付録1）Adamsの操り返し計算のプログラム

```
ADAMS.FORT
       PROGRAM ADAMS
       IMPLICIT REAL*8 (A-H,J-Z)
       WRITE(6,601)
   601 FORMAT(1H1///1H0,'      THE SUCCESSIVE APPROXIMATION OF',-
       /'     IONIC CONCENTRATION AND ACTIVITIES',-
       /'           IN SOIL SOLUTIONS')
    10 READ(2,END=999)    I,CA,MG,NH4,K,CL,SO4,NO3
 "MOLER CONCENTRATION (MOLE/L)
       MCA =CA /40080.
       MMG =MG /24305.
       MK  =K  /39102.
       MNH4=NH4/14007.
       MCL =CL /35450.
       MSO4=SO4/96064.
       MNO3=NO3/14007.
       SCA =MCA
       SMG =MMG
       SK  =MK
       SNH4=MNH4
       SSO4=MSO4
       SNO3=MNO3
       I    = 1
 "IONIC STRENGTH
     1 MU  = (MCA*4.+MMG*4.+MK+MNH4+MCL+MSO4*4.+MNO3)/2.
 "ACTIVITY OF EACH ION
 "                         (MMOLE/L)
       ACA =MCA*COACT(MU,2.,6.)
       AMG =MMG*COACT(MU,2.,8.)
       AK  =MK *COACT(MU,1.,3.)
       ANH4=MNH4*COACT(MU,1.,2.5)
       ASO4=MSO4*COACT(MU,2.,4. )
       ANO3=MNO3*COACT(MU,1.,3. )
 "ION PAIR CONCENTRATION (MMOLE/L)
       CASO4 =ACA*ASO4/5.25
       MGSO4 =AMG*ASO4/5.88
       NH4SO4=ANH4*ASO4/79.3
       KSO4  =AK*ASO4/110.
       CANO3 =ACA*ANO3/525.
 "REVISED IONIC CONCENTRATIONS & IONIC STRENGTH (MMOLE)
       MMCA  =MCA*1000.
       MMMG  =MMG*1000.
       MMNH4 =MNH4*1000.
       MMK   =MK*1000.
       MMSO4 =MSO4*1000.
       MMCL  =MCL*1000.
       MMNO3 =MNO3*1000.
       A=DABS(SCA*1000.-(MMCA+CASO4))
       IF (A-0.0001) 3,3,2
     2 CONTINUE
       IF (I .GE. 100)  GO TO 3
       MCA =SCA -(CASO4+CANO3)*0.001
       MMG =SMG -MGSO4*0.001
       MNH4=SNH4-NH4SO4*0.001
       MK  =SK  -KSO4*0.001
       MSO4=SSO4-(CASO4+MGSO4+NH4SO4+KSO4)/1000.
       MNO3=SNO3 -CANO3/1000.
       I    = I+1
                                GO TO 1
     3 CONTINUE
         PPCA=MMCA*40.088
         PPMG=MMMG*24.305
         PPNH4=MMNH4*14.007
         PPK=MMK*39.102
         PPCL=MMCL*35.45
         PPSO4=MMSO4*96.064
         PPNO3=MMNO3*14.007
         WRITE(3) PPCA,PPMG,PPNH4,PPK,PPCL,PPSO4,PPNO3,CA,MG,NH4,K,CL,SO-
         4,NO3
                                   GO TO 10
   999 STOP
       END
       FUNCTION COACT(MU,Z,AI)
 "ACTIVITY COEFFICIENTS
       IMPLICIT REAL*8 (A-H,M-Z)
       RMU  =DSQRT(MU)
       COACT=(1./10.**(0.509*Z**2*RMU/(1.+0.329*AI*RMU)))*1000.
       RETURN
       END
```

付録2）乾物生産とカリウム循環のモデルのプログラム(1)
（シミュレーション用プログラムBGS−1のサブルーチン・プログラム）

```
      SUBROUTINE MODEL(MZ001)
C
C  K CYCLING MODEL    ***** URINATED AREA *****
C
      IMPLICIT     REAL*8  (A-H,O-Z)
      REAL*8  L,LST,LMF,LRI,LRV,MGME,NO31,NO32,NO33,NO34,NO35,NO3
     *        ,LRK,LRKS,MPRPDG,MPRPDL,MFG,MFL
      COMMON/GENERA/TIME,STIME,DT,FTIME,NY
      COMMON/D/DDM(10),DAK(7),DGRK(5),DLRK(5),DTODAY
      COMMON/V/DM(10),AK(7),GRK(5),LRK(5),TODAY
      COMMON/IC/DMS(10),AKS(7),GRKS(5),LRKS(5),TODAYS
      COMMON/PARAM/A(40),B(20),C(20)
      COMMON/TABLE/TABT(8),TABG(12)
     *              ,CL1(14),CL2(14),CL3(14),CL4(14),CL5(14)
     *              ,SO41(14),SO42(14),SO43(14),SO44(14),SO45(14)
     *              ,NO31(14),NO32(14),NO33(14),NO34(14),NO35(14)
     *              ,H201(14),H202(14),H203(14),H204(14),H205(14)
      COMMON/F/MFG(5),RIG(5),DG(5),RMFG(5),RRIG(5),RDG(5)
     *        ,MFL(5),RIL(5),DL(5),RMFL(5),RRIL(5),RDL(5)
     *        ,GRV(5),LRV(5),EK(5),BK(5)
     *        ,TOTLEK,TOTLBK,TOTLK,CKG,CKL
     *        ,SGMFGM,SGMFLM,SGRIGM,SGRILM,SGDGM,SGDLM,WDM,TTLGRK,TTLLRK
      DIMENSION  DGRV(5,1),DLRV(5,1),CL(5),SO4(5),NO3(5),DIFGRV(5),DIFLR
     *V(5),H20(5),FKGRB(5),FKLRB(5),RR(5),DD(5),CBK(5)
     *,MPRPDG(5),MPRPDL(5)
C
      DATA PAI/3.141592653D0/
     *,MGME/0.02558/,RDK/30.0/,LRI/0.0015/,GRI/0.0017/
     *,LMF/0.005/,GMF/0.005/,DD/2.875,3.10,3.425,3.925,4.225/
C
      GO TO (1000,2000,3000,4000),MZ001
 1000 CONTINUE
      NY     = 28
      RR(1)  = 0.44
      RR(2)  = 0.21
      RR(3)  = 0.13
      RR(4)  = 0.10
      RR(5)  = 0.12
      SGMFG  = 0.
      SGMFL  = 0.
      SGRIG  = 0.
      SGRIL  = 0.
      SGDG   = 0.
      SGDL   = 0.
C
 2000 CONTINUE
      CL(1)  = TABL1(CL1,  TIME)
      CL(2)  = TABL1(CL2,  TIME)
      CL(3)  = TABL1(CL3,  TIME)
      CL(4)  = TABL1(CL4,  TIME)
      CL(5)  = TABL1(CL5,  TIME)
      SO4(1)= TABL1(SO41,TIME)
      SO4(2)= TABL1(SO42,TIME)
      SO4(3)= TABL1(SO43,TIME)
      SO4(4)= TABL1(SO44,TIME)
      SO4(5)= TABL1(SO45,TIME)
      NO3(1)= TABL1(NO31,TIME)
      NO3(2)= TABL1(NO32,TIME)
      NO3(3)= TABL1(NO33,TIME)
      NO3(4)= TABL1(NO34,TIME)
      NO3(5)= TABL1(NO35,TIME)
      H20(1)= TABL1(H201,TIME)
      H20(2)= TABL1(H202,TIME)
      H20(3)= TABL1(H203,TIME)
      H20(4)= TABL1(H204,TIME)
      H20(5)= TABL1(H205,TIME)
      DO 280  N=1,10
  280 IF(DM(N) .LT. 0.1D-10)  DM(N)=0.1D-10
      DO 290  N=1,7
  290 IF(AK(N) .LT. 0.1D-10)  AK(N)=0.1D-10
      DO 300  I=1,5
      IF(GRK(I) .LT. 0.1D-10)  GRK(I)=0.1D-10
  300 IF(LRK(I) .LT. 0.1D-10)  LRK(I)=0.1D-10
      DO 110 I=1,5
      BK(I) = (A(40)+CL(I)*B( 3)+SO4(I)*B(15)+NO3(I)*B(16))+H20(I)
     1        /1000./MGME
```

乾物生産とカリウム循環のモデルのプログラム(2)

```
CCC    BK(I) : MGK/100CM**2  :  CL(I) ETC : ME/L  :   H2O(I) : ML/100CM**2
  110 CONTINUE
      DO 120 I=1,5
  120 EK(I) = BK(I)*RDK
CCC    EK(1) : MGK/100CM**2
      DO 210 I=1,5
      IF(BK(I) .LT. 0.1D-10) BK(I)=0.1D-10
      IF(EK(I) .LT. 0.1D-10) EK(I)=0.1D-10
  210 CONTINUE
      T1     = TABL1(TABT,TIME)
      TG     = TABL1(TABG,TIME)
      DS     = DSIN(PAI*TODAY/180.)
      STUR   = A(36) * DM(5)
      YIELD  = DM(1) + DM(3)
      ZERO   = 0.
      F12    = A(1)/(1.+DEXP(-A(2)*(TODAY-A(3))))
      F18    = A(5)*DEXP(A(6)*TODAY)
      F19    = A(7)+A(8)*T1
      F21    = A(9)*DS
      F28    = A(10)
      F29    = A(11)+A(12)*T1
      F34    = A(13)/(1.+ DEXP(-A(14)*(TODAY-A(15))))
      F38    = A(17)*DEXP(A(18)*TODAY)
      F39    = A(19)+A(20)*T1
      F43    = A(21)*DS
      F48    = A(22)
      F49    = A(23)+A(24)*T1
      F79    = A(27)+A(28)*T1
      F89    = A(29)+A(30)*T1
C     ST     = A(31)*DS+A(32)+A(39)
      ST     = 46.0+0.92*TODAY-0.0073*TODAY**2
      PG     = A(37)
      PL     = 1. - A(37)
      G      = A(38)
      L      = 1. - A(38)
      GST    = G * ST * A(34)
      LST    = L * ST * A(35)
      F57    = SWITCH(ZERO,A(25),TG)
      F59    = SWITCH(ZERO,A(26),TG)
C
      IF (YIELD - STUR)  2,1,1
    1 F15 = 0.
      F35 = 0.
      GT     = SWITCH(ZERO,A(33),TG)
      GO TO 3
    2 F15    = SWITCH(ZERO,A(4),TG)
      F35    = SWITCH(ZERO,A(16),TG)
      GT     = 0.
    3 CONTINUE
C
      FK1GR = B(1)/(1.+DEXP(-B(2)*(TODAY-A(3))))
      FK1BK = B(5)*DEXP(B(6)*TODAY)
      FK21  = B(8)   + B(7)*DS
      FK43  = B(10) + B(9)*DS
      FK3BK = B(11)*DEXP(B(12)*TODAY)
      FK3LR = B(13)/(1.+DEXP(-B(14)*(TODAY-A(15))))
      FK6BK = B(19)
      FK7BK = B(20)
      FK56  = SWITCH(ZERO,B(17),TG)
      FK57  = SWITCH(ZERO,B(18),TG)
C
      CKG    = 100.*AK(1)/(DM(1))
      CKL    = 100.*AK(3)/(DM(3))
      GK     = B(4)*GT
C     IF (CKG .GT. 6.5) GST = GST*0.7
C     IF (CKL .GT. 6.5) LST = LST*0.7
      IF (CKG .GT. 6.5) FK21 = 0.
      IF (CKL .GT. 6.5) FK43 = 0.
C
      FK15  = F15
      FK35  = F35
      DO 140 I=1,5
      FKGRB(I)=C(I)
      FKLRB(I)=C(I+5)
  140 CONTINUE
      DO 150 I=1,5
      DIFGRV(I)=GRV(I)-DEADT(1,1.0,DGRV(I,1),GRV(I))
      DIFLRV(I)=LRV(I)-DEADT(1,1.0,DLRV(I,1),LRV(I))
  150 CONTINUE
```

乾物生産とカリウム循環のモデルのプログラム(3)

```
C
      DDM(1)= -(F12+F15+F18+F19)*DM(1)+F21*DM(2)+GST-PG*GT*DM(5)
      DDM(2)= F12*DM(1)-(F21+F28+F29)*DM(2)
      DDM(3)= -(F34+F35+F38+F39)*DM(3)+F43*DM(4)+LST-PL*GT*DM(5)
      DDM(4)= F34*DM(3)-(F43+F48+F49)*DM(4)
      DDM(5)= F15*DM(1)+F35*DM(3)-(F57+F59)*DM(5)+GT*DM(5)
      DDM(6)= 0.
      DDM(7)= F57*DM(5)-F79*DM(7)
      DDM(8)= F18*DM(1)+F28*DM(2)+F38*DM(3)+F48*DM(4)-F89*DM(8)
      DDM(9)= F19*DM(1)+F29*DM(2)+F39*DM(3)+F49*DM(4)+F59*DM(5)+F79*DM(7
     1)+F89*DM(8)
      DDM(10)=0.
C
      DAK(1)   = -(FK15+FK1GR+FK1BK)*AK(1)+FK21*(GRK(1)+GRK(2)+GRK(3)
     1            +GRK(4)+GRK(5))-PG*GK*DM(5)
      DAK(2)   = 0.
      DAK(3)   = -(FK35+FK3LR+FK3BK)*AK(3)+FK43*(LRK(1)+LRK(2)+LRK(3)
     1            +LRK(4)+LRK(5))-PL*GK*DM(5)
      DAK(4)   = 0.
      DAK(5)   = FK15*AK(1)+FK35*AK(3)-(FK56+FK57)*AK(5)+GK*DM(5)*0.2
      DAK(6)   = FK56*AK(5)-FK6BK*AK(6)
      DAK(7)   = FK57*AK(5)-FK7BK*AK(7)
C
      DO 130  I=1,5
           DIFG = DIFGRV(I)
           IF (DIFG .LE. 0.) DIFG=0.
           DIFL = DIFLRV(I)
           IF (DIFL .LE. 0.) DIFL=0.
CC
      CBK(I)   = BK(I)/H20(I)
      MFG(I)   = GMF*DM(1)*RR(I)*CBK(I)
      RIG(I)   = GRI*DIFG**0.75
      DG(I)    = CBK(I)*DD(I)
      MPRPDG(I)=MFG(I)+RIG(I)+DG(I)
           IF (MPRPDG(I) .LT. 0.1D-10) MPRPDG(I)=0.1D-10
      RMFG(I)  = MFG(I)/MPRPDG(I)
      RRIG(I)  = RIG(I)/MPRPDG(I)
      RDG(I)   =  DG(I)/MPRPDG(I)
      MFL(I)   = LMF*DM(3)*RR(I)*CBK(I)
      RIL(I)   = LRI*DIFL**0.75
      DL(I)    = CBK(I)*DD(I)
      MPRPDL(I)=MFL(I)+RIL(I)+DL(I)
           IF (MPRPDL(I) .LT. 0.1D-10) MPRPDL(I)=0.1D-10
      RMFL(I)  = MFL(I)/MPRPDL(I)
      RRIL(I)  = RIL(I)/MPRPDL(I)
      RDL(I)   =  DL(I)/MPRPDL(I)
CC
          IF (BK(I)) 131,132,132
  131      MPRPDG(I)=0.1D-10
           MPRPDL(I)=0.1D-10
           BK(I)=0.1D-10
  132 CONTINUE
           IF (CKG .GT. 6.5) MPRPDG(I)=0.1D-10
           IF (CKL .GT. 6.5) MPRPDL(I)=0.1D-10
         BBGK = MPRPDG(I)+FK1GR*RR(I)*AK(1)
         BBLK = MPRPDL(I)+FK3LR*RR(I)*AK(3)
         IF (FKGRB(I) .GT. 0.001) FKGRB(I)=0.1D-5
      DGRK(I) = BBGK
     *         - (FKGRB(I)+FK21*RR(I))*GRK(I)
CC
      DLRK(I) = BBLK
     *         - (FKLRB(I)+FK43*RR(I))*LRK(I)
  130 CONTINUE
      GMFG     = MFG(1)+MFG(2)+MFG(3)+MFG(4)+MFG(5)
      GMFL     = MFL(1)+MFL(2)+MFL(3)+MFL(4)+MFL(5)
      GRIG     = RIG(1)+RIG(2)+RIG(3)+RIG(4)+RIG(5)
      GRIL     = RIL(1)+RIL(2)+RIL(3)+RIL(4)+RIL(5)
      GDG      =  DG(1)+ DG(2)+ DG(3)+ DG(4)+ DG(5)
      GDL      =  DL(1)+ DL(2)+ DL(3)+ DL(4)+ DL(5)
      DTODAY=DT
```

乾物生産とカリウム循環のモデルのプログラム(4)

```
 3000 CONTINUE
      DO 180  N=1,10
  180 IF(DM(N) .LT. 0.1D-10)  DM(N)=0.1D-10
      DO 190  N=1,7
  190 IF(AK(N) .LT. 0.1D-10)  AK(N)=0.1D-10
      DO 200  I=1,5
      IF(GRK(I) .LT. 0.1D-10)  GRK(I)=0.1D-10
  200 IF(LRK(I) .LT. 0.1D-10)  LRK(I)=0.1D-10
      DO 160 I=1,5
      GRV(I)=DM(2)*RR(I)
      LRV(I)=DM(4)*RR(I)
  160 CONTINUE
C
           IF (I .EQ. 1) GO TO 133
         BK(I)=BK(I)-MPRPDG(I)+FKGRB(I)*GRK(I)
     *                 -MPRPDL(I)+FKLRB(I)*LRK(I)
                             GO TO 134
  133    BK(1)=BK(1)-MPRPDG(1)+FKGRB(1)*GRK(1)
     *                 -MPRPDL(1)+FKLRB(1)*LRK(1)
     *                 +FK6BK*AK(6)+FK7BK*AK(7)
  134 CONTINUE
C
      SGMFG   = SGMFG+GMFG
      SGMFL   = SGMFL+GMFL
      SGRIG   = SGRIG+GRIG
      SGRIL   = SGRIL+GRIL
      SGDG    = SGDG +GDG
      SGDL    = SGDL +GDL
C
          WDM = DM(5)/0.15
C       DM(5) = WDM
      TTLGRK  = GRK(1)+GRK(2)+GRK(3)+GRK(4)+GRK(5)
      TTLLRK  = LRK(1)+LRK(2)+LRK(3)+LRK(4)+LRK(5)
      TOTLEK  = EK(1)+EK(2)+EK(3)+EK(4)+EK(5)
      TOTLBK  = BK(1)+BK(2)+BK(3)+BK(4)+BK(5)
      TOTLK   = TOTLEK+TOTLBK
CCC   TOTLK ETC : MGK/100CM**2
 4000 CONTINUE
      SGMFGM  = SGMFG/30.
      SGMFLM  = SGMFL/30.
      SGRIGM  = SGRIG/30.
      SGRILM  = SGRIL/30.
      SGDGM   = SGDG /30.
      SGDLM   = SGDL /30.
      RETURN
      END
```

付録3）シミュレーションに使用したデータの1例 (1)

```
SIMTIME   ST    1.    DT    1.    FT    50.
METHOD    MD    0.
DATA
IC        28  1   100.  2    50.  3   100.  4 50.      5  135.  6 0.      7     .0
            8     0.  9      0. 10      0. 11 3.      12 0.     13   3.0 14     .0
           15    4.5 16      0. 17      0. 18 .22     19 0.105 20 0.065 21  0.005
           22 0.06   23    .22 24   .105 25 .065    26 .005  27 .006  28    1.0
PARAM     70  1 0.02    2 0.03    3 90.      4 0.5     5 0.015   6 0.001   7 0.0028
            8 0.0008  9 0.005  10 0.002   11 0.0014 12 .00042 13 0.02   14 0.03
           15 90.    16 0.5    17 0.015   18 0.001  19 0.0028 20 0.0008 21 0.0050
           22 0.002  23 0.0014 24 .00042  25 0.05   26 0.36   27 0.002  28 0.0020
           29 0.002  30 0.002  31 200.    32 10.0   33 0.4202 36 0.16   37 0.3300
           38 0.45   39 0.0    41 0.01    42 1.0    43 0.1437 45 0.015  46 0.0160
           47 .010   48 0.05   49 .0150   50 0.05   51 .015   52 .016   53 .01
           54 1.     55 0.1573 57 .0121   58 .0343  59 .121   60 .0121  61.001
           62.0005   63.0005   64.0005    65.0005   66.001    67.0005   68.0005
           69.0005   70.0005   44 .035    34 1.0    35 1.0    40-0.2982 56 .0586
TABLE      8  1     1.  2    6.8  3    10.  4    9.2  5    31.  6   11.0  7   50.0
            8   13.5
TABLE     12  9     1. 10      0. 11    45. 12     0. 13    46. 14    1.  15    50.
           16     1. 17    51. 18      0. 19   52.   20     0.
TABLE     14 21     1. 22 37.414 23      7. 24 23.324 25    14. 26  0.178 27   22.0
           28  0.079 29    28. 30  0.123 31    35. 32  0.181 33    50. 34  .0590
TABLE     14 35     1. 36  6.516 37      7. 38  8.022 39    14. 40  2.217 41   22.0
           42  4.601 43    28. 44  0.709 45    35. 46  0.350 47    50. 48  .1450
TABLE     14 49     1. 50  0.279 51      7. 52  1.379 53    14. 54  4.677 55   22.0
           56  4.746 57    28. 58  4.738 59    35. 60  1.299 61    50. 62 0.0590
TABLE     14 63     1. 64  0.226 65      7. 66  0.495 67    14. 68  3.731 69   22.0
           70  2.212 71    28. 72  2.086 73    35. 74  5.133 75    50. 76  6.765
TABLE     14 77     1. 78  0.220 79      7. 80  0.385 81    14. 82  0.855 83   22.0
           84  0.355 85    28. 86  1.089 87    35. 88  2.361 89    50. 90  5.450
TABLE     14 91     1. 92  15.11093      7. 94  7.918 95    14. 96  2.845 97   22.0
           98  1.044 99    28.100  0.121101    35.102  0.109103    50.104  0.109
TABLE     14105     1.106  0.591107      7.108  0.247109    14.110  1.178111   22.0
          112  2.265113    28.114  0.982115    35.116  0.985117    50.118  .5680
TABLE     14119     1.120  0.314121      7.122  0.202123    14.124  1.000125   22.0
          126  0.321127    28.128  1.833129    35.130  3.052131    50.132 3.7900
TABLE     14133     1.134  0.254135      7.136  0.283137    14.138  0.250139   22.0
          140  0.300141    28.142  0.086143    35.144  0.374145    50.146  .2640
TABLE     14147     1.148  0.163149      7.150  0.145151    14.152  0.083153   22.0
          154  0.466155    28.156  0.091157    35.158  0.188159    50.160  .2380
TABLE     14161     1.162  0.396163      7.164  0.316165    14.166  0.319167   22.0
          168  0.000169    28.170  0.016171    35.172  0.002173    50.174  .0510
TABLE     14175     1.176  0.328177      7.178  0.257179    14.180  0.557181   22.0
          182  0.024183    28.184  0.124185    35.186  0.015187    50.188 0.6760
TABLE     14189     1.190  0.004191      7.192  0.023193    14.194  0.416195   22.0
          196  0.004197    28.198  0.122199    35.200  0.000201    50.202 0.0000
TABLE     14203     1.204  0.164205      7.206  0.181207    14.208  0.081209   22.0
          210  0.000211    28.212  0.108213    35.214  0.015215    50.216 0.1550
TABLE     14217     1.218  0.320219      7.220  0.341221    14.222  0.124223   22.0
          224  0.002225    28.226  0.009227    35.228  0.004229    50.230  0.004
TABLE     14231     1.232    99.233      7.234  115.235    14.236  107.237   22.0
          238  106.239    28.240  111.241    35.242  109.243    50 244   99.0
TABLE     14245     1.246  123.247      7.248  124.249    14.250  143.251   22.0
          252  124.253    28.254  122.255    35.256  116.257    50.258  123.0
TABLE     14259     1.260  140.261      7.262  137.263    14.264  152.265   22.0
          266  142.267    28.268  137.269    35.270  126.271    50.272  140.0
TABLE     14273     1.274  149.275      7.276  157.277    14.278  164.279   22.0
          280  153.281    28.282  152.283    35.284  141.285    50.286  149.0
TABLE     14287     1.288  162.289      7.290  169.291    14.292  167.293   22.0
          294  167.295    28.296  147.297    35.298  152.299    50.300  162.0
EDATA
```

シミュレーションに使用したデータの1例 (2)

```
TITLE
      ***** DM PRODUCTION AND POTASSIUM CYCLE MODEL *****
RUNBGS
CONTBGS
SIMTIME              DT    1.    FT    80.
DATA
PARAM     6 34   1.5    35   0.9    40-.05508 43 .1652   55 .5798   56 .0973
TABLE     8  1     51.   2    14.3  3     60.   4    15.1  5     71.   6    17.3  7    80.0
             8    20.1
TABLE    12  9     51.  10      0.  11     75.  12     0.   13     76.  14     1.    15     80.
            16     1.   17     81.  18      0.  19    82.   20     0.
TABLE    14 21     51.  22 49.673 23     57.  24 46.150 25     64.  26  1.267 27    72.0
            28  0.329 29     78.  30  0.175 31     85.  32  0.264 33   100.  34   .0590
TABLE    14 35     51.  36 14.033 37     57.  38 11.804 39     64.  40  1.928 41    72.0
            42  2.213 43     78.  44  0.786 45     85.  46  0.337 47   100.  48 2.1710
TABLE    14 49     51.  50  2.471 51     57.  52  3.303 53     64.  54  9.067 55    72.0
            56  6.969 57     78.  58  3.220 59     85.  60  1.089 61   100.  62 18.443
TABLE    14 63     51.  64  1.588 65     57.  66  1.095 67     64.  68  8.871 69    72.0
            70  7.652 71     78.  72 11.528 73     85.  74  7.998 75   100.  76 18.871
TABLE    14 77     51.  78  1.627 79     57.  80  0.542 81     64.  82  3.664 83    72.0
            84  5.965 85     78.  86  6.751 87     85.  88  8.450 89   100.  90  9.476
TABLE    14 91     51.  92 35.831 93     57.  94 15.545 95     64.  96  1.941 97    72.0
            98  0.075 99     78.100  0.121101     85.102  0.135103   100.104  0.109
TABLE    14105     51.106  0.591107     57.108  3.130109     64.110  5.031111    72.0
           112  0.384113     78.114  1.140115     85.116  3.054117   100.118  .5680
TABLE    14119     51.120  0.314121     57.122  0.132123     64.124  3.587125    72.0
           126  1.604127     78.128  2.134129     85.130  3.196131   100.132 2.7400
TABLE    14133     51.134  0.254135     57.136  0.284137     64.138  0.433139    72.0
           140  0.050141     78.142  0.121143     85.144  0.124145   100.146  .0640
TABLE    14147     51.148  0.097149     57.150  0.094151     64.152  0.087153    72.0
           154  0.037155     78.156  0.091157     85.158  0.105159   100.160  .0790
TABLE    14161     51.162  0.396163     57.164  0.148165     64.166  2.123167    72.0
           168  1.275169     78.170  0.624171     85.172  0.144173   100.174  .0510
TABLE    14175     51.176  0.328177     57.178  0.525179     64.180  1.652181    72.0
           182  1.776183     78.184  0.895185     85.186  0.390187   100.188 4.8590
TABLE    14189     51.190  0.366191     57.192  0.084193     64.194  1.152195    72.0
           196  2.715197     78.198  2.005199     85.200  1.774201   100.202 6.4810
TABLE    14203     51.204  0.329205     57.206  0.079207     64.208  0.648209    72.0
           210  1.071211     78.212  2.506213     85.214  2.317215   100.216 6.2580
TABLE    14217     51.218  0.217219     57.220  0.356221     64.222  0.127223    72.0
           224  0.363225     78.226  0.552227     85.228  0.682229   100.230 4.6914
TABLE    14231     51.232     99.233     57.234    115.235     64.236    107.237    72.0
           238    106.239     78.240    111.241     85.242    109.243   100.244    99.0
TABLE    14245     51.246    123.247     57.248    124.249     64.250    143.251    72.0
           252    124.253     78.254    122.255     85.256    116.257   100.258   123.0
TABLE    14259     51.260    140.261     57.262    137.263     64.264    152.265    72.0
           266    142.267     78.268    137.269     85.270    126.271   100.272   140.0
TABLE    14273     51.274    149.275     57.276    157.277     64.278    164.279    72.0
           280    153.281     78.282    152.283     85.284    141.285   100.286   149.0
TABLE    14287     51.288    162.289     57.290    169.291     64.292    167.293    72.0
           294    167.295     78.296    147.297     85.298    152.299   100.300   162.0
EDATA
```

シミュレーションに使用したデータの１例 (3)

```
RUNBGS
CONTBGS
SIMTIME              DT    1.    FT   110.
DATA
PARAM       6 34   1.3    35   1.1    40-0.2982 43 .1437   55 .1573   56 .0586
TABLE       8  1     81.   2    20.1   3     90.   4    19.3   5    101.   6    18.6   7   110.0
               8   18.0
TABLE      12  9     81.  10      0.  11    105.  12      0.  13    106.  14    1.     15    110.
              16     1.   17    111.  18      0.  19    112.   20      0.
TABLE      14 21     81.  22  37.414  23     87.  24  23.324  25     94.  26   0.178  27   102.0
              28   0.079  29    108.  30   0.123  31    115.  32   0.181  33    130.  34   .0590
TABLE      14 35     81.  36   6.516  37     87.  38   8.022  39     94.  40   2.217  41   102.0
              42   4.601  43    108.  44   0.709  45    115.  46   0.350  47    130.  48   .1450
TABLE      14 49     81.  50   0.279  51     87.  52   1.379  53     94.  54   4.677  55   102.0
              56   4.746  57    108.  58   4.738  59    115.  60   1.299  61    130.  62  0.0590
TABLE      14 63     81.  64   0.226  65     87.  66   0.495  67     94.  68   3.731  69   102.0
         ,    70   2.212  71    108.  72   2.086  73    115.  74   5.133  75    130.  76   6.765
TABLE      14 77     81.  78   0.220  79     87.  80   0.385  81     94.  82   0.855  83   102.0
              84   0.355  85    108.  86   1.089  87    115.  88   2.361  89    130.  90   5.450
TABLE      14 91     81.  92  15.11093     87.  94   7.918  95     94.  96   2.845  97   102.0
              98   1.044  99    108.100   0.121101    115.102   0.109103    130.104   0.109
TABLE      14105     81.106   0.591107     87.108   0.247109     94.110   1.178111   102.0
             112   2.265113    108.114   0.982115    115.116   0.985117    130.118   .5680
TABLE      14119     81.120   0.314121     87.122   0.202123     94.124   1.000125   102.0
             126   0.321127    108.128   1.833129    115.130   3.052131    130.132  3.7900
TABLE      14133     81.134   0.254135     87.136   0.283137     94.138   0.250139   102.0
             140   0.300141    108.142   0.086143    115.144   0.374145    130.146   .2640
TABLE      14147     81.148   0.163149     87.150   0.145151     94.152   0.083153   102.0
             154   0.466155    108.156   0.091157    115.158   0.188159    130.160   .2380
TABLE      14161     81.162   0.396163     87.164   0.316165     94.166   0.319167   102.0
             168   0.000169    108.170   0.016171    115.172   0.002173    130.174   .0510
TABLE      14175     81.176   0.328177     87.178   0.257179     94.180   0.557181   102.0
             182   0.024183    108.184   0.124185    115.186   0.015187    130.188  0.6760
TABLE      14189     81.190   0.004191     87.192   0.023193     94.194   0.416195   102.0
             196   0.004197    108.198   0.122199    115.200   0.000201    130.202  0.0000
TABLE      14203     81.204   0.164205     87.206   0.181207     94.208   0.081209   102.0
             210   0.000211    108.212   0.108213    115.214   0.015215    130.216  0.1550
TABLE      14217     81.218   0.320219     87.220   0.341221     94.222   0.124223   102.0
             224   0.002225    108.226   0.009227    115.228   0.004229    130.230   0.004
TABLE      14231     81.232     99.233     87.234    115.235     94.236    107.237   102.0
             238    106.239    108.240    111.241    115.242    109.243    130.244    99.0
TABLE      14245     81.246    123.247     87.248    124.249     94.250    143.251   102.0
             252    124.253    108.254    122.255    115.256    116.257    130.258   123.0
TABLE      14259     81.260    140.261     87.262    137.263     94.264    152.265   102.0
             266    142.267    108.268    137.269    115.270    126.271    130.272   140.0
TABLE      14273     81.274    149.275     87.276    157.277     94.278    164.279   102.0
             280    153.281    108.282    152.283    115.284    141.285    130.286   149.0
TABLE      14287     81.288    162.289     87.290    169.291     94.292    167.293   102.0
             294    167.295    108.296    147.297    115.298   .152.299    130.300   162.0
EDATA
```

シミュレーションに使用したデータの１例 (4)

```
RUNBGS
CONTBGS
SIMTIME            DT    1.    FT   140.
DATA
PARAM      6 34   1.5     35   1.0     40-0.2982 43 .1437    55 .1573   56 .0586
TABLE      8  1    111.  2    18.0  3    120.  4    16.7  5    131.  6    15.0  7   140.0
              8    13.3
TABLE     12  9    111. 10      0. 11    135. 12      0.  13    136. 14    1.    15   140.
             16     1.  17    141. 18      0. 19    142.  20      0.
TABLE     14 21    111. 22  37.414 23    117. 24  23.324 25    124. 26   0.178 27   132.0
             28   0.079 29    138. 30   0.123 31    145.  32   0.181 33    160. 34   .0590
TABLE     14 35    111. 36   6.516 37    117. 38   8.022 39    124. 40   2.217 41   132.0
             42   4.601 43    138. 44   0.709 45    145.  46   0.350 47    160. 48   .1450
TABLE     14 49    111. 50   0.279 51    117. 52   1.379 53    124. 54   4.677 55   132.0
             56   4.746 57    138. 58   4.738 59    145.  60   1.299 61    160. 62 0.0590
TABLE     14 63    111. 64   0.226 65    117. 66   0.495 67    124. 68   3.731 69   132.0
             70   2.212 71    138. 72   2.086 73    145.  74   5.133 75    160. 76   6.765
TABLE     14 77    111. 78   0.220 79    117. 80   0.385 81    124. 82   0.855 83   132.0
             84   0.355 85    138. 86   1.089 87    145.  88   2.361 89    160. 90   5.450
TABLE     14 91    111. 92   15.11093    117. 94   7.918 95    124. 96   2.845 97   132.0
             98   1.044 99    138.100   0.121101    145.102   0.109103    160.104   0.109
TABLE     14105    111.106   0.591107    117.108   0.247109    124.110   1.178111   132.0
            112   2.265113    138.114   0.982115    145.116   0.985117    160.118   .5680
TABLE     14119    111.120   0.314121    117.122   0.202123    124.124   1.000125   132.0
            126   0.321127    138.128   1.833129    145.130   3.052131    160.132 3.7900
TABLE     14133    111.134   0.254135    117.136   0.283137    124.138   0.250139   132.0
            140   0.300141    138.142   0.086143    145.144   0.374145    160.146   .2640
TABLE     14147    111.148   0.163149    117.150   0.145151    124.152   0.083153   132.0
            154   0.466155    138.156   0.091157    145.158   0.188159    160.160   .2380
TABLE     14161    111.162   0.396163    117.164   0.316165    124.166   0.319167   132.0
            168   0.000169    138.170   0.016171    145.172   0.002173    160.174   .0510
TABLE     14175    111.176   0.328177    117.178   0.257179    124.180   0.557181   132.0
            182   0.024183    138.184   0.124185    145.186   0.015187    160.188 0.6760
TABLE     14189    111.190   0.004191    117.192   0.023193    124.194   0.416195   132.0
            196   0.004197    138.198   0.122199    145.200   0.000201    160.202 0.0000
TABLE     14203    111.204   0.164205    117.206   0.181207    124.208   0.081209   132.0
            210   0.000211    138.212   0.108213    145.214   0.015215    160.216 0.1550
TABLE     14217    111.218   0.320219    117.220   0.341221    124.222   0.124223   132.0
            224   0.002225    138.226   0.009227    145.228   0.004229    160.230   0.004
TABLE     14231    111.232     99.233    117.234   115.235    124.236   107.237   132.0
            238   106.239    138.240   111.241    145.242   109.243    160.244    99.0
TABLE     14245    111.246    123.247    117.248   124.249    124.250   143.251   132.0
            252   124.253    138.254   122.255    145.256   116.257    160.258   123.0
TABLE     14259    111.260    140.261    117.262   137.263    124.264   152.265   132.0
            266   142.267    138.268   137.269    145.270   126.271    160.272   140.0
TABLE     14273    111.274    149.275    117.276   157.277    124.278   164.279   132.0
            280   153.281    138.282   152.283    145.284   141.285    160.286   149.0
TABLE     14287    111.288    162.289    117.290   169.291    124.292   167.293   132.0
            294   167.295    138.296   147.297    145.298   152.299    160.300   162.0
EDATA
```

シミュレーションに使用したデータの１例 (5)

```
RUNBGS
CONTBGS
SIMTIME            DT    1.    FT   170.
DATA
PARAM     6 34   1.1    35   1.0    40-0.2982 43 .1437   55 .1573   56 .0586
TABLE     8  1    141.   2    13.3  3    150.   4    10.9  5    161.   6     9.0  7   170.0
             8     7.4
TABLE    12  9    141.  10      0.  11    165.  12      0.  13    166.  14    1.    15    170.
            16      1.  17    171.  18      0.  19   172.   20      0.
TABLE    14 21    141.  22 37.414  23    147.  24 23.324  25    154.  26   0.178 27   162.0
            28   0.079  29    168.  30   0.123  31    175.  32   0.181 33    190.  34   .0590
TABLE    14 35    141.  36  6.516  37    147.  38  8.022  39    154.  40   2.217 41   162.0
            42   4.601  43    168.  44   0.709  45    175.  46   0.350 47    190.  48   .1450
TABLE    14 49    141.  50  0.279  51    147.  52  1.379  53    154.  54   4.677 55   162.0
            56   4.746  57    168.  58   4.738  59    175.  60   1.299 61    190.  62 0.0590
TABLE    14 63    141.  64  0.226  65    147.  66  0.495  67    154.  68   3.731 69   162.0
            70   2.212  71    168.  72   2.086  73    175.  74   5.133 75    190.  76   6.765
TABLE    14 77    141.  78  0.220  79    147.  80  0.385  81    154.  82   0.855 83   162.0
            84   0.355  85    168.  86   1.089  87    175.  88   2.361 89    190.  90   5.450
TABLE    14 91    141.  92  15.11093    147.  94  7.918  95    154.  96   2.845 97   162.0
            98   1.044  99   168.100  0.121101   175.102  0.109103   190.104   0.109
TABLE    14105   141.106  0.591107   147.108  0.247109   154.110  1.178111   162.0
           112   2.265113   168.114  0.982115   175.116  0.985117   190.118   .5680
TABLE    14119   141.120  0.314121   147.122  0.202123   154.124  1.000125   162.0
           126   0.321127   168.128  1.833129   175.130  3.052131   190.132 3.7900
TABLE    14133   141.134  0.254135   147.136  0.283137   154.138  0.250139   162.0
           140   0.300141   168.142  0.086143   175.144  0.374145   190.146   .2640
TABLE    14147   141.148  0.163149   147.150  0.145151   154.152  0.083153   162.0
           154   0.466155   168.156  0.091157   175.158  0.188159   190.160   .2380
TABLE    14161   141.162  0.396163   147.164  0.316165   154.166  0.319167   162.0
           168   0.000169   168.170  0.016171   175.172  0.002173   190.174   .0510
TABLE    14175   141.176  0.328177   147.178  0.257179   154.180  0.557181   162.0
           182   0.024183   168.184  0.124185   175.186  0.015187   190.188 0.6760
TABLE    14189   141.190  0.004191   147.192  0.023193   154.194  0.416195   162.0
           196   0.004197   168.198  0.122199   175.200  0.000201   190.202 0.0000
TABLE    14203   141.204  0.164205   147.206  0.181207   154.208  0.081209   162.0
           210   0.000211   168.212  0.108213   175.214  0.015215   190.216 0.1550
TABLE    14217   141.218  0.320219   147.220  0.341221   154.222  0.124223   162.0
           224   0.002225   168.226  0.009227   175.228  0.004229   190.230   0.004
TABLE    14231   141.232    99.233   147.234   115.235   154.236   107.237   162.0
           238   106.239   168.240   111.241   175.242   109.243   190.244    99.0
TABLE    14245   141.246   123.247   147.248   124.249   154.250   143.251   162.0
           252   124.253   168.254   122.255   175.256   116.257   190.258   123.0
TABLE    14259   141.260   140.261   147.262   137.263   154.264   152.265   162.0
           266   142.267   168.268   137.269   175.270   126.271   190.272   140.0
TABLE    14273   141.274   149.275   147.276   157.277   154.278   164.279   162.0
           280   153.281   168.282   152.283   175.284   141.285   190.286   149.0
TABLE    14287   141.288   162.289   147.290   169.291   154.292   167.293   162.0
           294   167.295   168.296   147.297   175.298   152.299   190.300   162.0
EDATA
```

シミュレーションに使用したデータの1例 (6)

```
RUNBGS
OUTPUT
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 7TOPG V    1MARKG      ULMT   1400LLMT   0.
VARIABLE  ROTG V    2MARKI      ULMT   1400LLMT   0.
VARIABLE  TOPL V    3MARKL      ULMT   1400LLMT   0.
VARIABLE  ROTL V    4MARKM      ULMT   1400LLMT   0.
VARIABLE  HEFR F   92MARKH      ULMT   1400LLMT   0.
VARIABLE  DUNG V    7MARKD      ULMT   1400LLMT   0.
VARIABLE  LITR V    8MARKF      ULMT   1400LLMT   0.
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 5AK1   V  11MARK1      ULMT   60. LLMT   0.
VARIABLE  AK3   V  13MARK3      ULMT   60. LLMT   0.
VARIABLE  AK5   V  15MARK5      ULMT   15. LLMT   0.
VARIABLE  AK6   V  16MARK6      ULMT   5.  LLMT   0.
VARIABLE  AK7   V  17MARK7      ULMT   5.  LLMT   0.
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 5GRK1 V   18MARK1      ULMT   35. LLMT   0.
VARIABLE  GRK2 V   19MARK2      ULMT   35. LLMT   0.
VARIABLE  GRK3 V   20MARK3      ULMT   35. LLMT   0.
VARIABLE  GRK4 V   21MARK4      ULMT   35. LLMT   0.
VARIABLE  GRK5 V   22MARK5      ULMT   35. LLMT   0.
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 5LRK1 V   23MARK1      ULMT   35. LLMT   0.
VARIABLE  LRK2 V   24MARK2      ULMT   35. LLMT   0.
VARIABLE  LRK3 V   25MARK3      ULMT   35. LLMT   0.
VARIABLE  LRK4 V   26MARK4      ULMT   35. LLMT   0.
VARIABLE  LRK5 V   27MARK5      ULMT   35. LLMT   0.
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 2GRK   F  93MARKG      ULMT   70. LLMT   0.
VARIABLE  LRK   F  94MARKL      ULMT   70. LLMT   0.
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 2CKG   F  84MARKG      ULMT   10. LLMT   0.
VARIABLE  CKL   F  85MARKL      ULMT   10. LLMT   0.
GRAPH     INTV     1.STIM     1.FTIM   170.
VARIABLE 5BK1   F  76MARK1      ULMT   150.LLMT   0.
VARIABLE  BK2   F  77MARK2      ULMT   30. LLMT   0.
VARIABLE  BK3   F  78MARK3      ULMT   30. LLMT   0.
VARIABLE  BK4   F  79MARK4      ULMT   30. LLMT   0.
VARIABLE  BK5   F  80MARK5      ULMT   30. LLMT   0.
PRINT     INTV     1.STIME    1.FTIM   170.TITL     1.
VARIABLE 7TOPG V    1ROTG V    2TOPL V    3ROTL V    4HEFR F   92DUNG V    7LITR V    8
PRINT     INTV     1.STIME    1.FTIM   170.TITL     1.
VARIABLE 5AK1   V  11AK3   V  13AK5   V  15AK6   V  16AK7   V  17
PRINT     INTV     1.STIME    1.FTIM   170.TITL     1.
VARIABLE 5BK1   F  76BK2   F  77BK3   F  78BK4   F  79BK5   F  80
EOUTPUT
ENDBGS
```

Studies on Evaluation of Heifer Excreta Contribution on Grazing Pasture Fertility

by

Tomoyuki HAKAMATA*

SUMMARY

The purpose of the studies was to obtain information for the development of rational fetilization methods for grazing pasture 1) by analysing the characterisitics of the nutrient cycling system of grazing pasture, 2) by constructing system models, and 3) by determining the contribution of heifer excreta to pasture fertility.

§1. Nutrient cycling on grazing pasture

Fertilizer management should be rationalized based on the knowledge of nutrient cycling. In Japan, however, nutrient cycling in a pasture has been little investigated from the view point of the relation between soil, plant and cattle, because a convenient method by which subsystems and/or the pathway of the cycle can be combined as a pasture system has not been developed. This study was initiated to desingn a mathematical system model aimed of representing the verious aspects of nutrient cycling in a grazing pasture.

The improvement of grassland productivity by fertilization was discussed in considering the nitrogen (N), phosphorus (P) and potassium (K) cycles.

The results obtained were as follows:

1) In a grazing experiment on volcanic ash soil in the Nemuro district, Hokkaido, N–P–K fertilization improved the productivity of herbage yield and heifer growth compared with only K fertilizaition.

2) In the N–P–K cycles, i) the cycling nutrients were mainly affected by standing crop, ii) the nutrients removed amounted to 14－16% (N); 3.5－4% (P) and 12－14% (K) of the cycling nutrients and iii) the rate of nutrients returned to soil as excreta was N, 46－53%; P, 58－65% and K, 47－55%.

3) It is concluded that N–P–K fertilization removes the limiting factor associated with a low P supply, meets of the vequivements for N and compensates for the loss of the fertilizing effect of excreta in case of patchily aggregated return.

4) The patchy aggregation of nutrients should be analysed to identify precisely the contribution of nutrient cycling to pasture and to evaluate the fertility effect of heifer excreta.

---

* The Hokkaido Prefectural Konsen Agricultural Experiment Station, Nakashibetsu, Hokkaido 086-11 (Present Address: The National Institute for Environmental Stndies, Yatabe, Ibaraki 305 Japan)

§ 2. Excreta dispersion models and conditions of application

The dispersion characteristics of heifer excreta on a pasture were investigated and analyzed quantitatively. Dispersion patterns were examined by fitting the theoretical distributions to the observed excreta frequency distributions and by using the MORISITA's $I\delta$ −index. The results obtained are as follows:

1) Most of the excreta clumps occupying a 2 − 8a quadrat were associated with the use of grazing equipment, e.g., watering points and salt racks. Excreta dispersion including these clumps was more aggregated, but less aggregated when the clumps were removed.

2) Frequency distribution of excreta per quadrat was represented by the Poisson or negative binomial models after the clumps associated with the use of grazing equipment were removed.

3) When a significant number of clumps associated with the use of grazing equipment was removed, the conditions of application of the two kinds of models were divided into three groups based on the relationship between the quadrat size and the mean density of dung and urine, and the 'common *k*' of the negative binomial model estimated for dung was 4.40 (confidence limits: 4.00−4.88).

§ 3. Simulation studies on uneven excreta dispersion associated with a grazing equipment

The dispersion of heifer excreta in a flat and square pasture (1 ha) surrounded by fences with a watering point at one edge was examined, and the relationships between the excreta density of a site and its distance from the watering point were derived as decreasing exponential functions. Dispersion patterns of dung and urine in a pasture with the same phape as the field previously described were simulated by using the above mentioned relationships to define the formation process of excreta dispersion. It was shown that grazing equipment, e.g., watering points, causes uneven excreta dispersion, and that, when the spatially biased densities are formulated mathematically, the uneven dispersion of excreta can be represented by the Poisson model.

§ 4. Nutrient movement in soils to which heifer urine is or is not applied

A lysimeter experiment was conducted during a period of 36 days to determine the content and distribution of ions in a soil solution. Three factors were considered: urine *vs.* no urine; anion froms, chloride (Cl) *vs.* sulphate (SO_4); and planted *vs.* bare soil.

1) The results indicate that Cl in the soil solution moved downward more slowly SO_4, and that the nitrate (NO_3) concentration increased at all levels with time. By comparison, monovalent cations (K and NH_4) remained in the upper three layers (0 −15cm) and divalent cations (Ca and Mg) in the soil solution moved into the lower layers (10−25cm) with time.

2) The multiple regression analyses showed that the amount of K present in the soil solution is mainly controlled by the concentration of the anions and that NH_4 concentration is controlled by the Cl and SO_4 levels. In addition, K and NH_4 contents are regulated by the corresponding contents of exchangeable cations. Divalent cations are present in such proportions that electroneutrality is balanced, although

their contens are controlled by those of Cl and NO_3 to a certain extent.

3) Canonical correlation analysis showed that the 1st two canonical variates are positively and highly correlated with the concentration of each ion, and are considered to be weighted means of anion and cation concentrations. Summation of the respective anions or cations multipilied by the weights indicated a high correlation among them. This relationship may reflect accurately the electroneutrality in a soil solution.

§5. Release and transfer of nutrients from heifer dung to soil and forage

The release and transfer of N–P–K from heifer dung to plant and soil was studied in order to evalutae the effects of heifer dung on soil fertillity and plant growth.

1) Fresh dung contained relatively high levels of the water soluble fraction of N–P–K which was released rapidly. In contrast, after 30－40 days dung released N–P–K slowly. Potassium present mostly in the water soluble fraction was readily released and leached into the deeper soil layers. However, in dried dung, K was retained and was released slowly during three months. The level of the water soluble fractions of N and P in the soil was lower, and the release of N and P was associated with dung decomposition. Most of the N and P that was released did not leach into the lower soil layers, but was retained in the surface soil immediately beneath the dung pile.

2) Forms of N–P–K in the soil after release: N was mostly present as nitrate; after 30－40 days the soil contained large amounts of P soluble in 2.5% acetic acid; while K was present first in water soluble form and then in the exchangeable form. The exchangeable form of K was mainly present in the soil under the dung compared with virgin soil.

3) Forage growing inside a radius of 50cm from the center of the dung pile contained very high levels of N and K.

§6. Persistence of the effect of patchily aggregated reduced excreta

"Fertility effect" of excreta refers to the ratio of the plots where excreta are applied to the plots where no application was made, in relation to the content of the nutrients and yields.

1) A large quantity of N is contained in the dung and urine, but its fertility effect is not clear. K in dung and urine affected rapidly and significantly the K content in the pasture plants, whereas K in dung only lost its effect rapidly. A comparatively large quantity of Ca is contained in the dung, but its effect is related to the activity of K. The effect of P and Mg in the dung was comparatively significant and durable. Since Mg shows a strong antagonism against K in the absorption by grass plant, the effect of Mg became apparent when the effect of K decreased.

2) As for the characteristics of the effect of excreta on yield, it was observed that urine increased clover yield and decreased grass yield, and that dung in particuler increased the yield of these plants in July of each year.

3) The effect of the excreta, particularly on the K content, persisted until August of the fourth year in the longest case. The duration of the effect (more than three full years) ranks as the longest in the results ever reported.

§ 7. Dynamic model of dry matter production and K cycling in grazing pasture

K cycling model consisted of two subsystems related to dry matter production and K transport process. In this model, dry matter of grass or legume is produced in proportion to the average comparative growth rate (CGR) in eastern Hokkaido and is distributed into the tops and roots of herbage, a part of which being dead. When heifers are introduced into a pasture, they eat some portions of top and excrete them. K distributes from the solution phase to exchangeable sites and *vice versa* in five soil layers in this model. The amount of K which is absorbed by plant roots from the soil solution is proportional to the amount of top dry matter multiplied by K concentration in the solution, to the increament of the surface area of root and to the amount of K in the soil solution. K is transported reversibly to the roots and tops. A part of K is grazed by heifer and a part of it is excreted as urine or dung. K concentration of top affects dry matter production.

These processes can be described by 23 differential equations. Parameters in this model are determined on an experimental and empirical basis.

Herbage production and K uptake in a growing season were simulated by using the two models.

§ 8. Evaluation of excreta contribution on pasture fertility by simulation studies

1) Two system models (the K cycling model described previously and the excreta spatial dispersion model described in § 3) were constructed to determine how biased dispersion of K and herbage yields occurs in a pasture. Eighteen conditions [(no excretion + (urine, dung) × 4 excreted months) × (grass + legume)] were simulated by the K cycling model to define the standing crops of K and herbage at the end of a growing season. The standing crops per 1 m^2 were calculated in all the quadrats in the pasture by using the excreta dispersion model. The standing crops in each of the 18 cases were assumed to be normally distributed.

2) The frequency distributions of absorbed K and herbage yields on the whole paddock deviated from the normal distribution, but extreme variations and biases which are observed in a pasture were not recorded. This finding indicates that the non–normal distribution of K accumulation is reflected in the process of its cycling through cattle, especially urine, soil and herbage which are structured in the cycling model. The non–normal dispersion of herbage yields actually observed is contributed by the fertility effect simulated above, as well as by the lack of residual herbage associated with the grazing behavior of cattle.

3) This suggested that these system models which were constructed on the basis of observation and experiments in this study may account for the process of nutrient cycling and excreta effects on pasture fertility.