Supplementary Materials S1

The paper reports the results of a randomized controlled trial. We did not enter modifications in the BEEHAVE model in term of random variables; we used the same method. The pseudo-random number generator defined in the BEEHAVE model as the RAND_SEED variable was set to 8 as the default.
In the original BEEHAVE code there is a single treatment with a certain effectiveness in a certain time interval. This solution was limiting for us. We needed to insert more than one treatment, diversifying its effectiveness and time of action. For this reason we included the treatment in the phoretic phase and the treatment in the cell (diversifying for drones and workers).
In addition, the possibility of re-infesting the family which was not present in the BEEHAVE model, was added.

```
; ************************ORIGINAL CODE******************

let treatmentDay 270 ; 270: 27.September
let treatmentDuration 40 ; (28-40d) Fries et al. 1994
let treatmentEfficiency 0.115
; (0.115) Fries et al. 1994 kills X*100% of phoretic mites each treatment Day

ifelse ((varroaTreatment = true) and (Day >= treatmentDay)
and (Day <= treatmentDay + treatmentDuration )
and (N_INITIAL_MITES_HEALTHY + N_INITIAL_MITES_INFECTED > 0))

[
set PhoreticMites round(PhoreticMites * (1 - treatmentEfficiency))
ask signs with [shape = “x” or shape = “varroamite03”] [ show-turtle]
]
[
ask signs with [shape = “x” or shape = “varroamite03”] [ hide-turtle]
]

; ************************NEW CODE******************

; ************************EXTERNAL REINFESTATION******************

;External reinfastation
let reinfestation true
let reinfestationDay [160 200 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [10 20 30 100] ; **********N OF VARROA MITES**********
let iteration 0

foreach reinfestationDay
[
ifelse ((reinfestation = true) and (Day = ?))
[
set PhoreticMites PhoreticMites + item iteration reinfastationQty
ask signs with [shape = “x” or shape = “varroamite03”] [ show-turtle]
]
[
ask signs with [shape = “x” or shape = “varroamite03”] [ hide-turtle]
]
set iteration iteration + 1
]

; ******************CELLS TREATMENT*****************

;Cells treatment
let treatmentCells true ;
let treatmentDayCells [80 105 130 155 180 205 230 255 280] ;
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
```

```
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let iter 0
let i 0

let repetitionsWorker (MAX_INVADED_MITES_WORKERCELL + 1)
let repetitionsDrone (MAX_INVADED_MITES_DRONECELL + 1)

let InvadedCellWorkerBefore 0
let InvadedCellDroneBefore 0
let InvadedCellWorkerAfter 0
let InvadedCellDroneAfter 0

let multipWorker 0
let multipDrone 0

foreach treatmentDayCells
[
ifelse ((varroaTreatment = true) and (Day >= ?) and (treatmentCells = true)
and (Day <= ? + item iter treatmentDurationCells )
and (N_INITIAL_MITES_HEALTHY + N_INITIAL_MITES_INFECTED > 0))
[
ask miteOrganisers with [(age >= INVADING_DRONE_CELLS_AGE) and (age < EMERGING_AGE)]
[

set InvadedCellWorkerBefore 0
set InvadedCellDroneBefore 0
set InvadedCellWorkerAfter 0
set InvadedCellDroneAfter 0

set i 0
repeat repetitionsWorker
[
set InvadedCellWorkerBefore (InvadedCellWorkerBefore + (item i workerCellListCondensed))
set i i + 1
]; sum invaded workers cells before treatment

set i 0
repeat repetitionsDrone
[
set InvadedCellDroneBefore (InvadedCellDroneBefore + (item i droneCellListCondensed))
set i i + 1
]; sum invaded drone cells before treatment

set multipWorker (1 - item iter treatmentEfficiencyWorkerCells)
set multipDrone (1 - item iter treatmentEfficiencyDroneCells)

set workerCellListCondensed map [round( ? * multipWorker )] workerCellListCondensed
set droneCellListCondensed map [round( ? * multipDrone )] droneCellListCondensed

set i 0
repeat (repetitionsWorker - 1)
[
set InvadedCellWorkerAfter (InvadedCellWorkerAfter + (item i workerCellListCondensed))
set i i + 1
]; sum invaded workers cells after treatment minus empty of mite cells

set i 0
repeat (repetitionsDrone - 1)
[
set InvadedCellDroneAfter (InvadedCellDroneAfter + (item i droneCellListCondensed))
set i i + 1
```

```
]; sum invaded drone cells after treatment minus empty of mite cells

set workerCellListCondensed replace-item 0 workerCellListCondensed (InvadedCellWorkerBefore -
      InvadedCellWorkerAfter)
set droneCellListCondensed replace-item 0 droneCellListCondensed (InvadedCellDroneBefore -
      InvadedCellDroneAfter)
ask signs with [shape = "x" or shape = "varroamite03"] [ show-turtle]
]
]
[
ask signs with [shape = "x" or shape = "varroamite03"] [ show-turtle]
]
set iter iter + 1
]

; ******************PHORETIC TREATMENT*********************

;Phoretic treatment
let treatmentPhoretic true
let treatmentDay [80 105 130 155 180 205 230 255 280] ;
let treatmentDuration [0 0 0 0 0 0 0 0 0] ;
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3] ;
let iterat 0

foreach treatmentDay
[
       ifelse ((varroaTreatment = true) and (treatmentPhoretic = true) and (Day >= ?)
            and (Day <= ? + item iterat treatmentDuration )
            and (N_INITIAL_MITES_HEALTHY + N_INITIAL_MITES_INFECTED > 0))
            [
ifelse (round(PhoreticMites * (1 - item iterat treatmentEfficiency)) <= 0)
[
              set PhoreticMites 1
              ask signs with [shape = "x" or shape = "varroamite03"] [ show-turtle]
]
[
set PhoreticMites round(PhoreticMites * (1 - item iterat treatmentEfficiency))
ask signs with [shape = "x" or shape = "varroamite03"] [ show-turtle]
]
            ]
            [
              ask signs with [shape = "x" or shape = "varroamite03"] [ hide-turtle]
            ]
      set iterat iterat + 1
]
end
```

Supplementary Materials S2

```
########## Environmental conditions ##########
; "foragingPeriod" = HOURS SUNSHINE ON DAYS WITH Tmax > 15degC
; 2018: from weather data Torino, Italy, (1.1.-31.12.2018);
let foragingHoursListTorino2018
[ 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 2 2 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 6 5 0 0 3 8 9 0 4 0 0 0 0 0 0 7 0 1 7 9 5 8 0 2 11 6 0 0 7
10 10 9 0 4 0 0 0 10 8 10 12 13 12 12 12 13 13 13 14 14 12 13 10
12 10 0 4 0 7 11 10 12 14 13 12 8 8 3 11 12 13 1 0 2 12 5 14 14
15 10 13 0 5 8 15 14 15 14 6 15 12 10 13 14 16 11 16 11 15 15
15 15 13 15 15 15 15 15 14 15 15 15 15 15 15 15 15 15 14 12 15
15 15 14 14 14 14 14 12 14 12 14 14 14 14 9 14 14 14 14 13 13
9 14 14 14 14 14 14 13 14 14 14 12 13 14 14 13 13 12 13 13 13
13 13 13 12 13 13 13 13 12 12 13 13 13 8 13 10 10 13 13 7 12
13 13 13 13 12 12 12 12 12 8 12 10 12 12 12 12 12 12 6 8 8 9
8 1 7 7 8 8 7 6 10 8 10 0 10 8 8 7 7 10 8 8 9 7 6 7 7 8 9 7
0 0 0 0 0 2 0 3 0 0 6 3 0 0 0 4 4 4 0 0 0 0 0 0 0 0 0 0 0 0
2 0 0 0 0 0 0 2 0 0 0 2 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 ]

########## Figure 8a ##########
let reinfestationDay [] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [] ; **********N OF VARROA MITES**********
let treatmentDayCells []
let treatmentDurationCells []
let treatmentEfficiencyWorkerCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay []
let treatmentDuration []
let treatmentEfficiency []

########## Figure 8b ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [30 30 30 30] ; **********N OF VARROA MITES**********
let treatmentDayCells []
let treatmentDurationCells []
let treatmentEfficiencyWorkerCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay []
let treatmentDuration []
let treatmentEfficiency []

########## Figure 8c ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [150 150 150 150] ; **********N OF VARROA MITES**********
let treatmentDayCells []
let treatmentDurationCells []
let treatmentEfficiencyWorkerCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay []
let treatmentDuration []
let treatmentEfficiency []

########## Figure 8d ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [30 30 30 30] ; **********N OF VARROA MITES**********
let treatmentDayCells []
let treatmentDurationCells []
let treatmentEfficiencyWorkerCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [212]
```

```
let treatmentDuration [0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiency [0.95]

########## Figure 9a ##########
let reinfestationDay [] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3]


########## Figure 9b ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [30 30 30 30] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3]


########## Figure 9c ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [150 150 150 150] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3]


########## Figure 9d ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [150 150 250 250] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3]


########## Figure 10a ##########
let reinfestationDay [] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 212 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0 0]
```

```
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.95 0.3 0.3 0.3] ; *** 0.3 FOR HEAT TREATMENT, 0.95 FOR OXALIC
    ACID TREATMENT

########## Figure 10b ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [30 30 30 30] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 212 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.95 0.3 0.3 0.3] ; *** 0.3 FOR HEAT TREATMENT, 0.95 FOR OXALIC
    ACID TREATMENT

########## Figure 10c ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [150 150 150 150] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 212 230 255 280]
let treatmentDuration [0 0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.95 0.3 0.3 0.3] ; *** 0.3 FOR HEAT TREATMENT, 0.95 FOR OXALIC
    ACID TREATMENT

########## Figure 10d ##########
let reinfestationDay [160 190 220 250] ; **********N DAYS BEFORE JAN 1ST **********
let reinfastationQty [30 30 30 30] ; **********N OF VARROA MITES**********
let treatmentDayCells [80 105 130 155 180 205 230 255 280]
let treatmentDurationCells [0 0 0 0 0 0 0 0 0] ; ********* 0 BEAUSE OF INSTANT EFFECTIVENESS
let treatmentEfficiencyWorkerCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentEfficiencyDroneCells [0.5 0.6 0.7 0.7 0.7 0.7 0.7 0.6 0.5] ; ***** EFFECTIVENESS IN CELLS
let treatmentDay [80 105 130 155 180 205 212 230 237 255 262 280 287]
let treatmentDuration [0 0 0 0 0 0 0 0 0 0 0 0 0]
let treatmentEfficiency [0.3 0.3 0.3 0.3 0.3 0.3 0.95 0.3 0.95 0.3 0.95 0.3 0.95] ; *** 0.3 FOR HEAT TREATMENT, 0.95
    FOR OXALIC ACID TREATMENT
```