF ALGORITHM FOR ASSESSING EFFICIENCY OF AUTOMATIC INFORMATION AND TELECOMMUNICATION SYSTEMS FUNCTIONING FOR TRAFFIC MONITORING .....	914
<b>Olga Konnikova, Evgeniy Konnikov, Svetlana Bozhuk, Natalia Pletneva</b> DEVELOPMENT OF INTERNATIONAL TRANSPORT CORRIDORS TO MEET CHALLENGES OF AGRICULTURE.....	921
<b>Lilo Kunchev, Zlatin Georgiev</b> INVESTIGATION OF DAMPING PROPERTIES OF TELESCOPIC SHOCK ABSORBER AND ITS RUBBER MOUNTS IN FREQUENCY RANGE 50-150 HZ .....	936
<b>Somaya Aboelnaga, Tamas Toth, Gyoergy Ivan Neszmelyi</b> LAND USE MANAGEMENT ALONG URBAN DEVELOPMENT AXIS AS ONE OF URBAN REGENERATION PRINCIPLES .....	944
<b>Zanda Krukle, Liga Biezina, Raimonds Ernsteins</b> SUSTAINABLE URBAN MOBILITY PLANNING DEVELOPMENT PRECONDITIONS: GOVERNANCE SYSTEM APPROACH.....	954
<b>Kristaps Sondors, Aivars Birkavs, Vilnis Pirs, Gints Birzietis, Ilmars Dukulis</b> COMPARISON OF VEHICLE PERFORMANCE USING FOSSIL DIESEL FUEL BLENDS WITH BIODIESEL AND HVO FUEL .....	964
<b>Marie Sejkorova, Ivana Hurtova</b> ENGINE OIL ANALYSIS - EFFECTIVE INSTRUMENT TO EVALUATE RELIABILITY OF TRACTOR ENGINES .....	971
<b>Tomas Mickevicius, Stasys Slavinskas, Gvidonas Labeckas</b> IMPACT OF AVIATION FUEL ON DURABILITY OF DIESEL COMMON RAIL INJECTION SYSTEM .....	977
<b>Stefan Cornak</b> DIAGNOSIS OF FUELS WITH INFRARED SPECTROSCOPY UTILIZATION .....	982
<b>Mykola Gorbunov, Alexandr Kravchenko, Juraj Gerlici, Kateryna Kravchenko, Vladimir Hauser, Tomas Lack</b> PROCESSING AND RECYCLING OF RUBBER AND OIL WASTES INTO HYDROCARBON FUEL BY METHOD OF PHYSICO-CHEMICAL ACTIVATION.....	988
<b>Karlis Banis</b> DESIGN DEVELOPMENT OF DYNAMOMETER WATER ABSORBER .....	995
<b>Iryna Hren, Stefan Michna, Lenka Michnova</b> DEPENDENCE OF MECHANICAL PROPERTIES ON POROSITY OF ALSI7MG0.3 ALLOY DURING GRAVITY CASTING.....	1001
<b>Aleksandrs Urbahs, Igors Lebedevs, Aleksandrs Sorokins, Vladislavs Turko</b> EXPERIMENTAL EVALUATION OF STRENGTH OF HONEYCOMB STRUCTURE PRODUCTS WITH POLYMER COMPOSITE SHELL .....	1007
<b>Pavel Gavrilov, Viktor Ivanov</b> STUDY OF EXOTHERMIC WELDED JOINT GRINDING BY "SPENO" RAIL GRINDERS .....	1013
<b>Sandra Gusta, Janis Gruntmanis, Silvija Strausa, Andris Steinerts</b> SIGNIFICANCY OF MOVEMENT JOINTS OF MASONRY WALLS FOR BUILDINGS BEING IN OPERATION.....	1022
<b>Elena Strihavkova</b> ANALYSIS OF EFFECT OF CALCIUM CONTENT ON MACHINABILITY OF ALLOYS TYPE ALSI7MG0.3 .....	1030
<b>Martin Tichy, Viktor Kolar, Miroslav Muller, Petr Valasek</b> QUASI-STATIC TESTS ON POLYURETHANE ADHESIVE BONDS REINFORCED BY RUBBER POWDER.....	1035

<b>Aleksandrs Urbahs, Konstantins Savkovs</b> HEAT RESISTANT CONGLOMERATE TI-AL-SI-CR-N COATINGS FOR TITAN ALLOY-BASED PARTS OF GAS TURBINE ENGINES .....	1042
<b>Alexandru Saracin, Gheorghe Voicu, Ion Saracin, Pandia Olimpia</b> DETERMINATION OF USE OF DENTAL MATERIALS AND STOMATOLOGICAL FREES ON STAND.....	1048
<b>Volodymyr Bulgakov, Anastasiya Kutsenko, Semjons Ivanovs, Simone Pascuzzi</b> STUDY ON PROPAGATION REGULARITY OF HARMONIC WAVES IN PERIODIC STRUCTURES OF BEAMS .....	1053
<b>Anete Meija-Feldmane, Errj Sansonetti, Andris Morozovs, Uldis Spulle</b> THERMAL MODIFICATION AS TOOL TO INCREASE HYDROPHOBICITY OF VENEERS.....	1059
<b>Arturs Riekstins, Viktors Haritonovs, Valters Abolins, Verners Straupe, Janis Tihonovs</b> LIFE CYCLE COST ANALYSIS OF BBTM AND TRADITIONAL ASPHALT CONCRETES IN LATVIA .....	1065
<b>Ieva Bake, Vineta Afanasjeva, Silvija Kukle</b> EVALUATION OF MODIFIED KNITWEAR PROPERTIES .....	1073
<b>Anete Smoca</b> WATER ABSORPTION PROPERTIES OF HEMP FIBRES REINFORCED PLA BIO- COMPOSITES.....	1079
<b>Vitaly Krupenin</b> MODELING AND CALCULATION OF AUTORESONANCE MECHATRONIC VIBRATION DEVICE .....	1084
<b>Andrejs Jaunzems</b> VALUE ADDED CREATED BY INDUSTRY "EDUCATION" IN BALTIC STATES AND FINLAND.....	1090
<b>Andrejs Jaunzems, Ilze Balode</b> COMPARATIVE DYNAMIC ANALYSIS OF VALUE ADDED CREATED BY INDUSTRY "CROP AND ANIMAL PRODUCTION, HUNTING AND RELATED SERVICE ACTIVITIES" IN THE BALTIC STATES AND FINLAND .....	1104
<b>Radu Popa, Vlad Popa</b> COMPUTER ASSISTED SIMULATION OF FORAGE CHOPPING PROCESS .....	1118
<b>Valery Korzhakov, Alexey Korzhakov, Svetlana Korzhakova</b> METHOD OF POWER OPTIMIZATION IN GEOTHERMAL HEATING SYSTEM BY SOLVING INTERRELATED PROBLEMS OF ACOUSTIC AND MAGNETIC DEVICE MODEL .....	1123
<b>Barbara Jagosz, Stanislaw Rolbiecki, Roman Rolbiecki, Anna Figas, Wieslaw Ptach</b> EFFECT OF SPRINKLER IRRIGATION ON YIELD INCREASING OF CARROT ROOTS OBTAINED IN CULTIVATION ON LIGHT SOIL IN DIFFERENT REGIONS OF POLAND .....	1135
<b>Inga Ciprovica, Evalds Raits, Asnate Kirse-Ozolina</b> DESIGNING OF THERMAL TREATMENT PARAMETERS FOR TOMATO SAUCES .....	1140
<b>Aivars Aboltins, Harijs Kalis, Ilmars Kangro</b> CAM WITH SPECIAL SPLINES FOR SOLVING OF DIFFUSION-CONVECTION PROBLEMS WITH DISCONTINUOUS COEFFICIENTS FOR LAYERED MATERIALS EXPOSED TO FIRE .....	1147
<b>Egils Dzelzitis, Natalia Sidenko</b> NUMERICAL SIMULATION OF HEAT EXCHANGE IN DISCRETE-ROUGH CHANNELS AT FLOW SUPERIMPOSED OSCILLATIONS .....	1155
<b>Anna Figas, Barbara Jagosz, Stanislaw Rolbiecki, Roman Rolbiecki, Wieslaw Ptach</b> EFFECT OF THE PREDICTED CLIMATE CHANGES ON THE WATER NEEDS OF CAULIFLOWER CULTIVATED IN THE CENTRAL POLAND .....	1162

<b>Maris Eiduks, Edgars Kovals, Janis Viba, Lauris Stals</b> ANALYSIS OF BODY COLLISIONS AGAINST OBSTACLES .....	1168
<b>Oleh Marus, Gennadii Golub, Savelii Kukharets, Viacheslav Chuba</b> RESEARCH OF INFLUENCE OF AIR RESISTANCE ON PARTICLE MOVEMENT ON RADIAL PLANE FIXED IN HORIZONTAL ROTATING CYLINDER .....	1174
<b>Andrejs Kovalovs, Andris Chate</b> OPTIMAL ELECTRODE POSITION FOR DELAMINATION DETECTION IN CARBON FIBRE REINFORCED POLYMER COMPOSITES USING ELECTRIC RESISTANCE CHANGE METHOD .....	1180
<b>Oksana Takhumova, Tatiana Bondarenko, Sergei Shlykov, Ruslan Omarov</b> STUDYING IDENTIFICATION ALGORITHMS IN FOOD TECHNOLOGY .....	1186
<b>Erika Sujova, Helena Cierna, Roman Bambura</b> SIMULATION MODEL OF PRODUCTION AS TOOL FOR INDUSTRY 4.0 IMPLEMENTATION INTO PRACTICE.....	1192
<b>Harijs Kalis, Maksims Marinaki, Liva Ozola, Uldis Strautins</b> NUMERICAL STUDY OF ELECTRODYNAMIC CONTROL OF STRAW CO- FIRING WITH PROPANE .....	1198
<b>Marcis Eimanis, Janis Auzins</b> RESEARCH OF DYNAMICS OF DOUBLE HELICOIDAL VEHICLE IN GRANULAR MEDIA.....	1205
<b>Sergei Oskin, Dmitry Tsokur, Sergey Voloshin</b> MODELING PROCESS OF WATER BUBBLING WITH OZONE TO OBTAIN DISINFECTANT SOLUTIONS IN BEEKEEPING.....	1210
<b>Martins Irbe, Karlis Agris Gross, Janis Viba, Marina Cerpinska</b> MODELLING OF STIFFNESS VARIABILITY OF SKELETON SLED ON INCLINED ICE PLANE.....	1215
<b>Janis Galins, Aigars Laizans, Ainars Galins</b> PASSIVE COOLING OF ELECTRONIC COMPONENTS USING CLOSED ALUMINIUM HOUSING FILLED WITH LIQUID.....	1221
<b>Alexey Korzhakov, Sergei Oskin, Svetlana Korzhakova</b> TECHNIQUE OF CREATING NEW CONSTRUCTIONS OF ACOUSTIC AND MAGNETIC DEVICES BASED ON THEORY OF SIMILARITY AS DEVELOPMENT OF THEORY OF EXPERIMENT .....	1227
<b>Ivo Vaicis, Alexander Janushevskis, Janis Auzins, Janis Janushevskis</b> MODELING AND ANALYSIS OF DUST CONTROL HOPPER SYSTEM .....	1237
<b>Sharif E. Guseynov, Jekaterina V. Aleksejeva</b> ON ONE INVERSE PROBLEM OF OPTIMAL PLANNING UNDER UNCERTAINTY IN PREDICTION .....	1243
<b>Tatjana Rubina, Aivars Aboltins, Janis Palabinskis</b> DRYING CHARACTERISTICS OF RHUBARB CUBES AT LOW TEMPERATURE.....	1249
<b>Jan Krmela, Vladimira Krmelova</b> COMPUTATIONAL MODELLING OF BELT OF TIRE-CASING.....	1257
<b>Sergey Rakutko, Elena Rakutko, Ansis Avotins, Peteris Apse-Apsitis</b> METHOD AND DEVICE FOR MEASURING STABILITY OF PLANT DEVELOPMENT BY FLUCTUATING ASYMMETRY OF OPTICAL DENSITY OF LEAVES.....	1263
<b>Aleksandr Vostrukhin, Elena Vakhtina</b> TEMPERATURE SENSOR RESISTANCE CONVERSION TO BINARY CODE USING PULSE WIDTH MODULATION .....	1269
<b>Oksana Mamai, Sergey Mashkov, Velta Parsova</b> PROSPECTS FOR USE OF TECHNICAL CYBERNETICS IN ANIMAL HUSBANDRY .....	1275

<b>Jevgenijs Prostaks, Margarita Urbaha</b> EVALUATING ACCURACY OF FAULT LOCALIZATION WHEN MONITORING CONDITION OF LARGE STRUCTURES BY ACOUSTIC METHOD .....	1280
<b>Aleksandrs Gasparjans, Aleksandrs Terebkovs, Anastasija Ziravecka</b> THEORETICAL AND EXPERIMENTAL ANALYSIS OF TECHNICAL CONDITION OF PISTON RINGS OF VESSEL DIESEL INSTALLATIONS BY METHOD OF RESONANCE OSCILLATIONS .....	1287
<b>Andrius Nemeiksis, Vitalijs Osadcuks</b> APPLICATION OF COMBINATION OF NEURAL NETWORKS AND FUZZY LOGIC IN PLANNING OF MOBILE ROBOT MOTION IN UNKNOWN ENVIRONMENT .....	1295
<b>Nikolajs Glizde, Margarita Urbaha</b> REMOTELY PILOTED AIRCRAFT SYSTEM AIR VEHICLE TYPE SELECTION .....	1302
<b>Roman Trochimeczuk, Andrzej Lukaszewicz, Ryszard Szczebiot, Alexey G. Kirillov, Ile Mircheski</b> MODELING, PROGRAMMING AND SIMULATION OF ROBOTIZED WORKCELLS CREATED FOR INDUSTRIAL AND SERVICE NEEDS .....	1313
<b>Inesa Barmina, Antons Kolmickovs, Raimonds Valdmanis, Sergejs Vostrikovs</b> ELECTRODYNAMIC CONTROL OF STRAW CO-FIRING WITH PROPANE .....	1319
<b>Alexandros Sotirios Anifantis, Edmund Lorencowicz, Artur Przywara, Simone Pascuzzi, Giuseppe Ruggiero, Francesco Santoro</b> COMMON GREENHOUSE CONDITIONING PLANTS COMPARED WITH VERSATILE GEOTHERMAL SYSTEM IN AMES, IOWA.....	1325
<b>Savelii Kukharets, Gennadii Golub, Kornel Szalay, Oleh Marus</b> STUDY OF ENERGY COSTS IN PROCESS OF BIOMASS MIXING IN ROTARY DIGESTER .....	1331
<b>Yaroslav Yarosh, Gennadii Golub, Savelii Kukharets, Viacheslav Chuba</b> EXPERIMENTAL STUDY OF WOOD GAS-OPERATED POWER PLANT OPERATION .....	1337
<b>Gennadii Golub, Savelii Kukharets, Yaroslav Yarosh, Oksana Zavadska</b> STRUCTURAL MODELS OF AGROECOSYSTEMS AND CALCULATION OF THEIR ENERGY AUTONOMY.....	1344
<b>Nataliya Tsyvenkova, Anna Holubenko, Ivan Omarov, Marina Tereshchuk</b> THE INFLUENCE OF THE RECOVERY CHAMBER PARAMETERS ON THE EFFICIENCY OF BIOMASS GASIFICATION PROCESS.....	1351
<b>Raimunds Selegovskis, Janis Berzins</b> METHOD FOR DETERMINING CONSUMER HEAT ENERGY DEMAND PROFILE USING HEAT CONSUMPTION DATA FROM PREVIOUS PERIODS .....	1365
<b>Szymon Szewranski, Marian Kachniarz, Marta Sylla, Malgorzata Swiader, Katarzyna Tokarczyk-Dorociak</b> SPATIO-TEMPORAL ASSESSMENT OF ENERGY CONSUMPTION AND SOCIO- ECONOMIC DRIVERS IN RURAL AREAS IN POLAND .....	1372
<b>Muhannad Shahbari, Karam Sadi, Sergej Kolesnik, Moshe Sitbon, Alon Kuperman</b> INFLUENCE OF ELECTRICITY TARIFFS ON OPTIMAL SOLAR COLLECTORS ORIENTATION IN NEGEV REGION .....	1379
<b>Vilis Dubrovskis, Imants Plume, Indulis Straume</b> METHANE PRODUCTION POTENTIAL FROM VARIETY OF UNPRINTED PAPERS .....	1383
<b>Vilis Dubrovskis, Imants Plume, Indulis Straume</b> CO-DIGESTION OF MOLASSES WITH DRY GRAIN SWEEPS AND BIRCH LEAVES .....	1389
<b>Vilis Dubrovskis, Imants Plume, Indulis Straume</b> USE OF ENZYME ALPHA AMYLASE TO INCREASE BIOGAS YIELD FROM LUCERNE PELLETS AND BIRCH LEAVES PELLETS .....	1394

<b>Vladislav Zavadskiy, Alexandros Sotirios Anifantis, Francesco Santoro</b> SOLVING OF RENEWABLE ENERGY SOURCES USABLE POTENTIAL EVALUATION IN REMOTE RURAL AREA ON EXAMPLE OF BASILICATA REGION (SOUTHERN ITALY) - CASE STUDY .....	1401
<b>Shravan Koundinya Vutukuru, Janis Viba, Igors Tipans, Ilmars Viksne, Martins Irbe</b> ANALYSIS OF FLAT PLATE VIBRATIONS BY VARYING FRONTAL AREA TO THE FLOW .....	1408
<b>Anna Holubenko, Nataliya Tsyvenkova, Inna Nezdvetskaya, Oleg Pluzhnikov</b> RESULTS OF INVESTIGATION IN CORROSION PROCESSES IN GASIFYER GASIFYING FUELS CONTAINING STRAW AND LIGNIN .....	1415
<b>Van Doan Cao, Pavel Kic</b> EFFECT OF SHADING WITH TREES TO IMPROVE LOCAL TEMPERATURE CONDITIONS .....	1423
<b>Ilze Pelece, Imants Ziemeļis, Henriks Putans, Andrejs Snegovs</b> IMPROVEMENT OF EFFICIENCY OF PV PANELS FOR WATER HEATING BY CHANGING HEATER RESISTANCE .....	1430
<b>Marina Cerpinska, Martins Irbe, Rihards Elmanis-Helmanis</b> SWIRLING FLOW IN FRANCIS TURBINES DEPENDING ON GUIDE VANES OPENING POSITION .....	1435
<b>Aleksandrs Urbahs, Nikolaj Kuleshov, Dmitrijs Titovs, Leonid Chernin</b> CALCULATION AND SIMULATION OF AERODYNAMIC CHARACTERISTICS OF WIND POWER PLANT TURBINE .....	1441
<b>Modrite Pelse, Lasma Aleksejeva, Dace Ziedina</b> INNOVATION LEVEL ON GLOBAL AND NATIONAL SCALE IN CONTEXT OF RENEWABLE ENERGY PRODUCTION IN LATVIA .....	1449
<b>Gennady Nikitenko, Evgeny Konoplev, Vladimir Salpagarov, Alexander Lysakov</b> SOLAR AND WIND STAND-ALONE POWER SYSTEM .....	1456
<b>Rodions Saltanovs, Aivars Rubenis</b> BUILDING OF POWER BACKUP SYSTEM WITH PARALLEL CONNECTION TO GRID .....	1463
<b>Kaspars Kroics</b> SIMULATION BASED ANALYSIS OF QUASI Z-SOURCE CONVERTER FOR WIRELESS POWER TRANSFER .....	1468
<b>Lorant Denes David, Csilla Molnar, Joanna Kosmaczewska, Gyula Fodor, Martin Zsarnoczky, Imre Varga, Zuzana Palencikova</b> ECOENERGY TOURISM, STUDY INTO SOME ASPECTS OF RELATIONSHIP BETWEEN USE OF RENEWABLE ENERGY RESOURCES AND SUSTAINABLE REGIONAL AND RURAL DEVELOPMENT .....	1478
<b>Janar Kalder, Mart Hovi, Alo Allik, Andres Annuk</b> INTERSEASONAL HEAT STORAGE FOR RESIDENTIAL BUILDINGS WITH RENEWABLE ENERGY GENERATION .....	1484
<b>Georgiana Moiceanu, Gheorghe Voicu, Gigel Paraschiv, George Ipate</b> ASPECTS REGARDING MISCANTHUS CUTTING PROCESS FEM SIMULATION AND SOME EXPERIMENTAL DATA .....	1490
<b>Igor Devederkin, Gennady Nikitenko, Sergey Antonov, Alexander Lysakov</b> AUTONOMOUS WIND POWER SYSTEM FOR REMOTE SHEEP FARMS .....	1497
<b>Adrian Knapczyk, Slawomir Francik, Jaroslaw Fraczek, Zbigniew Slipek</b> ANALYSIS OF RESEARCH TRENDS IN PRODUCTION OF SOLID BIOFUELS .....	1503
<b>Elzbieta Szafranko</b> COMPARATIVE ANALYSIS OF RENEWABLE ENERGY RESOURCES POTENTIALLY ACCESSIBLE IN RURAL AREAS .....	1510
<b>Imants Nulle, Aivars Kakitis, Mareks Smits, Olafs Vronskis</b> MATHEMATICAL MODELING OF STALK BIOMASS SHREDDING PROCESS .....	1516



<b>Aleksandrs Adamovics, Rasma Platace, Aivars Kakitis, Semjons Ivanovs</b> EVALUATION OF COMBUSTION PROPERTIES OF BIOMASS FUEL .....	1523
<b>Edgars Repsa, Eriks Kronbergs</b> COMMON REED BRIQUETTING MODELING WITH WORKING MODEL PROGRAMME .....	1529
<b>Valentyna Krutyakova, Volodymyr Bulgakov, Aleksandrs Adamovics, Nonna Pishchanska</b> SELECTION OF OPTIMAL DIMENSIONS OF AIR HUMIDIFICATION SECTION IN MICROCLIMATE PREPARATION SYSTEM FOR GROWING OF ENTOMOPHAGES .....	1533
<b>Algirdas Jasinskas, Vilma Banioniene, Egle Jotautiene, Imants Ziemelis</b> INVESTIGATION OF BLACK POPLAR ( <i>POPULUS NIGRA</i> L.) PREPARATION AND UTILIZATION FOR ENERGY CONVERSION .....	1540
<b>Andis Lazdins, Edgars Iecelnieks, Agris Zimelis, Gints Spalva</b> EVALUATION OF WORK METHODS FOR PRODUCTION OF SOLID BIOFUEL FROM HARVESTING RESIDUES IN COMMERCIAL THINNING OF CONIFEROUS FORESTS.....	1546
<b>Vladislav Zavadskiy, Gita Revalde</b> POSSIBILITY OF USING ELECTRIC POWER STORAGE SYSTEMS IN RURAL REGIONS WITH COMBINATION OF RENEWABLE ENERGY SOURCES FOR AUTONOMOUS ENERGY SUPPLY .....	1552
<b>Egidijus Zvicevicius, Algirdas Raila, Ausra Cipliene, Kestutis Ziura</b> INFLUENCE OF MOISTURE ON OSIER WILLOW CHOPS CHARACTERISTICS .....	1561
<b>Krzysztof Mudryk, Taras Hutsol, Marek Wrobel, Marcin Jewiarz, Barbara Dziedzic</b> DETERMINATION OF FRICTION COEFFICIENTS OF FAST-GROWING TREE BIOMASS .....	1568
<b>Slawomir Kurpaska, Pawel Kielbasa</b> TECHNICAL AND ECONOMIC ANALYSIS OF USE OF SOLAR COLLECTORS IN GREENHOUSE PRODUCTION .....	1574
<b>Andrejs Snegovs, Henriks Putans, Liene Kancevica, Imants Ziemelis</b> DEVELOPMENT OF SOLAR PANELS TRACKER SENSOR .....	1581
<b>Viktorija Zagorska, Andrejs Snegovs, Henriks Putans, Imants Ziemelis</b> SINGLE MOTOR TWO-AXEL SOLAR PANELS TRACKING DEVICE USING SLIDER-CRANK MECHANISM .....	1587
<b>Valerii Vtoryi, Sergei Vtoryi, Roman Ylyin</b> AMMONIA CONCENTRATION IN COW BARN UNDER LIMITED AIR EXCHANGE.....	1593
<b>Dace Arina, Janis Kalnacs, Ruta Bendere, Aleksandrs Murasovs</b> MECHANICAL PRE-TREATMENT FOR SEPARATION OF BIO-WASTE FROM MUNICIPAL SOLID WASTE: CASE STUDY OF DISTRICT IN LATVIA .....	1599
<b>Ligita Melece, Ilze Shena</b> CLIMATE CHANGE ADAPTATION POLICY: ISSUES IN LATVIA.....	1605
<b>Mihails Urbans, Inese Vilcane, Jelena Malahova</b> ASSESSMENT OF TECHNOGENIC RISKS IN RECOVERING COMPANY FOR WORN TYRES.....	1616
<b>Stefan Vasilica, Simion Maria Andra, Lucretia Popa, Ancuta Nedelcu, Radu Ciuperca</b> PRE-TREATMENT OF INDUSTRIAL WASTE WATER WITH HYDROCARBON SEPARATORS .....	1623
<b>Andrea Pezzuolo, Cristina Sartori, Evelin Vigato, Stefano Guercini</b> EFFECT OF LITTER TREATMENT WITH PROBIOTIC BACTERIA ON AMMONIA REDUCTION IN COMMERCIAL BROILER FARM.....	1631
<b>Jurii Vlasov, Vladimir Katsadze, Irina Igotti, Aleksei Teppoev</b> EXPERIMENTAL STUDIES OF BIRCH BARKING WASTE SHREDDING.....	1636

<b>Karol Krol</b> ZOOMLENS – GRAPHIC FORM OF DATA PRESENTATION ON A WEB MAP, COMPARISON OF CHOSEN TOOL AND USAGE EXAMPLES .....	1641
<b>Dmitry Namiot, Manfred Sneps-Sneppe</b> ON PROXIMITY INFORMATION SYSTEMS .....	1649
<b>Dmitrijs Gorelikovs, Margarita Urbaha</b> CONTROL OF AGRICULTURAL LAND FLOODING BY USING REMOTELY PILOTED AIRCRAFT SYSTEM .....	1655
<b>Viktor Yarosh, Alexey Efanov, Sergey Yastrebov, Evgeny Privalov</b> PRESENTATION OF SPATIAL DATA OF ELECTRIC NETWORKS IN GEO- INFORMATION SYSTEMS .....	1661
<b>Raitis Melniks, Janis Ivanovs, Andis Lazdins</b> ESTIMATION OF DOMINANT TREE HEIGHT IN FOREST STANDS USING LIDAR DATA.....	1667
<b>Vladimir Trukhachev, Sergei Oliinyk, Tatyana Lesnyak, Nikolay Zlyidnev</b> APPLICATION OF UNMANNED AERIAL VEHICLES FOR REMOTE ESTIMATION OF PASTURE FERTILITY WHILE GROWING DZHALGINSKY MERINO SHEEP .....	1673
<b>Janis Ivanovs, Raitis Melniks, Ilona Skranda</b> EVALUATION OF IMPACT OF SOIL COMPACTION IN DITCH-SIDES DURING FORWARDING OF ROUNDWOOD ON GROUNDWATER LEVEL IN NEIGHBOURING FOREST STAND .....	1680
<b>Mikhail Aleshin, Larisa Gavrilova, Andrey Melnikov</b> USE OF UNMANNED AERIAL VEHICLES ON EXAMPLE OF PHANTOM 4 (STANDARD) FOR CREATING DIGITAL TERRAIN MODELS .....	1686
<b>Petr Matejka</b> UTILIZATION OF DIGITIZED BUILDING DATA AND INFORMATION MODELS (BIM) IN VALUE ESTIMATION OF BUILDING IN RURAL AREAS.....	1693
<b>Stanislav Vitasek</b> USING BUILDING INFORMATION MODELLING (BIM) IN CONSTRUCTION BUDGET: BENEFITS AND BARRIERS .....	1699
<b>Martin Stransky, Petr Matejka</b> DIGITAL QUALITY MANAGEMENT IN CONSTRUCTION INDUSTRY WITHIN BIM PROJECTS .....	1707
<b>Josef Zak, Stanislav Vitasek</b> BIM AND DATA STANDARD FOR EFFECTIVE INVESTMENT IN INFRASTRUCTURE.....	1719
<b>Aleksandr Birjukov, Evgeniy Dobryshkin, Igor Kravchenko, Maxim Glinskiy</b> OPTIMIZATION OF MANAGEMENT DECISIONS FOR CHOOSING THE STRATEGY OF ENTERPRISES FIXED ASSETS REPRODUCTION .....	1726
<b>Alexander Pastukhov, Eugeny Timashov, Tatyana Parnikova</b> ASSESSMENT OF OPERABILITY OF MAINTAINABLE CROSSPIECE .....	1736
<b>Jerzy Jozwik, Arkadiusz Tofil, Andrzej Lukaszewicz</b> APPLICATION OF MODERN MEASUREMENT TECHNIQUES FOR ANALYSIS OF INJECTION MOULDING SHRINKAGE .....	1742
<b>Magdalena Zawada-Michalowska, Pawel Piesko, Jerzy Jozwik, Andrzej Lukaszewicz</b> WEAR OF TURNING TOOL DURING MACHINING OF STEELS USED IN SURGICAL INSTRUMENTS .....	1749
<b>Ile Mircheski, Andrzej Lukaszewicz, Roman Trochimeczuk, Ryszard Szczebiot</b> APPLICATION OF CAX SYSTEM FOR DESIGN AND ANALYSIS OF PLASTIC PARTS MANUFACTURED BY INJECTION MOULDING.....	1755

<b>Igor Kravchenko, Maxim Glinskiy, Yury Kuznetsov, Tatiana Cheha</b> CONCEPTION OF CAE SYSTEM SUPPORT FOR PROTECTIVE COATING DEPOSITION PROCESS DESIGN IN AGROINDUSTRIAL COMPLEX .....	1761
<b>Sergey Strebkov, Andrey Bondarev, Alexey Slobodyuk</b> ECONOMIC ASSESSMENT OF RECOVERY OF ALUMINUM RADIATOR BY GAS-DYNAMIC SPRAYING .....	1772
<b>Aleksejs Nipers, Irina Pilvere, Agnese Krievina, Valda Bratka</b> PROJECTING INVESTMENTS AND FIXED ASSETS IN AGRICULTURE IN LATVIA .....	1779
<b>Justine Jaunzeme</b> HOLISTIC APPROACH TO FAIR VALUE ESTIMATION .....	1786
<b>Eduard Hromada</b> REAL ESTATE PRICES IN THE CZECH REPUBLIC: BEHAVIORAL APPROACH .....	1795
<b>Sandra Gusta, Inese Gusta</b> PROBLEMS OF PROVIDING AFFORDABLE HIGH QUALITY STUDENT HOUSING IN CONTEXT OF DEVELOPMENT OF MAJOR LATVIAN UNIVERSITIES .....	1801
<b>Jozsef Kaposzta, Henrietta Nagy, Samir Zaien, Gabriella Horvath-Csikos, Hanna Andrea Solyomfi</b> RURAL DEVELOPMENT ACCORDING TO REGIONAL PLANNING STRATEGIES CASE STUDY (EGYPT AND SAUDI ARABIA).....	1811
<b>Andrii Martyn, Ivan Openko, Taras Ievsiukov, Oleksandr Shevchenko, Artem Ripenko</b> ACCURACY OF GEODETIC SURVEYS IN CADASTRAL REGISTRATION OF REAL ESTATE: VALUE OF LAND AS DETERMINING FACTOR .....	1818
<b>Lilla Aldorfai-Czabadai, Gyorgy Aldorfai, Zoltan Topa</b> EXAMINATION OF DEVELOPMENT-AIMED SPATIAL DIVISION SYSTEMS IN HUNGARY .....	1826
<b>Tatjana Tambovceva, Maria Tereshina, Vera Samarina</b> GREEN INNOVATIONS IN REGIONAL ECONOMY .....	1832
<b>Hannu E.S. Haapala</b> SPEEDING UP INNOVATION PROCESSES IN AGRICULTURAL ENGINEERING THROUGH USER-CENTRED DESIGN AND MULTI-ACTOR APPROACH .....	1840
<b>Aivars Timofejevs, Valdis Avotins</b> ROLE AND VALUE OF USER BASE AROUND LARGE-SCALE RESEARCH FACILITIES .....	1846
<b>Grazyna Gawronska, Krzysztof Gawronski, Karol Krol</b> PROBLEMS OF TREE AND SHRUB FELLING – LESSON FROM POLAND.....	1858
<b>Roman Rolbiecki, Magdalena Rolbiecka, Stanislaw Rolbiecki, Barbara Jagosz, Ariel Langowski</b> COST-EFFECTIVENESS OF SPRINKLER IRRIGATION OF CHOSEN EARLY CULTIVARS OF POTATO GROWN ON VERY LIGHT SOIL IN CENTRAL POLAND.....	1864
<b>Radan Tomek</b> PROCESSING AND RECYCLING OF RUBBER AND OIL WASTES INTO HYDROCARBON FUEL BY METHOD OF PHYSICO-CHEMICAL ACTIVATION.....	1870
<b>Petr Jilek, Ivo Sefcik, Jan Verner, Jan Berg</b> SYSTEM ALLOWING ADHESION FORCE CHANGE OF ROAD VEHICLE .....	1876
<b>Boris Medvedev, Sergey Molodyakov</b> INTERNET OF THINGS FOR FARMERS: EDUCATIONAL ISSUES .....	1883
<b>Liga Feldmane</b> STUDENTS' SATISFACTION WITH THEIR HOST CITY: CASE OF JELGAVA, LATVIA .....	1888

<b>Elena Zorina, Irina Kartavtzeva, Irina Krusian, Svetlana Mikhienko, Natalya Poddubnaya</b> IMPACT OF STUDENT MOBILITY IN AGRO-ENGINEERING UNIVERSITIES ON DEVELOPMENT OF VOCATIONAL SPEECH CULTURE .....	1894
<b>Aliya Murzagaliyeva, Bakytgul Jugembayeva</b> READINESS FOR INNOVATIVE ACTIVITY AS IMPORTANT PROFESSIONAL COMPETENCE OF NEW GENERATION ENGINEER.....	1899
<b>Dagnija Cedere, Inese Jurgena, Rita Birzina</b> EVALUATION OF SCIENCE AND TECHNOLOGY AREA FIRST YEAR STUDENT LEARNING OUTCOMES.....	1903
<b>Gatis Vitols, Irina Arhipova, Liga Paura</b> ENGINEERING STUDY PROGRAM COMPLIANCE EVALUATION TO GUIDELINES FOR SOFTWARE ENGINEERING CURRICULUM.....	1909
<b>Olha Chaikovska, Lesia Zbaravska, Tetiana Bilyk</b> PODCASTS IN TEACHING EFL FOR STUDENTS MAJORING IN ENGINEERING.....	1915
<b>Sylvia Kusmierczak, Makovsky Martin</b> EXAMPLE OF USING COMPLEX SYSTEM APPROACH METHODOLOGY BY DEGRADATION OF SELECTED TECHNICAL OBJECT.....	1921
<b>Anda Zeidmane</b> ICT IN LIFE OF STUDENTS AT THE LATVIA UNIVERSITY OF LIFE SCIENCES AND TECHNOLOGIES .....	1927
<b>Stanislav Nikolaenko, Oksana Bulgakova, Ilmars Dukulis, Irina Pilvere</b> METHODOLOGICAL ASPECTS OF TRAINING FUTURE AGROENGINEERS .....	1933
<b>Aivars Aboltins, Svetlana Atslega, Natalija Sergejeva, Liene Strupule</b> ONE OF OPPORTUNITIES TO REDUCE STUDENT DROPOUTS.....	1941
<b>Anna Vintere, Baiba Briede</b> METHODICAL BACKGROUND OF COMPETENCE-BASED MATHEMATICS EDUCATION FOR STUDENTS OF INFORMATION TECHNOLOGIES SPECIALTIES .....	1947
<b>Anna Vintere, Liga Zvirgzdina</b> CASE STUDY ON DEVELOPMENT OF MATHEMATICAL COMPETENCE OF FOREST SPECIALTIES STUDENTS .....	1954
<b>Svetlana Asmuss, Natalja Budkina</b> ON USAGE OF VISUALIZATION TOOLS IN TEACHING MATHEMATICS AT UNIVERSITIES .....	1962

**REVIEWERS**

Aboltins A., Atilgan A., Aleknavicius A., Abramovics B., Andres A., Ibrahim Nasr Elhendawi A., Ariko S., Anifantis A., Bondarevs A., Burg P., Birkavs A., Bulgakovs V., Berjoza D., Bielski S., Briede B., Bietresato M., Barmina I., Birkavs A., Banaszuk P., Bracacescu C., Birzietis G., Baltusite R., Berzina M., Biris-Sorin S., Budnikov D., Braginets S., Belinskaia I., Benes L., Ciprovica I., Cerpinska M., Chuba V., Caban J., Cielava L., Cedere D., Cardei P., Cwiklan J., Duma M., Dorbe A., Dubrovskis V., Dukulkis I., Erdal I., Fornai D., Freimanis J., Goworski M., Gedzurs A., Gasparjans A., Gailis M., Grinchenko V., Galins A., Gadjos I., Gusta S., Gritsans A., Gozdowski D., Hazners J., Hurtova I., Haapala H., Ivanovs S., Ikase L., Iriste S., Ivanovs J., Juhnevica Radenkova K., Judrups J., Jankauskas V., Masek J., Jilek P., Jasinskas A., Jakusonoks A., Jaunzeme J., Jurmalietis R., Jankava A., Jansons V., Janmiere L., Jaskiewicz B., Jaroskav J., Jonikavicius D., Jaunzems A., Jotautiene E., Knapczyk A., Kreslins K., Kakitis A., Kalinin A., Kalis H., Kronbergs E., Kukharets S., Kreicbergs J., Katane I., Kirse-Ozolina A., Kaposzta J., Koloszko-Chamentovska Z., Kroics K., Kic P., Korzhakov A., Kanaska D., Kromanis A., Krupenin V., Kleperis J., Kancevica L., Karol K., Kulesza Z., Kleinbergs V., Lipinskas T., Leimane I., Licite L., Laurs A., Latal O., Lebedeva K., Lacekli-Bertmanis J., Lazdina D., Laiveniece L., Lukaszewicz A., Lorant Denes D., Laizans A., Marinello F., Minajeva A., Mangalis M., Mironovs D., Melece L., Muizniece-Brasava S., Marchenko V., Mullers M., Morozovs A., Matejka P., Mielcarek P., Moskvins G., Manea D., Medvedskyi O., Mikhaylenko I., Masan V., Mazure G., Nulle I., Naprstkova N., Nadulski R., Nagy H., Novotny J., Osadcuks V., Omar S., Oskina A., Palabinskis J., Parsova V., Popa L., Palabinska A., Pavlyuk R., Poisa L., Pascuzzi S., Pudzs M., Proskina L., Pelse M., Pilvere I., Popluga D., Plataca R., Priekulis J., Pecka A., Pastukhov A., Panysheva T., Pezzuolo A., Pakrastins L., Pekka H., Pruss B., Popluga D., Polukoshko S., Pelece I., Petaja G., Ptach W., Rucins A., Rubina T., Rolbieckis S., Ruska D., Revalde G., Rzeznik W., Ilves I., Rimkuviene D., Repsa E., Rolbieckis S., Saplavaska J., Shimanovskis A., Shalavina E., Stoilova S., Sieczko L., Svobodova J., Saltuk B., Subbotin I., Spiridonovs J., Szafranko E., Salamandra K., Strihavkova E., Santoro Fr., Scheiner J., Sergejeva N., Slavinskas S., Sejkorova M., Szewranski s., Sloka B., Sojka M., Szfaranko E., Shipkovs P., Strausa S., Sarangthem Sanajaoba S., Selegovskis R., Smits M., Tsyvenkova N., Trupa A., Terebkovs A., Tambovceva T., Tamas T., Ungureanu N., Viba J., Viesturs D., Verdins G., Vartukapteinis K., Vtoryi V., Volodko I., Wierzbiskis D., Vronska N., Vronskis O., Voicu G., Zewdie R., Zagorska J., Ziemelis I., Zagorska V., Zvicevicius E., Zake M., Zimelis A., Zaimis U., Zorina E., Zlobina E., Zabava B., Zalcmanis G., Zukerstein J., Zhauyt A.

## EXPERIMENTAL INVESTIGATION OF TECHNICAL AND OPERATIONAL INDICES OF ASYMMETRIC SWATH REAPER MACHINE-AND-TRACTOR AGGREGATE

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**Abstract.** Asymmetric machine-and-tractor aggregates are often used for two-phase harvesting of cereals, when, at first, the cereals are in the phase of wax ripeness and they are mown into swaths, and then, as the mass dries out, reaching full maturity, they are threshed by combine harvesters. Such a method of harvesting cereals is very efficient in case the crops are wet and with an insufficiently even degree of maturity. A specificity of such trailed units is the presence of asymmetric tractive load upon the tractor, which causes unstable dynamics of the movement in a horizontal plane, a need to correct the direction of the movement, etc. The purpose of the investigation – to determine the optimal technical and operational indices of an asymmetric swath reaper machine-and-tractor aggregate according to the results of its field experimental research. Better quality of the operation of an improved swath reaper is ensured by the devices for setting its supporting wheels at an angle of 8° to the direction of its movement. When using a more improved swath reaper, in contrast to the base variant, the productivity of the main time increases from 4.1 ha·h<sup>-1</sup> to 4.34 ha·h<sup>-1</sup>, the specific fuel consumption – from 2.85 kg·ha<sup>-1</sup> to 2.65 kg·ha<sup>-1</sup>, and the total loss of the loose grains and the grains in the cut ear – from 1.3 % to 0.2 %.

**Keywords:** asymmetric, reaper, aggregate, productivity, losses, grain.

### Introduction

Asymmetric machine-and-tractor aggregates are often used for harvesting cereals and grass [1-2]. Especially widely used in Ukraine are asymmetric swathe reaper aggregates for two-phase harvesting of cereals, when, at first, the cereals are in the phase of wax ripeness and they are mown into swaths, and then, as the mass dries out, reaching full maturity, they are threshed by combine harvesters. Such a method of harvesting cereals is very efficient in case the crops are wet and with an insufficiently even degree of maturity [3].

A specificity of such trailed units is the presence of asymmetric tractive load upon the tractor [4;5]. This causes unstable dynamics of the movement in a horizontal plane, a need to correct the direction of the movement, etc., which affects the operational and technological indicators of the aggregate as a whole [3;5]. To follow to the path of the movement of the machine-and-tractor aggregate, it is necessary to install the guiding (driving) wheels of the tractor at a certain angle to the longitudinal axis of symmetry of the tractor and to correct their direction constantly; the movement takes place at a certain speed.

The operation of asymmetric machine-and-tractor aggregates has been investigated by many scientists [4-7], the designs of the trailed machines that improve stability of the movement are being constantly improved. However, there are practically few studies of the impact of the design parameters upon the quality of work of the grain harvesters. For instance, there are an insufficient number of investigations of the impact of the speed conditions or certain improvement upon such technological and agrotechnical indicators as the losses of grain, the stubble cutting height, the width of the swathe, etc. Asymmetrical swath reapers ZVP-6 are widely used in Ukraine; in Western European countries Stoll R1405S, Krone Swadro TC930 V1.1.0.0, Agromet Famarol Z211 and others are used.

The purpose of the investigation – to determine the optimal technical and operational indices of an asymmetric swath reaper machine-and-tractor aggregate (MTA) according to the results of its field experimental research.

### Materials and methods

The program of experimental investigation provided for the study of the impact of the speed of the movement of the harvesting aggregate upon the quality indicators of the cut stalk density of cereals

and the parameters of the swath to be formed [8-12]. In particular, the object of research was a trailed swath reaper aggregate with a device for turning its supporting wheels.

The experimental investigations were conducted at four speeds – 1.8; 2.1; 2.8 and 3.8 m·s<sup>-1</sup>, which correspond to the range of the operating speed of the swath reapers. The exact speed of the movement was controlled using a track measuring wheel.

In this case as the quality indicators of the cut stalk density the average height of the stubble and the coefficient of its variation, as well as the losses of grain were assumed. The average height of the stubble was determined by measuring it at five reference points by means of a tape measure with an accuracy of  $\pm 1$  mm after the passage of the harvesting unit, followed by the determination of the arithmetic average value and coefficient of variation according to generally accepted expressions. The grain losses were determined by overlaying a frame of 1 m<sup>2</sup> at five points after the passage of the harvesting aggregate, collecting the loose grains and the grains in the ear, and then weighing them on electronic scales with an accuracy of  $\pm 0.001$  g.

When conducting the experimental field investigations, as the main parameters of the swath were selected its width and thickness, measured in five test points according to existing methods by means of a tape measure with an accuracy of  $\pm 1$  mm.

The research results were processed by the methods of mathematical statistics [13;14] and by constructing graphical and functional dependencies using the PC for PC Excel and Statistic. To estimate the fluctuations of the measured parameters, the standard deviation  $\sigma$  was calculated (further indicated in the explanatory notes to the graphs).

In order to determine the operational and technological indicators of the asymmetric machine-and-tractor aggregate, we carried out experimental investigations. For this purpose an aggregate was prepared, consisting of an MTZ-82 aggregating tractor and a trailed swath reaper (Fig. 1). Thus, on the basis of the swath reaping machine-and-tractor aggregate an experimental installation was created, which made it possible to obtain the performance indicators under real field conditions.



**Fig. 1. Asymmetric swath reaper aggregate,  
prepared for experimental field investigations**

During the experimental field investigations of this asymmetrical swath reaping machine-and-tractor aggregate for a pre-calculated number of repetitions of experiments, accurate measurements of the performance indicators of this aggregate were made. A track-measuring wheel was installed on the swath reaper, which allowed to determine the actual speed of the movement and the path travelled by the aggregate with a sufficient degree of accuracy when conducting the field experimental studies (Fig. 2). In order to measure the forces that create the unwinding moment on the asymmetrically trailed swath reaper, a DEF-A2t strain gauge was used, the readings of which were recorded and processed using a special program on the PC (Fig. 3).



Fig. 2. Track-measuring wheel, installed on trailed swath reaper



Fig. 3. Strain gauge DEF-A2t

The experimental investigations were performed on an agricultural background (agrofone), the characteristics of which are given in Table 1.

Table 1

### Characteristics of the agrophone during the experimental investigations

Indicator	Value
Soil moisture (%) in the layer:	
0...5 cm	9.7
5...10 cm	12.4
10...15 cm	14.8
Soil hardness in the layer 0...15 cm, MPa	2.3
Yield of wheat, t·ha <sup>-1</sup>	3.6
Plant density, pcs·m <sup>-2</sup>	496
Average plant height, m	0.84
Weight of 1000 pcs. of seeds, g	46
Ratio of the grain weight to the straw weight	1:1.6
Losses of grain from self-shedding, %	0.2
Weediness of crops, g·m <sup>-2</sup>	42

### Results and discussion

As the results of the preliminary experimental investigations and tests of the trailed swath reapers show, during the harvesting period the soil moisture in the soil layer 0...10 cm varies within the limits 10...20 %. Hence it follows that, to ensure the desired stability of the movement of the trailed swath reaper, its design must provide that the supporting wheels are mounted in a horizontal plane at an angle of 0...10°. The analysis of the obtained data showed that an increase in the speed of the working movement of the harvesting machine-and-tractor aggregate from 2.1 to 2.8 m·s<sup>-1</sup> does not cause a growth in the height of the stubble of wheat. The difference between the average values of this indicator of 1.7 cm (Table 2) at a statistical significance level of 0.05 is random, since in this case HIP<sub>05</sub> equals 2.1 cm (the smallest significant difference at the current level of significance 0.05) [13].

At the same time, with an increase in the speed of the movement up to 3.8 m·s<sup>-1</sup>, the average value of the height of the stubble of wheat increased to 23.6 cm, which is significant and not random in contrast to the two previous modes of speed.

The same can be said about the mean square deviations of the estimated indicator. According to Fisher's F-criterion [13], the zero hypothesis of equality of the compared standards is rejected only when the harvesting machine-and-tractor aggregate is moving at a speed of 3.8 m·s<sup>-1</sup>.

As a result of the experimental field investigations, the value of the working width of the swath reaper was established, corresponding to the working speed of the forward movement of the asymmetrical trailed aggregate, at which efficient interaction of the operating tools of the reaper with the cut stalk density of cereals is achieved. Thus, to the speed of 1.8 m·s<sup>-1</sup> corresponds a working width of the reaper of 6.08 m, to 2.1 m·s<sup>-1</sup> corresponds 5.92 m, to 2.8 m·s<sup>-1</sup> corresponds 5.88 m, to



$3.8 \text{ m}\cdot\text{s}^{-1}$  corresponds 5.8 m. Based on the analysis of the experimental data, the function of the dependence of the working width of the trailed swath reaper  $B$  on the speed of the harvesting aggregate  $V$  has been established:

$$B = 0.0743V^2 - 0.537V + 6.774. \quad (1)$$

Table 2

Performance indicators of the trailed swath reaper

Indicator	Speed of the movement of the MTA, $\text{m}\cdot\text{s}^{-1}$			
	1.8	2.1	2.8	3.8
Parameters of the swath reaper:				
turn the left wheel, deg.	8	8	8	8
turn the right wheels, deg.	8	8	8	8
Stubble height:				
average value, cm	17.8	18.8	20.5	23.6
(HIP <sub>05</sub> = 2.1 cm) standard, $\pm$ cm	2.4	2.4	2.3	5.8
coefficient of variation, %	11.9	12.7	11.2	21.8
Average value of the working width, m (HIP <sub>05</sub> = 0.10 m)	6.08	5.92	5.88	5.80
Characteristics of the swath:				
thickness cm	23.2	23.6	25.0	27.6
width, cm	177.4	175.5	154.8	149.5
distance to soil,	12	12	13	14
Preferred angle of the stems, deg.	66	65	56	58
Losses behind the swath reaper:				
total, %	0.16	0.17	0.21	0.27
including the loose grain	0.10	0.10	0.11	0.10
grain from the cut ears	0.06	0.07	0.10	0.13
grain from not-cut ears	0	0	0	0.04

As a result of the conducted experimental investigations, the impact of the speed of the movement of the asymmetric harvesting aggregate  $V$  upon the quality of the cut stalk density, determined by the average height of the stubble  $H$  and the coefficient of variation of its value  $V_N$ , was established. Their graphical interpretation is shown in Fig. 4, Curve 1.

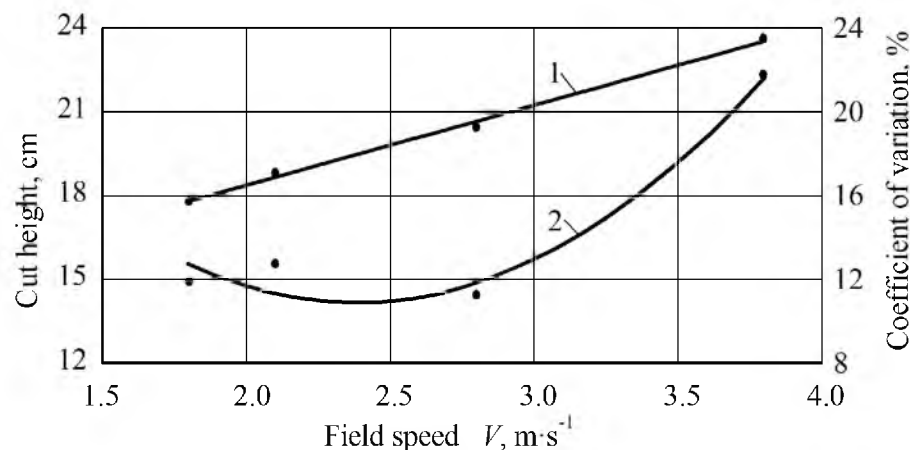


Fig. 4. Dependence of average value of height of stubble (1) and coefficient of variation of height of stubble (2) upon working speed of movement of asymmetric harvesting aggregate ( $\sigma = 1.20 \text{ cm}$ )

It has been established that, with an increase in the speed of the movement of the aggregate, the height of the stubble will increase proportionally according to a linear dependence: from 17.8 cm at a speed of  $1.8 \text{ m}\cdot\text{s}^{-1}$  to 23.6 cm at  $3.8 \text{ m}\cdot\text{s}^{-1}$ . This dependence is represented by a function that best approximates the experimental data of the form:

$$H = 2.8564 V + 12.677. \quad (2)$$

The increase in the value of the coefficient of variation of the height of the stubble  $V_N$ , when the working speed of the movement of the aggregate  $V$  increases, is described by a function of a polynomial of the second degree of the following kind:

$$V_N = 5.2918 V^2 - 25.157 V + 40.842, \quad (3)$$

and the graph of this dependence has the form given in Fig. 4, Curve 2.

According to this dependence, the minimum value of the coefficient of variation of the cutting height, which determines the most uniform cut, is achieved at the forward speed of the harvesting aggregate equal to  $2.38 \text{ m}\cdot\text{s}^{-1}$ .

During the operation of the asymmetric swath reaper aggregate a swath is formed, the width and thickness of which, according to the research, is also affected by the working speed of the aggregate (Fig. 5).

Increasing the speed of the movement of the swath reaper, the width of the formed swath decreases (Fig. 3, Curve 1), but its thickness, on the contrary, increases (Fig. 5, Curve 2). Their value also depends on the working width of the swath reaper, which depends on the speed of its movement. Thus, at a speed of the reaper  $1.8 \text{ m}\cdot\text{s}^{-1}$ , which corresponds to the minimum speed during the experimental field investigations, the width of the swath is  $177.4 \text{ cm}$ , and its thickness is  $23.2 \text{ cm}$ . At a speed of the movement of the swath reaper of  $3.8 \text{ m}\cdot\text{s}^{-1}$ , the width and thickness of the swath are  $149.5 \text{ cm}$  and  $27.6 \text{ cm}$ , respectively. In addition to it, at all speeds the asymmetrical reaper aggregate formed rectilinear swaths (Fig. 6).

The impact of the speed of the movement of the harvesting aggregate  $V$  upon the width  $B_L$  and the thickness of the roll  $H_L$  is described by functions of such type:

$$B_L = 7.5581 V^2 - 57.717 V + 259.25, \quad (4)$$

$$H_L = 0.4091 V^2 - 0.0791 V + 21.996. \quad (5)$$

It has been substantiated that one of the main ways of efficient formation of a swath by a swath reaper, when harvesting cereals, is an ability to change the speed of the conveyor belts of the swathe reaper depending on the working speed of the harvesting aggregate. Since one of the most significant indicators of the quality of work during the cereal harvesting is the loss of grains behind the reaper, the impact of the speed of the movement of the harvester  $V$  upon the total losses of the grains  $P$  behind the reaper, as well as the losses of the loose grains  $P_1$ , the grains in the cut ear  $P_2$  and the grains in the not-cut ear  $P_3$  were established. The graphs of dependences of the value of the total loss of cereals and their individual kinds are shown in Fig. 7.

According to the analysis of the obtained results, it was found that, increasing the forward speed of the movement of the swath reaper, the total losses of cereals also increase (Fig. 7, Curve 1).

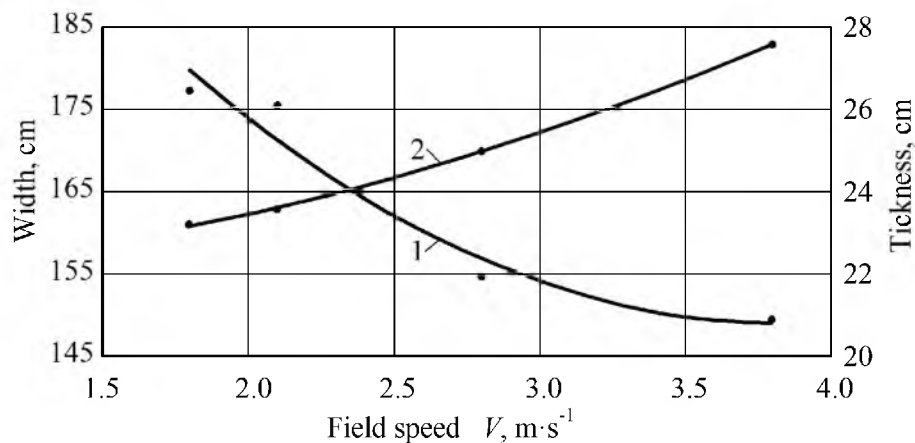


Fig. 5. Dependence of width (1) and thickness (2) of swath on working speed of reaper aggregate ( $\sigma = 3.80 \text{ cm}$ )



Fig. 6. View of swaths formed by swath reaper at speed of working movement of harvesting machine-and-tractor aggregate equal to  $3.8 \text{ m}\cdot\text{s}^{-1}$

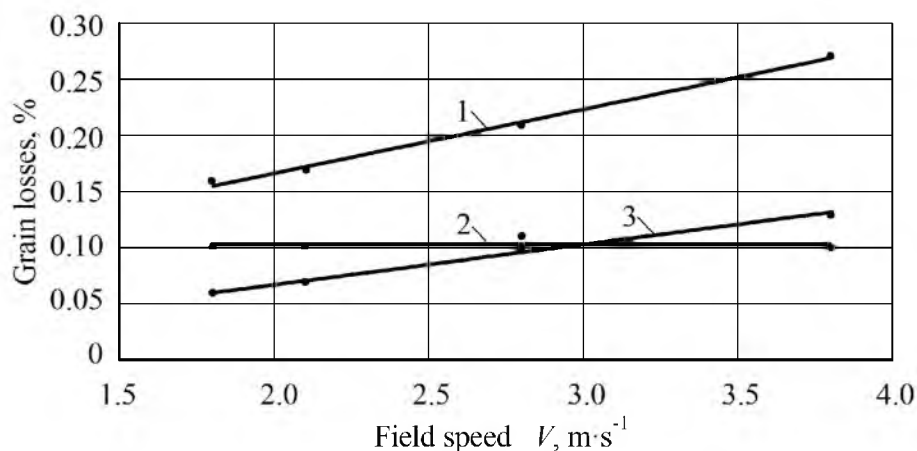


Fig. 7. Graph of dependence of total losses of cereals behind swath reaper (1), loose grains (2) and grains in cut ear (3), upon working speed of aggregate ( $\sigma = 0.008 \%$ )

In addition to this, increasing the speed of the movement of the swath reaper, the losses of grains in the cut ear will also increase (Fig. 7, Curve 3), although the value of the losses of cereals has an almost constant value at different speeds of the header –  $0.10\text{...}0.11 \%$  (Fig. 7, Curve 2). The increase in the total losses of grain at the speed of the movement of the reaper  $3.8 \text{ m}\cdot\text{s}^{-1}$  is explained by the losses of grain in the uncut ears ( $0.04 \%$ ), which did not appear at lower speeds. On the whole, the total losses of grain behind the trailed swath reaper at all speeds did not exceed the values that are set by the agrotechnical requirements.

The impact of the speed of the movement of the swath reaper upon the total loss of cereals is described by a functional dependence of the following kind:

$$P = 0.0056 V^2 + 0.0242 V + 0.0966. \quad (6)$$

When using a more improved swath reaper, in contrast to the base variant, the productivity of the main time increases from  $4.1 \text{ ha}\cdot\text{h}^{-1}$  to  $4.34 \text{ ha}\cdot\text{h}^{-1}$ , the specific fuel consumption – from  $2.85 \text{ kg}\cdot\text{ha}^{-1}$  to  $2.65 \text{ kg}\cdot\text{ha}^{-1}$ , and the total loss of the loose grains and the grains in the cut ear – from  $1.3 \%$  to  $0.2 \%$ , which confirms the expediency of the improvement.

The mean square deviations of the height of the wheat stubble in the first and the second high-speed modes represent the same random process, i.e. they are statistical characteristics of the same general totality. As regards the variability of the considered process (fluctuation in the height of the wheat stubble), when the harvesting machine-and-tractor aggregate is moving at a speed  $2.1$  and  $2.8 \text{ m}\cdot\text{s}^{-1}$ , then, judging by the values of the coefficients of variation, this variability is average, but at the speed of the movement  $3.7 \text{ m}\cdot\text{s}^{-1}$  it is high (Table 2).

Analysis of the data in Table 2 shows that, with the increase in the speed of the movement of the harvesting aggregate, the width of the swaths decreases, but their thickness, on the contrary, increases.

The obtained result is entirely logical, yet it points to the need to reequip the reaper so that its design is provided for a change in the speed of the conveyor belts depending on the change in the forward motion of this harvesting machine-and-tractor aggregate. The operational and technological tests of the experimental and the basic (a similar machine-and-tractor aggregate without a device for turning the supporting wheels of the trailed swath reaper) harvesting aggregates were carried out against the same agrotechnical background. The experimental harvesting machine-and-tractor aggregate moved at an average speed  $7.36 \text{ km}\cdot\text{h}^{-1}$  ( $2.04 \text{ m}\cdot\text{s}^{-1}$ ). The basic productivity of work was  $4.27 \text{ ha}\cdot\text{h}^{-1}$  (Table 3).

Table 3

**Operational and technological indicators  
of the swath reaper machine-and-tractor aggregates**

Indicator	Value for the machine-and-tractor aggregates	
	new	basic
Conditions and mode of operation:		
length of the furrow, m	1200	
speed of the movement, $\text{km}\cdot\text{h}^{-1}$	7.36	7.30
working width, m	5.90	5.60
height of the stubble, cm	15.0	16.0
amount of the performed operation, ha	60.0	57.0
Labour productivity per 1 hour :		
basic time, ha	4.34	4.10
shift time, ha	3.70	3.44
operating time, ha	3.60	3.30
technological time, ha	3.54	3.25
Specific consumption of fuel, $\text{kg}\cdot\text{ha}^{-1}$	2.65	2.85
Agrotechnical indicators: grain losses behind the swath reaper (loose grains and grains in the ear), %	0.20	1.30

Nevertheless, taking into account the value of  $\text{HIP}_{05}$ , which under the conditions of the experiment was 0.10 m, this change is significant only in comparison of the first and the third modes of speed, i.e. it can be affirmed that by increasing the harvesting speed of the machine-and-tractor aggregate not less than by 67 % (in this case, from 2.1 to  $3.7 \text{ m}\cdot\text{s}^{-1}$ ), the working width of the swath reaper decreases (and it is no coincidence) by 2.0 %.

The basic harvesting machine-tractor aggregate moved at the same speed of the forward movement. But, due to a larger deviation of the swath reaper in a horizontal plane, its working width was by 5.1 % less. As a result, the basic productivity of its work turned out to be by 5.5 % and of the shift productivity – by 7 % less. As the final result, this led to an increase in the specific fuel costs for the basic harvesting machine-and-tractor aggregate in comparison with the experimental one (see Table 3). The operational and technological indicators of the compared machine-and-tractor aggregates turned out to be approximately the same. As for such agrotechnical indicators, which are losses behind the swath reaper, the new aggregate has significantly (6.5 times) less losses. Higher-quality work of the latter is ensured by practically absent deviation of a swath reaper, equipped with the devices for setting its supporting wheels at an angle to the direction of the movement (in this case,  $8^\circ$ ). In case the supporting wheels of the trailed swath reaper are installed at an angle to the direction of its movement, there is practically no lagging during the right-side turn on the headland.

## Conclusions

Better quality of the operation of an improved swath reaper is ensured by the devices for setting its supporting wheels at an angle of  $8^\circ$  to the direction of its movement. When using a more improved swath reaper, in contrast to the base variant, the productivity of the main time increases from  $4.1 \text{ ha}\cdot\text{h}^{-1}$  to  $4.34 \text{ ha}\cdot\text{h}^{-1}$ , the specific fuel consumption – from  $2.85 \text{ kg}\cdot\text{ha}^{-1}$  to  $2.65 \text{ kg}\cdot\text{ha}^{-1}$ , and the total loss of the loose grains and the grains in the cut ear – from 1.3 % to 0.2 %, which confirms the expediency of the improvement.

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