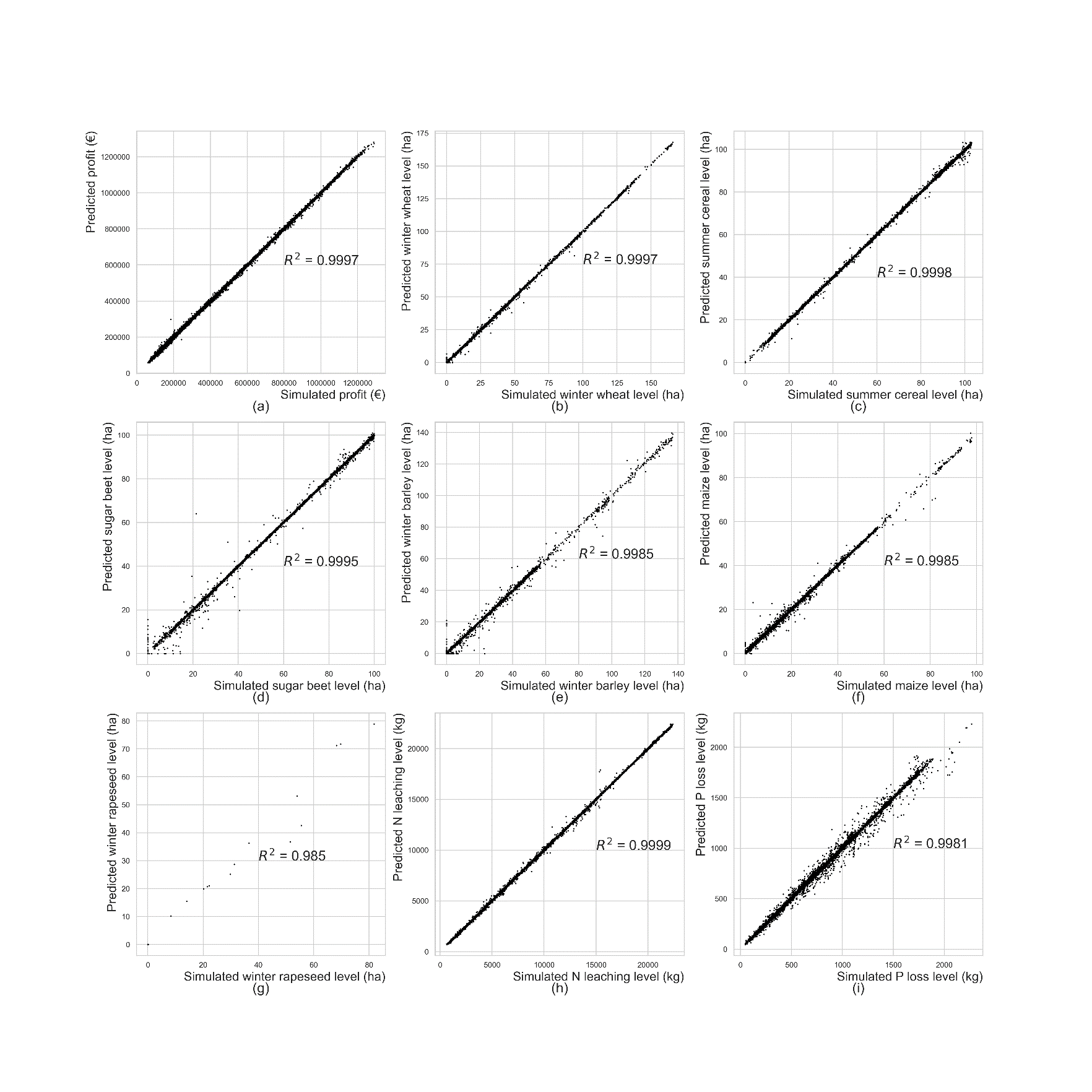
**Surrogate modelling of a detailed farm-level model using deep learning**

# Linmei Shang, Jifeng Wang, David Schäfer, Thomas Heckelei, Juergen Gall, Franziska Appel and Hugo Storm

**ON-LINE APPENDICES.**

# Appendix A: Predictions of BiLSTM3 against simulated outputs of a few selected output variables



# Appendix B: Maximum Information Coefficient (MIC) (Reshef et al., 2011)

For two variables *x* and *y*, the MIC is calculated with Eq. (B.1).

|  |  |
| --- | --- |
|  | (B.1) |

where is the mutual information (Cover & Thomas, 2006) between and ;

is the minimum joint entropy (Cover & Thomas, 2006) between and ;

and are the number of bins of and .

**Citations in the appendix**

Cover, T. M. and Thomas, J. A. *Elements of information theory* (Hoboken, N.J.: John Wiley & Sons, Inc, 2006).

Reshef, D. N., Reshef, Y. A., Finucane, H. K., Grossman, S. R., McVean, G., Turnbaugh, P. J., Lander, E. S., Mitzenmacher, M. and Sabeti, P. C. ‘Detecting novel associations in large data sets’ *Science (New York, N.Y.)*, Vol. 334 (2011) pp. 1518–1524.

# Appendix C: Surrogate modelling of dairy farms in FarmDyn

In addition, in order to test if our approach is also applicable to other farm types, we use the case of dairy farms in FarmDyn, which have a higher number of variables and equations than arable farms. To focus on the most relevant variables, we selected 19 inputs and 27 outputs. Following the training procedure described in section 3, surrogate models for dairy farms are developed. To simplify the process, we only train MLP type of surrogates. The best trained surrogate model achieves a level of high accuracy ( = 0.97) using 52,160 data points for training. According to our experience with arable farms, BiLSTM could get a better performance with sufficient hyperparameter tuning. The required amount of training data is different from arable farms because the underlying relationships and the number of variables are different. The selected MLP has three hidden layers with 2048, 64, and 128 neurons in each hidden layer. Other hyperparameters are as the following: learning rate = 0.001, optimiser = Adam, mini-batch size = 32.

We fix the hyperparameters and experiment with different amounts of training data (see the detailed procedure in section 3.3.3). Table C.1 presents the results of the experiment.

**Table C.1: Amount of training data and goodness of fit of surrogate models of dairy farms**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Amount of training data | 1,000 | 5,000 | 10,000 | 52,160 |
| Goodness of fit | 0.59 | 0.87 | 0.90 | 0.97 |

Note: The goodness of fit in this table is the average results of five surrogate models trained with different random seeds.

# Appendix D: Input and output variables of arable farms in FarmDyn

**Table D.1: Detailed list of inputs of arable farms in FarmDyn**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No.** | **Name of inputs** | **Short definition** | **Sampling range** | **Unit** |
| 1 | Crops\_hours\_\_mean | working hours dedicated to cropping activities | 0-2918 | h |
| 2 | WinterWheat\_Price\_conv | price of winter wheat | 0-155.82 | €/t |
| 3 | WinterBarley\_Price\_conv | price of winter barley | 0-147.98 | €/t |
| 4 | SummerCere\_Price\_conv | price of summer cereal | 176.4-177.38 | €/t |
| 5 | WinterRape\_Price\_conv | price of winter rapeseed | 0-180 | €/t |
| 6 | Sugarbeet\_Price\_conv | price of sugar beet | 0-198 | €/t |
| 7 | Summerpeas\_Price\_conv | price of summer peas | 0-164 | €/t |
| 8 | Summerbeans\_Price\_conv | price of summer beans | 0-32 | €/t |
| 9 | Diesel\_Price\_\_mean | price of diesel | 0-0.84 | €/L |
| 10 | AHL\_Price\_\_mean | price of fertiliser AHL (Ammoniumnitrat-Harnstoff-Lösung: solution of urea and ammonium nitrate) | 0-0.2856 | €/kg |
| 11 | seed\_Price\_\_mean | price of seed | 0-1.2 | €/kg |
| 12 | PK\_18\_10\_Price\_\_mean | price of fertiliser “PK\_18\_10” (Phosphor + Kalium: phosphorus + potassium) | 0-0.2832 | €/kg |
| 13 | Lime\_Price\_\_mean | price of lime | 0-0.0648 | €/t |
| 14 | Herb\_Price\_\_mean | price of herbicide | 0-1.2 | €/kg |
| 15 | Fung\_Price\_\_mean | price of fungicide | 0-1.2 | €/kg |
| 16 | Insect\_Price\_\_mean | price of insecticide | 0-1.2 | €/kg |
| 17 | growthContr\_Price\_\_mean | price of growth control | 0-1.2 | €/kg |
| 18 | hailIns\_Price\_\_mean | price of a unit of hail insurance | 0-11.892 | €/unit |
| 19 | plough\_Price\_\_mean | price of a plough | 10400-15600 | €/unit |
| 20 | workOpp4\_wage\_\_mean | wage rate for off-farm work assumed to be a 200% position | 0-14.22 | €/h |
| 21 | hourly\_wage\_\_mean | hourly wage rate for hourly off-farm | 0-9 | €/h |
| 22 | tractor\_Price\_\_mean | price of a tractor | 38400-57600 | €/unit |
| 23 | tractorSmall\_Price\_\_mean | price of a small tractor | 32000-48000 | €/unit |
| 24 | chiselPlough\_Price\_\_mean | price of a chisel plough | 4480-6720 | €/unit |
| 25 | sowMachine\_Price\_\_mean | price of sow machine | 10000-15000 | €/unit |
| 26 | directSowMachine\_Price\_\_mean | price of a direct sow machine | 36800-55200 | €/unit |
| 27 | seedBedCombi\_Price\_\_mean | price of a seedbed combination machine | 8000-12000 | €/unit |
| 28 | circHarrow\_Price\_\_mean | price of a circular harrow | 10400-15600 | €/unit |
| 29 | springTineHarrow\_Price\_\_mean | price of a spring tine harrow | 5880-8820 | €/unit |
| 30 | fingerHarrow\_Price\_\_mean | price of a finger harrow | 2800-4200 | €/unit |
| 31 | combine\_Price\_\_mean | price of a combine | 120800-181200 | €/unit |
| 32 | cuttingUnitCere\_Price\_\_mean | price of a cutting unit for cereal | 15600-23400 | €/unit |
| 33 | cuttingAddRape\_Price\_\_mean | price of an additional cutting unit for rapeseed | 7120-10680 | €/unit |
| 34 | cuttingUnitMaiz\_Price\_\_mean | price of a cutting unit for maize | 27200-40800 | €/unit |
| 35 | rotaryHarrow\_Price\_\_mean | price of a rotary harrow | 6080-9120 | €/unit |
| 36 | mulcher\_Price\_\_mean | price of a mulcher | 6720-10080 | €/unit |
| 37 | potatoPlanter\_Price\_\_mean | price of a potato planter | 21200-31800 | €/unit |
| 38 | potatoLifter\_Price\_\_mean | price of a potato lifter | 56000-84000 | €/unit |
| 39 | hoe\_Price\_\_mean | price of a hoe | 4720-7080 | €/unit |
| 40 | ridger\_Price\_\_mean | price of a ridger | 6240-9360 | €/unit |
| 41 | haulmCutter\_Price\_\_mean | price of a haulm cutter | 7840-11760 | €/unit |
| 42 | forkLiftTruck\_Price\_\_mean | price of a fork lifter truck | 38-57 | €/unit |
| 43 | threeWayTippingTrailer\_Price\_\_mean | price of a three-way tipping trailer | 14000-21000 | €/unit |
| 44 | Sprayer\_Price\_\_mean | price of a sprayer | 10800-16200 | €/unit |
| 45 | singleSeeder\_Price\_\_mean | price of a single seeder | 12400-18600 | €/unit |
| 46 | beetHarvester\_Price\_\_mean | price of a beet harvester | 56800-85200 | €/unit |
| 47 | fertSpreaderSmall\_Price\_\_mean | price of a small fertiliser spreader | 2880-4320 | €/unit |
| 48 | fertSpreaderLarge\_Price\_\_mean | price of a large fertiliser spreader | 25200-37800 | €/unit |
| 49 | cornHeader\_Price\_\_mean | price of a corn header | 40000-60000 | €/unit |
| 50 | mowerConditioner\_Price\_\_mean | price of a mower conditioner | 11200-16800 | €/unit |
| 51 | grasReseedingUnit\_Price\_\_mean | price of a grass reseeding unit | 11600-17400 | €/unit |
| 52 | rotaryTedder\_Price\_\_mean | price of a rotary tedder | 5200-7800 | €/unit |
| 53 | rake\_Price\_\_mean | price of rake | 4160-6240 | €/unit |
| 54 | roller\_Price\_\_mean | price of a roller | 1960-2940 | €/unit |
| 55 | balePressHay\_Price\_\_mean | price of bale presser for hay | 2720-4080 | €/unit |
| 56 | manbarrel\_Price\_\_mean | price of a manure barrel | 23200-34800 | €/unit |
| 57 | draghose\_Price\_\_mean | price of a drag hose | 16400-24600 | €/unit |
| 58 | injector\_Price\_\_mean | price of a injector | 20400-30600 | €/unit |
| 59 | trailingshoe\_Price\_\_mean | price of a trailing shoe | 15200-22800 | €/unit |
| 60 | solidManDist\_Price\_\_mean | price of solid manure distributor | 53600-80400 | €/unit |
| 61 | frontLoader\_Price\_\_mean | price of a front loader | 306.67 | €/unit |
| 62 | siloBlockCutter\_Price\_\_mean | price of a silo block cutter | 840-1260 | €/unit |
| 63 | shearGrab\_Price\_\_mean | price of a shear grab | 616-924 | €/unit |
| 64 | dungGrab\_Price\_\_mean | price of a dung grab | 192-288 | €/unit |
| 65 | fodderMixingVeh8\_Price\_\_mean | price of a fodder mixing vehicle (8 m3) | 4250-6375 | €/unit |
| 66 | fodderMixingVeh10\_Price\_\_mean | price of a fodder mixing vehicle (10 m3) | 3000-4500 | €/unit |
| 67 | fodderMixingVeh16\_Price\_\_mean | price of a fodder mixing vehicle (16 m3) | 4400-6600 | €/unit |
| 68 | nNeed\_Quant\_\_mean | crop specific nitrogen need from fertiliser | 0-41401 | kg/ha |
| 69 | nMin\_Quant\_\_mean | nitrogen from mineral fertiliser | 0-45001 | kg/ha |
| 70 | pNeed\_Quant\_\_mean | crop specific phosphate need from fertiliser | 0-17405 | kg/ha |
| 71 | pMin\_Quant\_\_mean | phosphate from mineral fertiliser | 0-15321 | kg/ha |
| 72 | totLand\_arab\_\_mean | total size of the arable farm | 0-300 | ha |
| 73 | workOpp2\_wage\_\_mean | wage rate for off-farm work assumed to be a 100% position | 0-14.22 | €/h |
| 74 | workOpp1\_wage\_\_mean | wage rate for first off-farm work assumed to be a 50% position | 0-10 | €/h |
| 75 | workOpp5\_wage\_\_mean | wage rate for off-farm work assumed to be a 250% position | 0-13.36 | €/h |
| 76 | workOpp3\_wage\_\_mean | wage rate for off-farm work assumed to be a 150% position | 0-12.79 | €/h |
| 77 | workOpp6\_wage\_\_mean | wage rate for off-farm work assumed to be a 300% position | 0-14.17 | €/h |

Note:

1. The unit of hail insurance: a hail insurance to cover 1000€ of crop value.
2. Ranges of crop prices are based on KTBL (2018) but extended by the authors for simulation.
3. Explanation about the input variables whose value starts from 0: We included 0s in training to make the surrogate models learn a wider range of input variables. In a dynamic perspective, including 0s could be important for the coupling with an ABM where a price or farm size of zero could occur. Consider studying an input subsidy that effectively makes the input free, or output prices could be zero if there is no demand, or farmers lose their rental contract.
4. Explanation about the input variables that range from 0 to 1.2: For simulation, these variables vary from 80% to 120% of the average prices reported in KTBL (2018), and they differ from crop to crop. These variables include “Seed\_Price\_mean”, “Herb\_Price\_mean”, “Fung\_Price\_mean”, “Insect\_Price\_mean”, and “growthContr\_Price\_mean”.

**Table D.2: Detailed list of outputs of arable farms in FarmDyn**

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Name of output** | **Short definition** | **unit** |
| 1 | Crops\_hours\_FEB\_mean | labor hours dedicated to cropping in February | h |
| 2 | Crops\_hours\_MAR\_mean | labor hours dedicated to cropping in March | h |
| 3 | Crops\_hours\_APR\_mean | labor hours dedicated to cropping in April | h |
| 4 | Crops\_hours\_MAY\_mean | labor hours dedicated to cropping in May | h |
| 5 | Crops\_hours\_JUN\_mean | labor hours dedicated to cropping in June | h |
| 6 | Crops\_hours\_JUL\_mean | labor hours dedicated to cropping in July | h |
| 7 | Crops\_hours\_AUG\_mean | labor hours dedicated to cropping in August | h |
| 8 | Crops\_hours\_SEP\_mean | labor hours dedicated to cropping in September | h |
| 9 | Crops\_hours\_OCT\_mean | labor hours dedicated to cropping in October | h |
| 10 | WinterWheat\_AHL\_\_mean | amount of fertiliser “AHL” used for winter wheat per ha | kg/ha |
| 11 | WinterWheat\_PK\_18\_10\_\_mean | amount of fertiliser “PK\_18\_10” used for winter wheat per ha | kg/ha |
| 12 | WinterWheat\_levl\_\_mean | output of winter wheat in ha | ha |
| 13 | WinterWheat\_SReve\_\_mean | revenue from winter wheat | € |
| 14 | WinterWheat\_OQuant\_\_mean | output of winter wheat in tons | t |
| 15 | WinterWheat\_SQuant\_\_mean | sale quantity of winter wheat in tons | t |
| 16 | Sugarbeet\_AHL\_\_mean | amount of fertiliser "AHL" used for sugar beet per ha | kg/ha |
| 17 | Sugarbeet\_PK\_18\_10\_\_mean | amount of fertiliser "PK\_18\_10" used for sugar beet per ha | kg/ha |
| 18 | Sugarbeet\_levl\_\_mean | output of sugar beet in ha | ha |
| 19 | Sugarbeet\_SReve\_\_mean | revenue from sugar beet | € |
| 20 | Sugarbeet\_OQuant\_\_mean | output of sugar beet in tons | t |
| 21 | Sugarbeet\_SQuant\_\_mean | sale quantity of sugar beet in tons | t |
| 22 | Idle\_levl\_\_mean | amount of idle land in ha | ha |
| 23 | Diesel\_sum\_\_mean | expenditure on diesel | € |
| 24 | Diesel\_Quant\_\_mean | amount of diesel used | L |
| 25 | AHL\_sum\_\_mean | expenditure on "AHL" (Ammoniumnitrat-Harnstoff-Lösung) | € |
| 26 | AHL\_Quant\_\_mean | amount of "AHL" (Ammoniumnitrat-Harnstoff-Lösung) used | kg |
| 27 | seed\_sum\_\_mean | expenditure on seed | € |
| 28 | seed\_Quant\_\_mean | amount of seed used | kg |
| 29 | PK\_18\_10\_sum\_\_mean | expenditure on "PK\_18\_10" (Phosphor + Kalium) | € |
| 30 | PK\_18\_10\_Quant\_\_mean | amount of "PK\_18\_10" (Phosphor + Kalium) used | kg |
| 31 | Lime\_sum\_\_mean | expenditure on lime | € |
| 32 | Lime\_Quant\_\_mean | amount of lime used | kg |
| 33 | Herb\_sum\_\_mean | expenditure on herbicide | € |
| 34 | Herb\_Quant\_\_mean | amount of herbicide used | kg |
| 35 | Fung\_sum\_\_mean | expenditure on fungicide | € |
| 36 | Fung\_Quant\_\_mean | amount of fungicide used | kg |
| 37 | Insect\_sum\_\_mean | expenditure on insecticide | € |
| 38 | Insect\_Quant\_\_mean | amount of insecticide used | kg |
| 39 | growthContr\_sum\_\_mean | expenditure on growth control | € |
| 40 | growthContr\_Quant\_\_mean | amount of growth control used | kg |
| 41 | water\_sum\_\_mean | expenditure on water | € |
| 42 | water\_Quant\_\_mean | amount of water used | L |
| 43 | hailIns\_sum\_\_mean | total costs for hail insurance for crops | € |
| 44 | hailIns\_Quant\_\_mean | the amount of "hail insurance" units | unit |
| 45 | WCresidues\_SReve\_\_mean | revenue received from cereal residues | € |
| 46 | WCresidues\_OQuant\_\_mean | output of cereal residues | t |
| 47 | WCresidues\_SQuant\_\_mean | sale quantity of cereal residues | t |
| 48 | plough\_newCost\_\_mean | fixed costs of a plough | € |
| 49 | plough\_costs\_\_mean | variable costs of a plough | € |
| 50 | plough\_Use\_\_mean | use (in hectare) of a plough | ha |
| 51 | noTill\_levl\_\_mean | area of idle land without tillage | ha |
| 52 | normal\_levl\_\_mean | area of land that is normally prepared | ha |
| 53 | Other\_sum\_\_mean | total variable cost of machinery | € |
| 54 | fixedMach\_sum\_\_mean | total fixed cost of machinery | € |
| 55 | field\_P\_\_mean | phosphorus emissions from all farm sources | kg |
| 56 | field\_N2O\_\_mean | nitrous oxide emissions from all farm sources | kg |
| 57 | field\_N2Oind\_\_mean | indirect nitrous oxide emissions from all sources | kg |
| 58 | field\_NO3\_\_mean | nitrate emissions from all farm sources | kg |
| 59 | field\_CO2\_\_mean | carbon dioxide equivalent emissions from all sources | kg |
| 60 | field\_PM25\_\_mean | particulate matter (<2.5 um diameter) emission | kg |
| 61 | field\_PM10\_\_mean | particulate matter (<10 um diameter) emission | kg |
| 62 | leisure\_hours\_\_mean | slack variable to distribute labour not used in farming of off-farm activities | h |
| 63 | workOpp4\_hours\_\_mean | hours spent for off-farm work assumed to be a 200% position | h |
| 64 | workOpp4\_earn\_\_mean | yearly earnings for off-farm work assumed to be a 200% position | € |
| 65 | hourly\_hours\_\_mean | additional hours spent off-farm working on an hourly rate | h |
| 66 | hourly\_earn\_\_mean | yearly earnings of hourly work | € |
| 67 | tractor\_newCost\_\_mean | fixed costs of a tractor | € |
| 68 | tractor\_costs\_\_mean | variable costs of a tractor | € |
| 69 | tractor\_Use\_\_mean | use (in hours) of a tractor | h |
| 70 | tractorSmall\_newCost\_\_mean | fixed costs of a small tractor | € |
| 71 | tractorSmall\_costs\_\_mean | variable costs of a small tractor | € |
| 72 | tractorSmall\_Use\_\_mean | use (in hours) of a small tractor | h |
| 73 | chiselPlough\_newCost\_\_mean | fixed costs of a chisel plough | € |
| 74 | chiselPlough\_costs\_\_mean | variable costs of a chisel plough | € |
| 75 | chiselPlough\_Use\_\_mean | use (in hectare) of a chisel plough | ha |
| 76 | sowMachine\_newCost\_\_mean | fixed costs of a sow machine | € |
| 77 | sowMachine\_costs\_\_mean | variable costs of a sow machine | € |
| 78 | sowMachine\_Use\_\_mean | use (in hectare) of a sow machine | ha |
| 79 | seedBedCombi\_newCost\_\_mean | fixed costs of a seedbed combination machine | € |
| 80 | seedBedCombi\_costs\_\_mean | variable costs of a seedbed combination machine | € |
| 81 | seedBedCombi\_Use\_\_mean | use (in hectare) of a seedbed combination machine | ha |
| 82 | combine\_newCost\_\_mean | fixed costs of a combine | € |
| 83 | combine\_costs\_\_mean | variable costs of a combine | € |
| 84 | combine\_Use\_\_mean | use (in hours) of a combine | h |
| 85 | cuttingUnitCere\_newCost\_\_mean | fixed costs of a cutting unit for cereal | € |
| 86 | cuttingUnitCere\_costs\_\_mean | variable costs of a cutting unit for cereal | € |
| 87 | cuttingUnitCere\_Use\_\_mean | use (in hectare) of a cutting unit for cereal | ha |
| 88 | threeWayTippingTrailer\_newCost\_\_mean | fixed costs of a three-way tipping trailer | € |
| 89 | threeWayTippingTrailer\_costs\_\_mean | variable costs of a three-way tipping trailer | € |
| 90 | threeWayTippingTrailer\_Use\_\_mean | use (in hours) of a three-way tipping trailer | h |
| 91 | Sprayer\_newCost\_\_mean | fixed costs of a sprayer | € |
| 92 | Sprayer\_costs\_\_mean | variable costs of a sprayer | € |
| 93 | Sprayer\_Use\_\_mean | use (in hectare) of a sprayer | ha |
| 94 | singleSeeder\_newCost\_\_mean | fixed costs of a single seeder | € |
| 95 | singleSeeder\_costs\_\_mean | variable costs of a single seeder | € |
| 96 | singleSeeder\_Use\_\_mean | use (in hectare) of a single seeder | ha |
| 97 | beetHarvester\_newCost\_\_mean | fixed costs of a beet harvester | € |
| 98 | beetHarvester\_costs\_\_mean | variable costs of a beet harvester | € |
| 99 | beetHarvester\_Use\_\_mean | use (in hectare) of a beet harvester | ha |
| 100 | fertSpreaderSmall\_newCost\_\_mean | fixed costs of a small fertiliser spreader | € |
| 101 | fertSpreaderSmall\_Use\_\_mean | use (in hectare) of a small fertiliser spreader | ha |
| 102 | fertSpreaderLarge\_newCost\_\_mean | fixed costs of a large fertiliser spreader | € |
| 103 | fertSpreaderLarge\_Use\_\_mean | use (in hectare) of a large fertiliser spreader | ha |
| 104 | NMinApplied\_FEB\_\_mean | mineral nitrogen fertiliser applied in February | kg |
| 105 | NMinApplied\_Quant\_\_mean | mineral nitrogen fertiliser applied on farm | kg |
| 106 | PMinApplied\_FEB\_\_mean | mineral phosphorus fertiliser in February | kg |
| 107 | PMinApplied\_Quant\_\_mean | mineral phosphorus fertiliser applied on farm | kg |
| 108 | vCost\_Crops\_\_mean | total variable costs for crops | € |
| 109 | vCost\_cashCrops\_\_mean | total variable costs for cash crops (excl. idle) | € |
| 110 | vCost\_sum\_\_mean | sum of above | € |
| 111 | minAppl\_N2O\_\_mean | nitrous oxide emissions from mineral fertiliser application | kg |
| 112 | minAppl\_NH3\_\_mean | ammonia emissions from mineral fertiliser application | kg |
| 113 | minAppl\_NOx\_\_mean | nitric oxide emissions from mineral fertiliser application | kg |
| 114 | minAppl\_N2\_\_mean | nitrogen emissions from mineral fertiliser application | kg |
| 115 | minAppl\_N2Oind\_\_mean | indirect nitrous oxide emissions from mineral fertiliser application | kg |
| 116 | cropRev\_sum\_\_mean | crop revenue | € |
| 117 | offFarmRev\_sum\_\_mean | off farm revenue | € |
| 118 | sumInv\_sum\_\_mean | sum of investments | € |
| 119 | objval\_sum\_\_mean | objective value (net-profit) | € |
| 120 | profit\_sum\_\_mean | liquidity (coming from net(cash flow) - net withdrawal - leisure | € |
| 121 | opCashFlow\_sum\_\_mean | operational cash flow (all money inflow - variable costs) | € |
| 122 | finCashFlow\_sum\_\_mean | repayment on past credits + new credits - profit withdrawals | € |
| 123 | invCashFlow\_sum\_\_mean | deinvestment - investment | € |
| 124 | withDraw\_sum\_\_mean | profit withdrawal | € |
| 125 | netWithDraw\_sum\_\_mean | profit withdrawal (same as above) | € |
| 126 | depr\_sum\_\_mean | depreciation | € |
| 127 | sfPrem\_sum\_\_mean | total premium paid (i.e. direct payment 300€/Ha) | € |
| 128 | SalesRevenue\_sum\_\_mean | revenue from output | € |
| 129 | Income\_sum\_\_mean | earnings from sales revenues/premium/interest | € |
| 130 | sumVarCost\_sum\_\_mean | sum of the variable cost | € |
| 131 | inputCost\_sum\_\_mean | total sum of inputs used (includes synthetic fertiliser and phytosanitary) | € |
| 132 | syntfertCost\_sum\_\_mean | total cost of synthetic fertiliser | € |
| 133 | phytoSaniCost\_sum\_\_mean | total phytosanitary cost | € |
| 134 | machCost\_sum\_\_mean | total variable costs for machinery | € |
| 135 | vcostsActivity\_sum\_\_mean | total variable costs for crop activity | € |
| 136 | offFarm\_hours\_\_mean | total off farm hours | h |
| 137 | offFarm\_wage\_\_mean | average off farm wage rate | €/h |
| 138 | offFarm\_earn\_\_mean | total earnings from off farm work | € |
| 139 | farmManag\_hours\_JAN\_mean | hours spent on farm management in January | h |
| 140 | farmManag\_hours\_FEB\_mean | hours spent on farm management in February | h |
| 141 | farmManag\_hours\_MAR\_mean | hours spent on farm management in March | h |
| 142 | farmManag\_hours\_APR\_mean | hours spent on farm management in April | h |
| 143 | farmManag\_hours\_MAY\_mean | hours spent on farm management in May | h |
| 144 | farmManag\_hours\_JUN\_mean | hours spent on farm management in June | h |
| 145 | farmManag\_hours\_JUL\_mean | hours spent on farm management in July | h |
| 146 | farmManag\_hours\_AUG\_mean | hours spent on farm management in August | h |
| 147 | farmManag\_hours\_SEP\_mean | hours spent on farm management in September | h |
| 148 | farmManag\_hours\_OCT\_mean | hours spent on farm management in October | h |
| 149 | farmManag\_hours\_NOV\_mean | hours spent on farm management in November | h |
| 150 | farmManag\_hours\_DEC\_mean | hours spent on farm management in December | h |
| 151 | onFarm\_hours\_\_mean | total working hours onfarm | h |
| 152 | onFarm\_hours\_JAN\_mean | onfarm hours in January | h |
| 153 | onFarm\_hours\_FEB\_mean | onfarm hours in February | h |
| 154 | onFarm\_hours\_MAR\_mean | onfarm hours in March | h |
| 155 | onFarm\_hours\_APR\_mean | onfarm hours in April | h |
| 156 | onFarm\_hours\_MAY\_mean | onfarm hours in May | h |
| 157 | onFarm\_hours\_JUN\_mean | onfarm hours in June | h |
| 158 | onFarm\_hours\_JUL\_mean | onfarm hours in July | h |
| 159 | onFarm\_hours\_AUG\_mean | onfarm hours in August | h |
| 160 | onFarm\_hours\_SEP\_mean | onfarm hours in September | h |
| 161 | onFarm\_hours\_OCT\_mean | onfarm hours in October | h |
| 162 | onFarm\_hours\_NOV\_mean | onfarm hours in November | h |
| 163 | onFarm\_hours\_DEC\_mean | onfarm hours in December | h |
| 164 | total\_hours\_\_mean | Total hours used for on-farm and off-farm activities | h |
| 165 | NSurplus\_Quant\_\_mean | average nitrogen surplus on farm based on Duev values | kg/ha |
| 166 | NInputSyntNBalanceDuev\_Quant\_\_mean | average nitrogen input from mineral fertiliser on farm | kg/ha |
| 167 | PInputSyntPBalanceDuev\_Quant\_\_mean | average phosphorus input from mineral fertiliser on farm | kg/ha |
| 168 | PSurplus\_Quant\_\_mean | average phosphorus surplus on farm based on Duev Values | kg/ha |
| 169 | POutputPBalanceDuev\_Quant\_\_mean | average phosphorus removal from plant based on Duev values | kg/ha |
| 170 | applMinNH3\_Quant\_\_mean | total ammonia emissions from mineral fertiliser application | kg |
| 171 | applMinN2O\_Quant\_\_mean | total nitrous oxide emissions from mineral fertiliser application | kg |
| 172 | applMinNOx\_Quant\_\_mean | total nitric oxide emissions from mineral fertiliser application | kg |
| 173 | applMinN2\_Quant\_\_mean | total nitrogen emissions from mineral fertiliser application | kg |
| 174 | applMinN2Oind\_Quant\_\_mean | total indirect nitrous oxide emissions from mineral fertiliser application | kg |
| 175 | limingCO2\_Quant\_\_mean | total carbon dioxide equivalent emissions from liming | kg |
| 176 | cropResiN2O\_Quant\_\_mean | total nitrous oxide emissions from crop residues | kg |
| 177 | croppingPMF25\_Quant\_\_mean | particulate matter (<2.5 um diameter) emission from cropping activities | kg |
| 178 | croppingPMF10\_Quant\_\_mean | particulate matter (<10 um diameter) emission from cropping activities | kg |
| 179 | leachN\_Quant\_\_mean | total nitrogen leaching on farm | kg |
| 180 | lossP\_Quant\_\_mean | total phosphorus loss from field on farm | kg |
| 181 | humBal\_Quant\_\_mean | total humus losses from field | Humusäquivalent (kg C ha-1) |
| 182 | leachN2Oind\_Quant\_\_mean | indirect nitrous oxide emissions from leaching | kg |
| 183 | totGWP\_Quant\_\_mean | total global warming potential as CO2-eq of entire farm | kg |
| 184 | minApplGWP\_Quant\_\_mean | total global warming potential as CO2-eq from mineral fertiliser application | kg |
| 185 | fieldGWP\_Quant\_\_mean | total global warming potential as CO2-eq from field operations | kg |
| 186 | totPMFP\_Quant\_\_mean | total particulate matter formation potential of entire farm | kg |
| 187 | minApplPMFP\_Quant\_\_mean | total particulate matter formation potential from mineral fertiliser application | kg |
| 188 | fieldPMFP\_Quant\_\_mean | total particulate matter formation potential from field operations | kg |
| 189 | totTAP\_Quant\_\_mean | total terrestrial acidification potential as Kg mol H+ of entire farm | kg |
| 190 | minApplTAP\_Quant\_\_mean | total terrestrial acidification potential as Kg mol H+ from mineral fertiliser | kg |
| 191 | fieldTAP\_Quant\_\_mean | total terrestrial acidification potential as Kg mol H+ from field operations | kg |
| 192 | totFEP\_Quant\_\_mean | total freshwater eutrophication potential as Kg PO4-eq of entire farm | kg |
| 193 | fieldFEP\_Quant\_\_mean | freshwater eutrophication potential as Kg PO4-eq from mineral fertiliser | kg |
| 194 | totMEP\_Quant\_\_mean | total marine water eutrophication potential as Kg N-eq of entire farm | kg |
| 195 | minApplMEP\_Quant\_\_mean | marine water eutrophication potential as Kg N-eq from mineral fertiliser | kg |
| 196 | fieldMEP\_Quant\_\_mean | marine water eutrophication potential as Kg N-eq from field operations | kg |
| 197 | carbBal\_Quant\_\_mean | same as humBal\_Quant | Humusäquivalent (kg C ha-1) |
| 198 | NH3aggr\_Quant\_\_mean | total ammonia emissions on farm | kg |
| 199 | N2Oaggr\_Quant\_\_mean | total nitrous oxide emissions on farm | kg |
| 200 | NOxaggr\_Quant\_\_mean | total nitric oxide emissions on farm | kg |
| 201 | N2aggr\_Quant\_\_mean | total nitrogen emissions on farm | kg |
| 202 | margTot1\_sum\_\_mean | shadow price of 1 additional hectare of land | €/ha |
| 203 | WinterBarley\_AHL\_\_mean | amount of fertiliser “AHL” used for winter barley per ha | kg/ha |
| 204 | WinterBarley\_PK\_18\_10\_\_mean | amount of fertiliser “PK\_18\_10” used for winter barley per ha | kg/ha |
| 205 | WinterBarley\_levl\_\_mean | output of winter barley in ha | ha |
| 206 | WinterBarley\_SReve\_\_mean | revenue from winter barley | € |
| 207 | WinterBarley\_OQuant\_\_mean | output of winter barley in tons | t |
| 208 | WinterBarley\_SQuant\_\_mean | sale quantity of winter barley in tons | t |
| 209 | SummerCere\_AHL\_\_mean | amount of fertiliser "AHL" used for summer cereal per ha | kg/ha |
| 210 | SummerCere\_PK\_18\_10\_\_mean | amount of fertiliser "PK\_18\_10" used for summer cereal per ha | kg/ha |
| 211 | SummerCere\_levl\_\_mean | output of summer cereal in ha | ha |
| 212 | SummerCere\_SReve\_\_mean | revenue from summer cereal | € |
| 213 | SummerCere\_OQuant\_\_mean | output of summer cereal in tons | t |
| 214 | SummerCere\_SQuant\_\_mean | sale quantity of summer cereal in tons | t |
| 215 | WinterRape\_AHL\_\_mean | amount of fertiliser “AHL” used for winter rape seed per ha | kg/ha |
| 216 | WinterRape\_PK\_18\_10\_\_mean | amount of fertiliser “PK\_18\_10” used for winter rape seed per ha | kg/ha |
| 217 | WinterRape\_levl\_\_mean | output of winter rape seed in ha | ha |
| 218 | WinterRape\_SReve\_\_mean | revenue from winter rape seed | € |
| 219 | WinterRape\_OQuant\_\_mean | output of winter rape seed in tons | t |
| 220 | WinterRape\_SQuant\_\_mean | sale quantity of winter rape seed in tons | t |
| 221 | SCresidues\_SReve\_\_mean | total revenue received for SC residues | € |
| 222 | SCresidues\_OQuant\_\_mean | output quantity of SC residues | t |
| 223 | SCresidues\_SQuant\_\_mean | sale quantity of SC residues in ton | t |
| 224 | WBresidues\_SReve\_\_mean | total revenue received for WB residues | € |
| 225 | WBresidues\_OQuant\_\_mean | output quantity of WB residues | t |
| 226 | WBresidues\_SQuant\_\_mean | sale quantity of WB residues in ton | t |
| 227 | workOpp2\_hours\_\_mean | hours spent for off-farm work assumed to be a 100% position | h |
| 228 | workOpp2\_earn\_\_mean | yearly earnings for off-farm work assumed to be a 100% position | € |
| 229 | cuttingAddRape\_newCost\_\_mean | fixed costs of an additional cutting unit for rapeseed | € |
| 230 | cuttingAddRape\_costs\_\_mean | variable costs of an additional cutting unit for rapeseed | € |
| 231 | cuttingAddRape\_Use\_\_mean | use (in hectare) of an additional cutting unit for rapeseed | ha |
| 232 | workOpp1\_hours\_\_mean | hours spent for first off-farm work assumed to be a 50% position | h |
| 233 | workOpp1\_earn\_\_mean | yearly earnings for first off-farm work assumed to be a 50% position | € |
| 234 | workOpp5\_hours\_\_mean | hours spent for off-farm work assumed to be a 250% position | h |
| 235 | workOpp5\_earn\_\_mean | yearly earnings for off-farm work assumed to be a 250% position | € |
| 236 | MaizCorn\_AHL\_\_mean | amount of fertiliser “AHL” used for maize per ha | kg/ha |
| 237 | MaizCorn\_PK\_18\_10\_\_mean | amount of fertiliser “PK\_18\_10” used for maize per ha | kg/ha |
| 238 | MaizCorn\_levl\_\_mean | output of maize in ha | ha |
| 239 | MaizCorn\_SReve\_\_mean | revenue from maize | € |
| 240 | MaizCorn\_OQuant\_\_mean | output of maize in tons | t |
| 241 | MaizCorn\_SQuant\_\_mean | sale quantity of maize in tons | t |
| 242 | cuttingUnitMaiz\_newCost\_\_mean | fixed costs of a cutting unit for maize | € |
| 243 | cuttingUnitMaiz\_costs\_\_mean | variable costs of a cutting unit for maize | € |
| 244 | cuttingUnitMaiz\_Use\_\_mean | use (in hectare) of a cutting unit for maize | ha |
| 245 | workOpp3\_hours\_\_mean | hours spent for off-farm work assumed to be a 150% position | h |
| 246 | workOpp3\_earn\_\_mean | yearly earnings for off-farm work assumed to be a 150% position | € |
| 247 | workOpp6\_hours\_\_mean | hours spent for off-farm work assumed to be a 300% position | h |
| 248 | workOpp6\_earn\_\_mean | yearly earnings for off-farm work assumed to be a 300% position | € |

**Citation in the appendix**

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V.). *Neue Datensammlung Betriebsplanung Landwirtschaft 2018/19 (New data collection for agricultural operational planning 2018/19)* (Darmstadt, 2018). ISBN 978-3-945088-62-3.