figure/s5

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```r
rm(list= ls())
require(terra)
```

```
## 载入需要的程序包：terra
```

```
## terra 1.8.42
```

```r
  require(data.table)
```

```
## 载入需要的程序包：data.table
```

```
##
## 载入程序包：'data.table'
```

```
## The following object is masked from 'package:terra':
##
##     shift
```

```r
  require(metafor)
```

```
## 载入需要的程序包：metafor
```

```
## 载入需要的程序包：Matrix
```

```
## 载入需要的程序包：metadat
```

```
## 载入需要的程序包：numDeriv
```

```
##
## Loading the 'metafor' package (version 4.8-0). For an
## introduction to the package please type: help(metafor)
```

```r
    # what rasters are in data
    rfiles <- list.files('D:/date/homework/data', pattern = 'tif$',full.names = TRUE)
    rfiles <- rfiles[!grepl('cropland',rfiles)]

    # read in raster files
```

```r
    r.ma <- terra::sds(rfiles)

    # convert to raster
    r.ma <- terra::rast(r.ma)

# convert rasters to data.table

    # set first to xy data.frame (NA=FALSE otherwise gridcels are removed)
    r.df <- as.data.frame(r.ma,xy = TRUE, na.rm = FALSE)

    # convert to data.table
    r.dt <- as.data.table(r.df)

    # setnames
    setnames(r.dt,old = c('climate_mat', 'climate_pre','soil_isric_phw_mean_0_5','soil_isric_clay_
                          'nifert_nfert_nh4','nifert_nfert_no3','nofert_nofert','cropintensity_cro
             new = c('mat','pre','phw','clay','soc','nh4','no3','nam','cropintensity'),skip_absent

    # select only land area
    r.dt <- r.dt[!(is.na(mat)|is.na(pre))]
    r.dt <- r.dt[!(is.na(tillage_RICE) & is.na(tillage_MAIZ) & is.na(tillage_other) & is.na(tillag
    r.dt <- r.dt[!(is.na(ma_crops_RICE) & is.na(ma_crops_MAIZ) & is.na(ma_crops_other) & is.na(ma_

    # replace area with 0 when missing
    cols <- colnames(r.dt)[grepl('^ma_|nh4|no3|nam',colnames(r.dt))]
    r.dt[,c(cols) := lapply(.SD,function(x) fifelse(is.na(x),0,x)),.SDcols = cols]
    cols <- colnames(r.dt)[grepl('^tillage',colnames(r.dt))]
    r.dt[,c(cols) := lapply(.SD,function(x) fifelse(is.na(x),1,x)),.SDcols = cols]
    r.dt[is.na(cropintensity), cropintensity := 1]

    # melt the data.table
    r.dt.melt <- melt(r.dt,
                      id.vars = c('x','y','mat', 'pre','phw','clay','nh4','no3','nam','soc','cropi
                      measure=patterns(area="^ma_crops", tillage ="^tillage_"),
                      variable.factor = FALSE,
                      variable.name = 'croptype')

    # set the crop names (be aware, its the order in ma_crops)
    r.dt.melt[,cropname := c('rice','maize','other','wheat')[as.numeric(croptype)]]
```

```
    # set names to tillage practices
    r.dt.melt[, till_name := 'conventional']
    r.dt.melt[tillage %in% c(3,4,7), till_name := 'no-till']

# derive the meta-analytical model

    # read data
    d1 <- readxl::read_xlsx('D:/date/homework/Source Data.xlsx',sheet = "FigureS5")
    d1 <- as.data.table(d1)


    # add CV for NUE treatment and estimate the SD for missing ones
    d2<-d1
    CV_nuet_bar<-mean(d2$nuet_sd[is.na(d2$nuet_sd)==FALSE]/d2$nuet_mean[is.na(d2$nuet_sd)==FALSE])
    d2$nuet_sd[is.na(d2$nuet_sd)==TRUE]<-d2$nuet_mean[is.na(d2$nuet_sd)==TRUE]*1.25*CV_nuet_bar

    CV_nuec_bar<-mean(d2$nuec_sd[is.na(d2$nuec_sd)==FALSE]/d2$nuec_mean[is.na(d2$nuec_sd)==FALSE])
    d2$nuec_sd[is.na(d2$nuec_sd)==TRUE]<-d2$nuec_mean[is.na(d2$nuec_sd)==TRUE]*1.25*CV_nuec_bar


    # clean up column names
    setnames(d2,gsub('\\/','_',gsub(' |\\(|\\)','',colnames(d2))))
    setnames(d2,tolower(colnames(d2)))


    # calculate effect size (NUE)
    es21 <- escalc(measure = "MD", data = d2,
                   m1i = nuet_mean, sd1i = nuet_sd, n1i = replication,
                   m2i = nuec_mean, sd2i = nuec_sd, n2i = replication )

    # convert to data.tables
    d02 <- as.data.table(es21)

    # what are the treatments to be assessed
    d02.treat <- data.table(treatment =  c('ALL',unique(d02$management)))

    # what are labels
    d02.treat[treatment=='ALL',desc := 'All']
```

```r
d02.treat[treatment=='EE',desc := 'Enhanced Efficiency']
d02.treat[treatment=='CF',desc := 'Combined fertilizer']
d02.treat[treatment=='RES',desc := 'Residue retention']
d02.treat[treatment=='RFP',desc := 'Fertilizer placement']
d02.treat[treatment=='RFR',desc := 'Fertilizer rate']
d02.treat[treatment=='ROT',desc := 'Crop rotation']
d02.treat[treatment=='RFT',desc := 'Fertilizer timing']
d02.treat[treatment=='OF',desc := 'Organic fertilizer']
d02.treat[treatment=='RT',desc := 'Reduced tillage']
d02.treat[treatment=='NT',desc := 'No tillage']
d02.treat[treatment=='CC',desc := 'Crop cover']


# update the missing values for n_dose and p2o5_dose (as example)
d02[is.na(n_dose), n_dose := median(d02$n_dose,na.rm=TRUE)]

# scale the variables to unit variance
d02[,clay_scaled := scale(clay)]
d02[,soc_scaled := scale(soc)]
d02[,ph_scaled := scale(ph)]
d02[,mat_scaled := scale(mat)]
d02[,map_scaled := scale(map)]
d02[,n_dose_scaled := scale(n_dose)]

# update the database (it looks like typos)
d02[g_crop_type=='marize', g_crop_type := 'maize']


#Combining different factors

d02[tillage=='reduced', tillage := 'no-till']

# # Combining different factors

d02[,fertilizer_type := factor(fertilizer_type,
                               levels = c('mineral','organic', 'combined','enhanced'))]
d02[,fertilizer_strategy := factor(fertilizer_strategy,
                                   levels = c("conventional", "placement","rate","timing"))]
d02[,g_crop_type := factor(g_crop_type,
```

```r
                                levels = c('maize','wheat','rice'))]

    d02[,rfp := fifelse(fertilizer_strategy=='placement','yes','no')]
    d02[,rft := fifelse(fertilizer_strategy=='timing','yes','no')]
    d02[,rfr := fifelse(fertilizer_strategy=='rate','yes','no')]
    d02[,ctm := fifelse(g_crop_type=='maize','yes','no')]
    d02[,ctw := fifelse(g_crop_type=='wheat','yes','no')]
    d02[,ctr := fifelse(g_crop_type=='rice','yes','no')]
    #d02[,cto := fifelse(g_crop_type=='other','yes','no')]
    d02[,ndose2 := scale(n_dose^2)]



    # make metafor model

    m1 <- rma.mv(yi,vi,
                       mods = ~fertilizer_type + rfp + rft + rfr + crop_residue + tillage +
                         cover_crop_and_crop_rotation + n_dose_scaled + clay_scaled + ph_scaled +
                         n_dose_scaled:soc_scaled + ctm:rfp + ctm + ctw + ctr + ctm:mat_scaled  +
                       data = d02,
                       random = list(~ 1|studyid), method="REML",sparse = TRUE)
```

```
## Warning: Redundant predictors dropped from the model.
```

```r
    # see model structure that need to be filled in to predict NUE as function of the system prope
    p1 <- predict(m1,addx=T)

    # this is the order of input variables needed for model predictions (=newmods in predict funct
    m1.cols <- colnames(p1$X)

    # make prediction dataset for situation that soil is fertilized by both organic and inorganic
    dt.new <- copy(r.dt.melt)

    # add the columns required for the ma model, baseline scenario
    # baseline is here defined as "strategy conventional", and mineral fertilizers, no biochar, no
    dt.new[, fertilizer_typeenhanced := 0]
    dt.new[, fertilizer_typemineral := 1]
    dt.new[, fertilizer_typeorganic := 0]
    dt.new[, fertilizer_typecombined := 0]
    dt.new[, rfpyes := 0]
    dt.new[, rftyes := 0]
```

```
dt.new[, rfryes := 0]
dt.new[, crop_residueyes := 0]
dt.new[, cover_crop_and_crop_rotationyes := 0]
dt.new[, cover_crop_and_crop_rotationyes := fifelse(cropintensity>1,1,0)]
dt.new[, `tillageno-till` := fifelse(till_name =='no-till',1,0)]
#dt.new[,`tillageno-till` := 0]
dt.new[, ctryes := fifelse(cropname=='rice',1,0)]
dt.new[, ctwyes := fifelse(cropname=='wheat',1,0)]
dt.new[, ctmyes := fifelse(cropname=='maize',1,0)]
dt.new[, ph_scaled := (phw * 0.1 - mean(d02$ph)) / sd(d02$ph)]
dt.new[, clay_scaled := (clay * 0.1 - mean(d02$clay)) / sd(d02$clay)]
dt.new[, soc_scaled := (soc * 0.1 - mean(d02$soc)) / sd(d02$soc)]
dt.new[, n_dose_scaled := scale(nh4+no3+nam)]
dt.new[, ndose2 := scale((nh4+no3+nam)^2)]
dt.new[, map_scaled := (pre - mean(d02$map)) / sd(d02$map)]
dt.new[, mat_scaled := (mat  - mean(d02$mat)) / sd(d02$mat)]
dt.new[, `n_dose_scaled:soc_scaled` := n_dose_scaled*soc_scaled]
dt.new[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.new[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.new[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))

# add predictions to the data.table
cols <- c('pMDmean','pMDse','pMDcil','pMDciu','pMDpil','pMDpiu')
dt.new[,c(cols) := dt.pred]


############################################## scenario SI0 (EE) #############################

# make local copy
dt.s10 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]
```

```r
# update actions taken for scenario 1
dt.s10[, fertilizer_typeenhanced := 1]
dt.s10[, fertilizer_typemineral := 0]
dt.s10[, fertilizer_typeorganic := 0]
dt.s10[, fertilizer_typecombined := 0]
dt.s10[, rfpyes := 0]
dt.s10[, rftyes := 0]
dt.s10[, rfryes := 0]
dt.s10[, crop_residueyes := 0]
dt.s10[, cover_crop_and_crop_rotationyes := 0]
dt.s10[, tillageno_till := 0]
dt.s10[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s10[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1)*soc_scaled]
dt.s10[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s10[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s10[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s10 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s10[,c(cols) := dt.pred.s10]



# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s10[,.(x,y,s10 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s10 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]
```

```r
# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI0.tif', overwrite = TRUE)

############################################## scenario SI1 (CF) ##############################
# scenario SI1. the  combination of measures with change in Combined fertilizer (CF vs. MF)

# make local copy
dt.s11 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s11[, fertilizer_typeenhanced := 0]
dt.s11[, fertilizer_typemineral := 0]
dt.s11[, fertilizer_typeorganic := 0]
dt.s11[, fertilizer_typecombined := 1]
dt.s11[, rfpyes := 0]
dt.s11[, rftyes := 0]
dt.s11[, rfryes := 0]
dt.s11[, crop_residueyes := 0]
dt.s11[, cover_crop_and_crop_rotationyes := 0]
dt.s11[, tillageno_till := 0]
dt.s11[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s11[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s11[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s11[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s11[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s11 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
```

```r
dt.s11[,c(cols) := dt.pred.s11]


# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s11[,.(x,y,s11 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s11 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI1.tif', overwrite = TRUE)


############################################## scenario SI2 (OF) ##############################
# scenario SI2. the  combination of measures with change in OF (OF vs. MF)

# make local copy
dt.s12 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s12[, fertilizer_typeenhanced := 0]
```

```r
dt.s12[, fertilizer_typemineral := 0]
dt.s12[, fertilizer_typeorganic := 1]
dt.s12[, fertilizer_typecombined := 0]
dt.s12[, rfpyes := 0]
dt.s12[, rftyes := 0]
dt.s12[, rfryes := 0]
dt.s12[, crop_residueyes := 0]
dt.s12[, cover_crop_and_crop_rotationyes := 0]
dt.s12[, tillageno_till := 0]
dt.s12[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s12[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s12[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s12[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s12[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s12 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s12[,c(cols) := dt.pred.s12]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s12[,.(x,y,s12 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s12 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
```

```r
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI2.tif', overwrite = TRUE)


############################################## scenario SI3 (RFP) ############################
# scenario SI3. the combination of measures with change in RFP. (Optimized fertilizer strategy

# make local copy
dt.s13 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s13[, fertilizer_typeenhanced := 0]
dt.s13[, fertilizer_typemineral := 1]
dt.s13[, fertilizer_typeorganic := 0]
dt.s13[, fertilizer_typecombined := 0]
dt.s13[, rfpyes := 1]
dt.s13[, rftyes := 0]
dt.s13[, rfryes := 0]
dt.s13[, crop_residueyes := 0]
dt.s13[, cover_crop_and_crop_rotationyes := 0]
dt.s13[, tillageno_till := 0]
dt.s13[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s13[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s13[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s13[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s13[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s13 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s13[,c(cols) := dt.pred.s13]
```

```r
# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s13[,.(x,y,s13 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s13 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI3.tif', overwrite = TRUE)



############################################## scenario SI4 (RFR) ############################
# scenario SI4. the combination of measures with change in RFR. (Optimized fertilizer strategy

# make local copy
dt.s14 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s14[, fertilizer_typeenhanced := 0]
dt.s14[, fertilizer_typemineral := 1]
dt.s14[, fertilizer_typeorganic := 0]
```

```r
dt.s14[, fertilizer_typecombined := 0]
dt.s14[, rfpyes := 0]
dt.s14[, rftyes := 0]
dt.s14[, rfryes := 1]
dt.s14[, crop_residueyes := 0]
dt.s14[, cover_crop_and_crop_rotationyes := 0]
dt.s14[, tillageno_till := 0]
dt.s14[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s14[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s14[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s14[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s14[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s14 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s14[,c(cols) := dt.pred.s14]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s14[,.(x,y,s14 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s14 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'
```

```
# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI4.tif', overwrite = TRUE)



############################################## scenario SI5 (RFT) ##############################
# scenario SI5. the combination of measures with change in RFT. (Optimized fertilizer strategy

# make local copy
dt.s15 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s15[, fertilizer_typeenhanced := 0]
dt.s15[, fertilizer_typemineral := 1]
dt.s15[, fertilizer_typeorganic := 0]
dt.s15[, fertilizer_typecombined := 0]
dt.s15[, rfpyes := 0]
dt.s15[, rftyes := 1]
dt.s15[, rfryes := 0]
dt.s15[, crop_residueyes := 0]
dt.s15[, cover_crop_and_crop_rotationyes := 0]
dt.s15[, tillageno_till := 0]
dt.s15[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s15[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s15[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s15[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s15[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s15 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s15[,c(cols) := dt.pred.s15]

# compare baseline with scenario
```

```
# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s15[,.(x,y,s15 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s15 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI5.tif', overwrite = TRUE)



############################################## scenario SI7 (RES) ############################
# scenario SI7. the combination of measures with change in RES. (Optimized fertilizer strategy

# make local copy
dt.s17 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s17[, fertilizer_typeenhanced := 0]
dt.s17[, fertilizer_typemineral := 1]
dt.s17[, fertilizer_typeorganic := 0]
dt.s17[, fertilizer_typecombined := 0]
```

```
dt.s17[, rfpyes := 0]
dt.s17[, rftyes := 0]
dt.s17[, rfryes := 0]
dt.s17[, crop_residueyes := 1]
dt.s17[, cover_crop_and_crop_rotationyes := 0]
dt.s17[, tillageno_till := 0]
dt.s17[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s17[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s17[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s17[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s17[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s17 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s17[,c(cols) := dt.pred.s17]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s17[,.(x,y,s17 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s17 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'
```

```r
# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI7.tif', overwrite = TRUE)


############################################## scenario SI8 (CC/ROT) ########################
# scenario SI8. the combination of measures with change in CC/ROT. (Optimized fertilizer strat

# make local copy
dt.s18 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s18[, fertilizer_typeenhanced := 0]
dt.s18[, fertilizer_typemineral := 1]
dt.s18[, fertilizer_typeorganic := 0]
dt.s18[, fertilizer_typecombined := 0]
dt.s18[, rfpyes := 0]
dt.s18[, rftyes := 0]
dt.s18[, rfryes := 0]
dt.s18[, crop_residueyes := 0]
dt.s18[, cover_crop_and_crop_rotationyes := 1]
dt.s18[, tillageno_till := 0]
dt.s18[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s18[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s18[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s18[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s18[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s18 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s18[,c(cols) := dt.pred.s18]

# compare baseline with scenario

# select relevant columns of the baseline
```

```r
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s18[,.(x,y,s18 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s18 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_SI8.tif', overwrite = TRUE)


##############################################################################################
############################################### scenario 1 (Nutrient management) #############
# scenario 1. the combination of measures with change in RFR, RFT and BC. (Optimized fertilize

# make local copy
dt.s1 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s1[, fertilizer_typeenhanced := 1]
dt.s1[, fertilizer_typemineral := 0]
dt.s1[, fertilizer_typeorganic := 1]
dt.s1[, fertilizer_typecombined := 1]
dt.s1[, rfpyes := 1]
dt.s1[, rftyes := 1]
```

```
dt.s1[, rfryes := 1]
dt.s1[, crop_residueyes := 0]
dt.s1[, cover_crop_and_crop_rotationyes := 0]
dt.s1[, tillageno_till := 0]
dt.s1[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s1[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s1[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s1[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s1[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s1 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s1[,c(cols) := dt.pred.s1]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s1[,.(x,y,s1 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s1 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_1.tif', overwrite = TRUE)
```

```r
############################################### scenario 2 (crop management)##################
# scenario 2. the combination of measures with change in RES, CC, ROT (Optimized crop manageme

# make local copy
dt.s2 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 3
dt.s2[, fertilizer_typeenhanced := 0]
dt.s2[, fertilizer_typemineral := 1]
dt.s2[, fertilizer_typeorganic := 0]
dt.s2[, fertilizer_typecombined := 0]
dt.s2[, rfpyes := 0]
dt.s2[, rftyes := 0]
dt.s2[, rfryes := 0]
dt.s2[, crop_residueyes := 1]
dt.s2[, cover_crop_and_crop_rotationyes := 1]
dt.s2[, tillageno_till := 0]
dt.s2[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s2[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s2[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s2[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]


# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s2[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s2 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s2[,c(cols) := dt.pred.s2]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]
```

```r
# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s2[,.(x,y,s2 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s2 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_2.tif', overwrite = TRUE)


############################################## scenario 3 (NT/RT) ###########################
# scenario 3. the combination of measures with change in NT/RT. (Optimized fertilizer strategy

# make local copy
dt.s3 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 1
dt.s3[, fertilizer_typeenhanced := 0]
dt.s3[, fertilizer_typemineral := 1]
dt.s3[, fertilizer_typeorganic := 0]
dt.s3[, fertilizer_typecombined := 0]
dt.s3[, rfpyes := 0]
dt.s3[, rftyes := 0]
dt.s3[, rfryes := 0]
dt.s3[, crop_residueyes := 0]
```

```
dt.s3[, cover_crop_and_crop_rotationyes := 0]
dt.s3[, `tillageno-till` := 1]
dt.s3[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s3[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s3[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s3[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s3[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s3 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s3[,c(cols) := dt.pred.s3]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s3[,.(x,y,s3 = pMDmean,cropname)],by=c('x','y','cropname'))

# estimate relative improvement via senario 1
dt.fin[, improvement := s3 - base]

# estimate area weighted mean relative improvement
dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


# make spatial raster of the estimated improvement

# convert to spatial raster
r.fin <- terra::rast(dt.fin,type='xyz')
terra::crs(r.fin) <- 'epsg:4326'

# write as output
terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_3.tif', overwrite = TRUE)
```

```r
############################################## scenario 4 (combination)########################
# scenario 4. the combination of measures with change in EE, CF, RFR, RFT, BC, RES, CC, ROT

# make local copy
dt.s4 <- copy(dt.new)

# baseline mean and sd for total N input
dt.fert.bs <- dt.new[,list(mean = mean(nh4+no3+nam), sd = sd(nh4+no3+nam))]

# update actions taken for scenario 3
dt.s4[, fertilizer_typeenhanced := 1]
dt.s4[, fertilizer_typemineral := 0]
dt.s4[, fertilizer_typeorganic := 1]
dt.s4[, fertilizer_typecombined := 1]
dt.s4[, rfpyes := 1]
dt.s4[, rftyes := 1]
dt.s4[, rfryes := 1]
dt.s4[, crop_residueyes := 1]
dt.s4[, cover_crop_and_crop_rotationyes := 1]
dt.s4[, tillageno_till := 1]
dt.s4[, n_dose_scaled := ((nh4+no3+nam) * 0.7 - dt.fert.bs$mean)/ dt.fert.bs$sd ]
dt.s4[, `n_dose_scaled:soc_scaled` := (n_dose_scaled - 0.1 )*soc_scaled]
dt.s4[, `rfpyes:ctmyes` := rfpyes*ctmyes]
dt.s4[, `mat_scaled:ctmyes` := mat_scaled*ctmyes]

# convert to matrix, needed for rma models
dt.newmod <- as.matrix(dt.s4[,mget(c(m1.cols))])

# predict the NUE via MD model
dt.pred.s4 <- as.data.table(predict(m1,newmods = dt.newmod,addx=F))
dt.s4[,c(cols) := dt.pred.s4]

# compare baseline with scenario

# select relevant columns of the baseline
dt.fin <- dt.new[,.(x,y,base = pMDmean,cropname,area)]

# select relevant columns of scenario 1 and merge
dt.fin <- merge(dt.fin,dt.s4[,.(x,y,s4 = pMDmean,cropname)],by=c('x','y','cropname'))
```

```r
    # estimate relative improvement via senario 1
    dt.fin[, improvement := s4 - base]

    # estimate area weighted mean relative improvement
    dt.fin <- dt.fin[,list(improvement = weighted.mean(improvement,w = area)),by = c('x','y')]


    # make spatial raster of the estimated improvement

    # convert to spatial raster
    r.fin <- terra::rast(dt.fin,type='xyz')
    terra::crs(r.fin) <- 'epsg:4326'

    # write as output
    terra::writeRaster(r.fin,'D:/date/homework/tif/scenario_4.tif', overwrite = TRUE)

###################################################################################################
    # plotting

    library(ggplot2)
    library(sf)
```

```
## Linking to GEOS 3.13.0, GDAL 3.10.1, PROJ 9.5.1; sf_use_s2() is TRUE
```

```r
    library(rnaturalearth)
    library(rnaturalearthdata)
```

```
##
## 载入程序包：'rnaturalearthdata'

## The following object is masked from 'package:rnaturalearth':
##
##     countries110
```

```r
    library(terra)
    library(cowplot)
    library(vcd)
```

```
## 载入需要的程序包：grid

##
## 载入程序包：'grid'
```

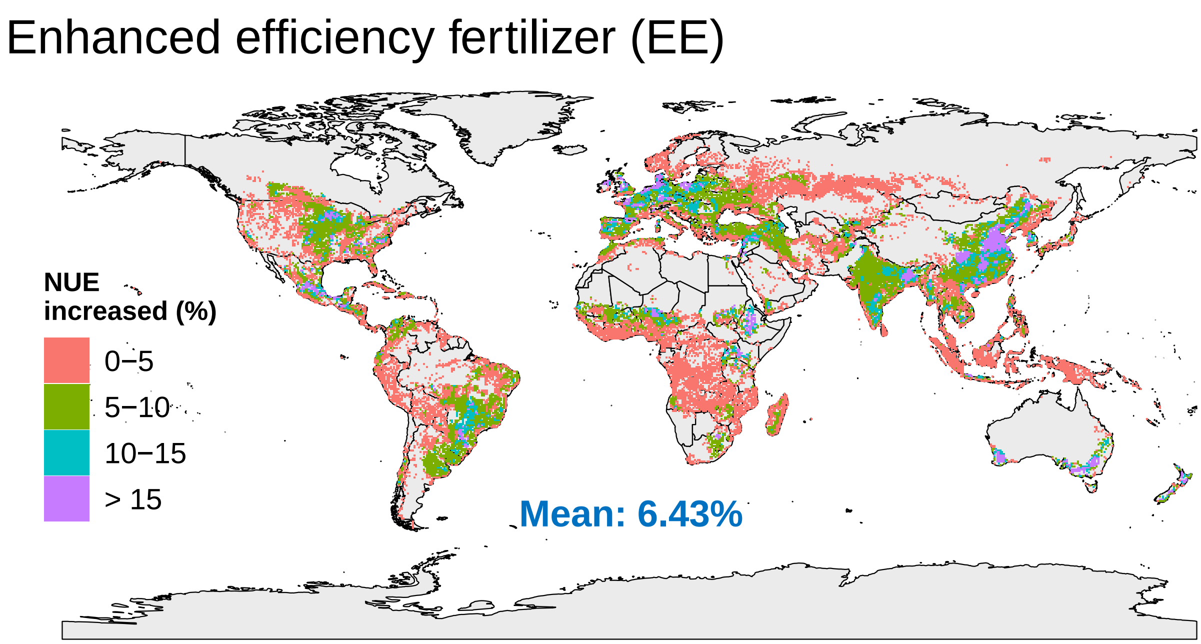
```
## The following object is masked from 'package:terra':
##
##     depth
##
## 载入程序包: 'vcd'
## The following objects are masked from 'package:terra':
##
##     mosaic, sieve
```

```
######################################### scenario_SI0 (EE) ####################################
# set theme
theme_set(theme_bw())

# get the raster to plot
r10 <- terra::rast('D:/date/homework/tif/scenario_SI0.tif')

# convert to data.frame
r10.p <- as.data.frame(r10,xy=TRUE)
# Exclude outliers greater than 70%
r10.p <- r10.p[r10.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

#plot a basic world map plot
p10 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
  geom_tile(data = r10.p,aes(x=x,y=y, name ='none',
                           fill = cut(improvement,limits = c(-10,1000), breaks= c(-10,0,5,10
                                      labels = c('< 0','0-5','5-10','10-15','> 15')))) +

  # scale_fill_gradientn(colours = rainbow(3)) +
  #scale_fill_viridis_c()+
  theme_void() +
  theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
        legend.background = element_rect(fill = NA,color = NA),
        panel.border = element_blank()) +
  labs(fill = 'NUE\nincreased (%)') +
  theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
```

```r
            legend.text = element_text(color = "black", size = 11))+
      #theme(legend.position = "none")+
      #theme(NULL)+
      xlab("Longitude") + ylab("Latitude") +
      ggtitle("Enhanced efficiency fertilizer (EE)") +
      annotate("text",x=0.5,y=-50,label="Mean: 6.43%",size=5, colour="#0070C0",fontface = "bold")+
      # ggtitle("World map", subtitle = "Mean change for scenario 1") +
      coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r10.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name

## Warning: A numeric `legend.position` argument in `theme()` was deprecated in ggplot2
## 3.5.0.
## i Please use the `legend.position.inside` argument of `theme()` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

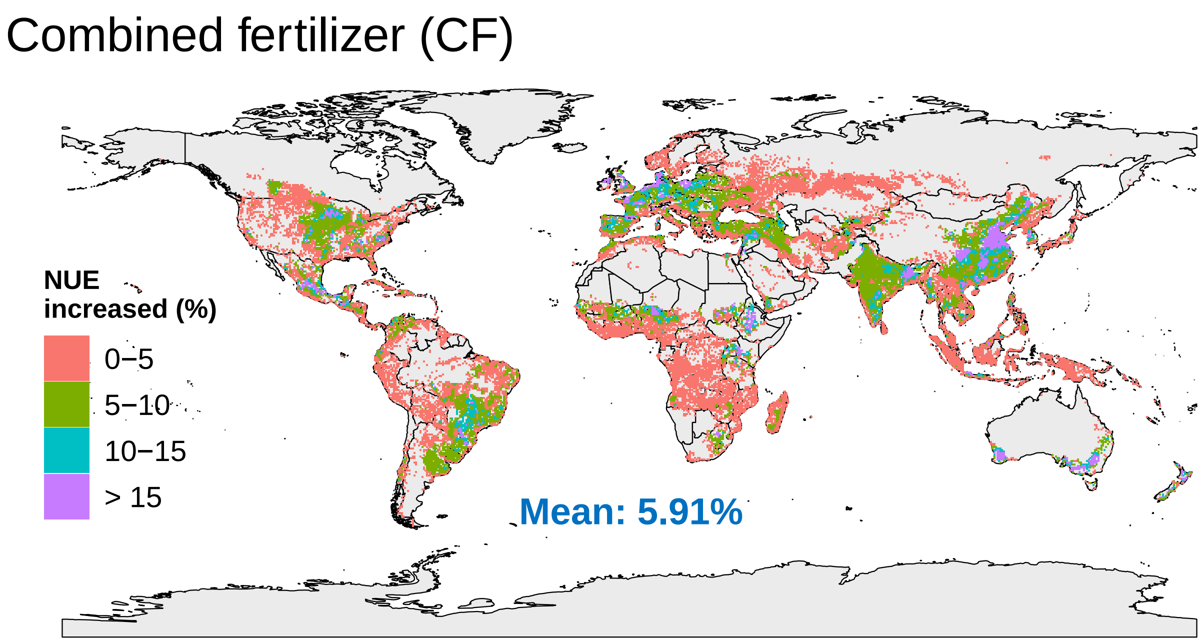
```r
p10
```



```r
########################################## scenario_SI1 (CF) ##################################

# set theme
theme_set(theme_bw())

# get the raster to plot
r11 <- terra::rast('D:/date/homework/tif/scenario_SI1.tif')

# convert to data.frame
r11.p <- as.data.frame(r11,xy=TRUE)
# Exclude outliers greater than 70%
r11.p <- r11.p[r11.p$improvement <70,]


# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p11 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
  geom_tile(data = r11.p,aes(x=x,y=y, name ='none',
                           fill = cut(improvement,breaks= c(-10,0,5,10,15,1000),
                                      labels = c('< 0','0-5','5-10','10-15','> 15') ))) +
  theme_void() +
  theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
        legend.background = element_rect(fill = NA,color = NA),
        panel.border = element_blank()) +
  labs(fill = 'NUE\nincreased (%)') +
  theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
        legend.text = element_text(color = "black", size = 11))+
  #theme(legend.position = "none")+
  xlab("Longitude") + ylab("Latitude") +
  ggtitle("Combined fertilizer (CF)") +
  #ggtitle("World map", subtitle = "Mean change for scenario 4") +
  annotate("text",x=0.5,y=-50,label="Mean: 5.91%",size=5, colour="#0070C0",fontface = "bold")+
  coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r11.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```
p11
```



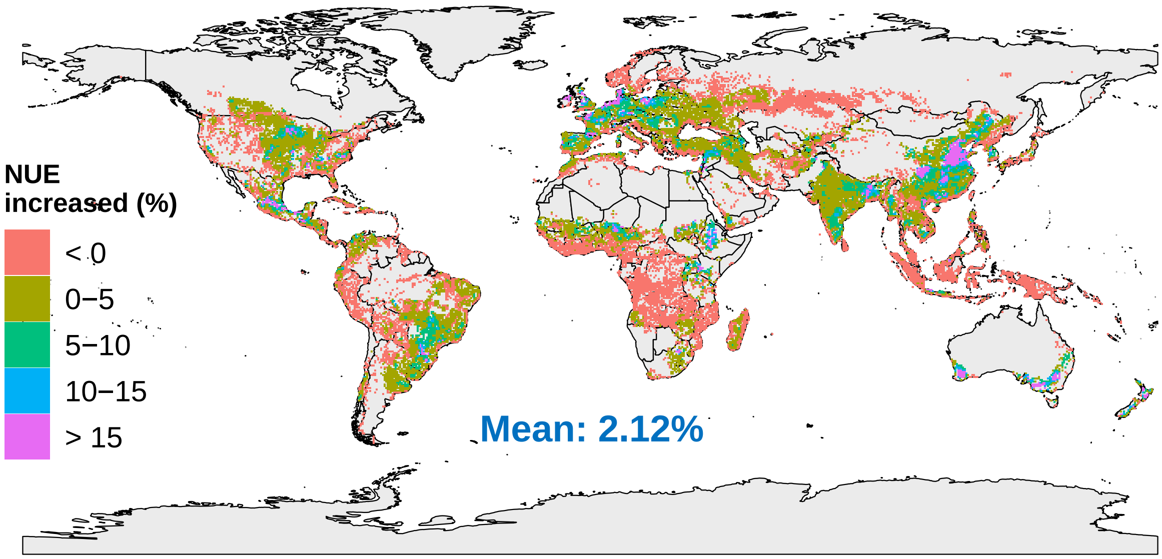

```
############################################ scenario_SI2 (OF) ##################################

# set theme
theme_set(theme_bw())

# get the raster to plot
r12 <- terra::rast('D:/date/homework/tif/scenario_SI2.tif')

# convert to data.frame
r12.p <- as.data.frame(r12,xy=TRUE)
# Exclude outliers greater than 70%
r12.p <- r12.p[r12.p$improvement <70,]

# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
```

```r
p12 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
  geom_tile(data = r12.p,aes(x=x,y=y, name ='none',
                             fill = cut(improvement,breaks= c(-10,0,5,10,15,1000),
                                        labels = c('< 0','0-5','5-10','10-15','> 15') ))) +
  theme_void() +
  theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
        legend.background = element_rect(fill = NA,color = NA),
        panel.border = element_blank()) +
  labs(fill = 'NUE\nincreased (%)') +
  theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
        legend.text = element_text(color = "black", size = 11))+
  #theme(legend.position = "none")+
  xlab("Longitude") + ylab("Latitude") +
  ggtitle("Organic fertilizer (OF)") +
  #ggtitle("World map", subtitle = "Mean change for scenario 4") +
  annotate("text",x=0.5,y=-50,label="Mean: 2.12%",size=5, colour="#0070C0",fontface = "bold")+
  coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r12.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
p12
```

Organic fertilizer (OF)

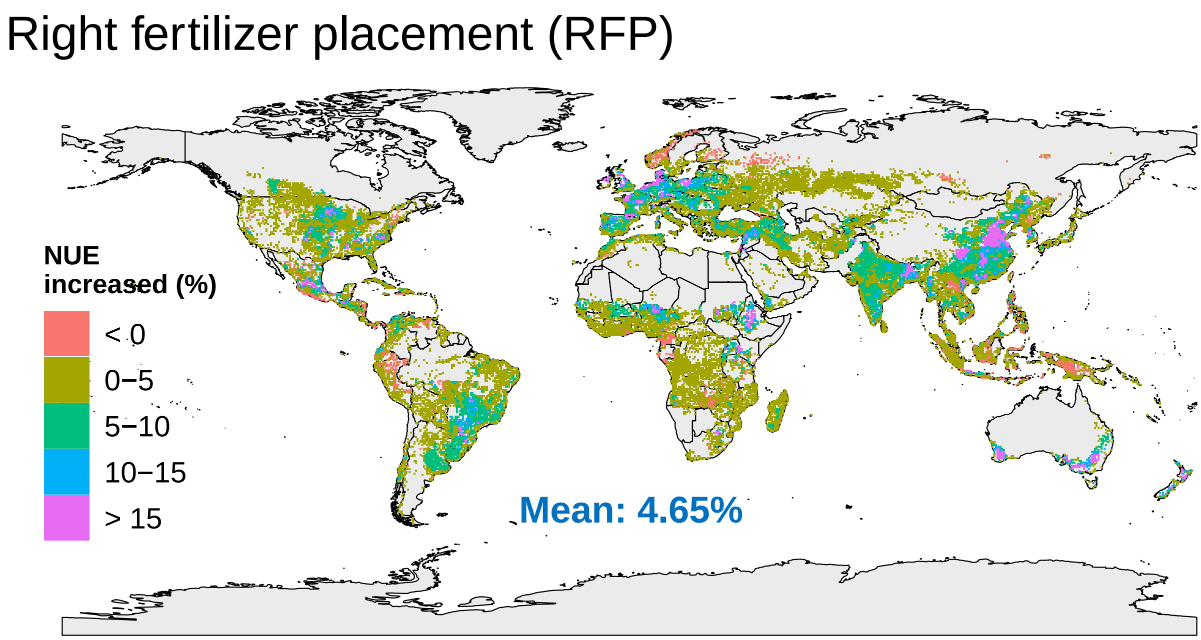



```
############################################ scenario_SI3 (RFP) ################################

# set theme
theme_set(theme_bw())

# get the raster to plot
r13 <- terra::rast('D:/date/homework/tif/scenario_SI3.tif')

# convert to data.frame
r13.p <- as.data.frame(r13,xy=TRUE)
# Exclude outliers greater than 70%
r13.p <- r13.p[r13.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p13 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
```

```r
    geom_tile(data = r13.p,aes(x=x,y=y, name ='none',
                               fill = cut(improvement,breaks= c(-10,0,5,10,15,1000),
                                          labels = c('< 0','0-5','5-10','10-15','> 15') ))) +
    theme_void() +
    theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
          legend.background = element_rect(fill = NA,color = NA),
          panel.border = element_blank()) +
    labs(fill = 'NUE\nincreased (%)') +
    theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
          legend.text = element_text(color = "black", size = 11))+
    #theme(legend.position = "none")+
    xlab("Longitude") + ylab("Latitude") +
    ggtitle("Right fertilizer placement (RFP)") +
    #ggtitle("World map", subtitle = "Mean change for scenario 4") +
    annotate("text",x=0.5,y=-50,label="Mean: 4.65%",size=5, colour="#0070C0",fontface = "bold")+
    coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r13.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
p13
```

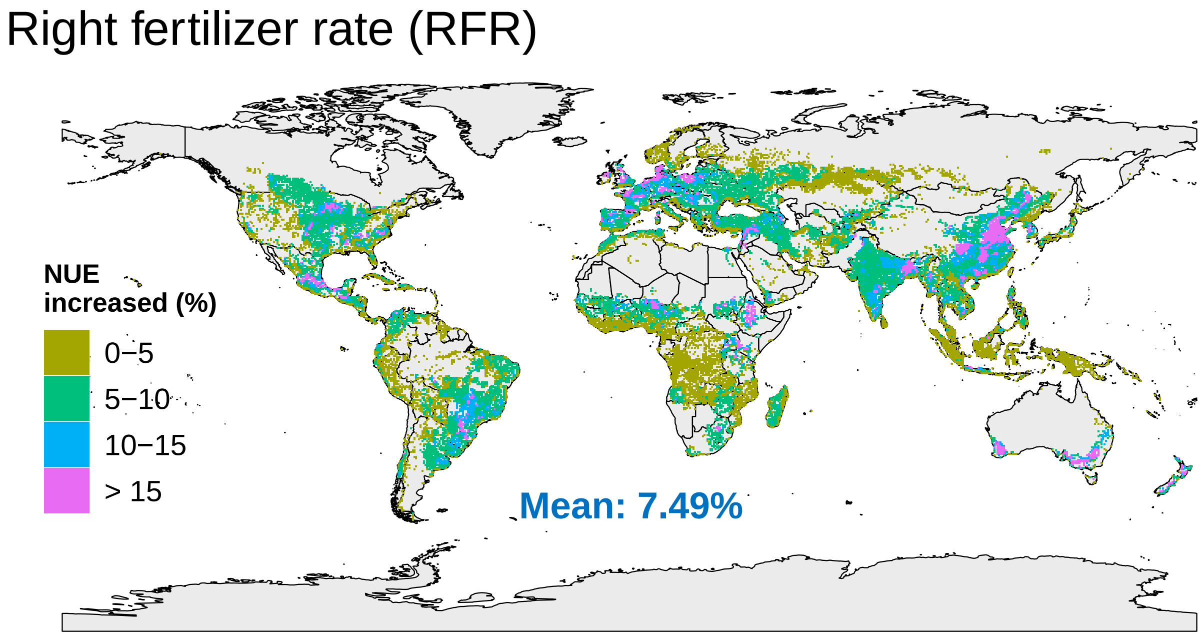



```r
############################################ scenario_SI4 (RFR) ################################

# set theme
theme_set(theme_bw())

# get the raster to plot
r14 <- terra::rast('D:/date/homework/tif/scenario_SI4.tif')

# convert to data.frame
r14.p <- as.data.frame(r14,xy=TRUE)
# Exclude outliers greater than 70%
r14.p <- r14.p[r14.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p14 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
```

```r
    geom_tile(data = r14.p,aes(x=x,y=y, name ='none',
                               fill = cut(improvement,limits = c(-10,1000), breaks= c(0,5,10,15,
                                          labels = c('0-5','5-10','10-15','> 15') ))) +
    theme_void() +
    theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
          legend.background = element_rect(fill = NA,color = NA),
          panel.border = element_blank()) +
    labs(fill = 'NUE\nincreased (%)') +
    theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
          legend.text = element_text(color = "black", size = 11))+
    scale_fill_manual(values = c("#a3a500", "#00bf7d", "#00b0f6","#e76bf3"))+
    #theme(legend.position = "none")+
    xlab("Longitude") + ylab("Latitude") +
    ggtitle("Right fertilizer rate (RFR)") +
    #ggtitle("World map", subtitle = "Mean change for scenario 4") +
    annotate("text",x=0.5,y=-50,label="Mean: 7.49%",size=5, colour="#0070C0",fontface = "bold")+
    coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r14.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
p14
```



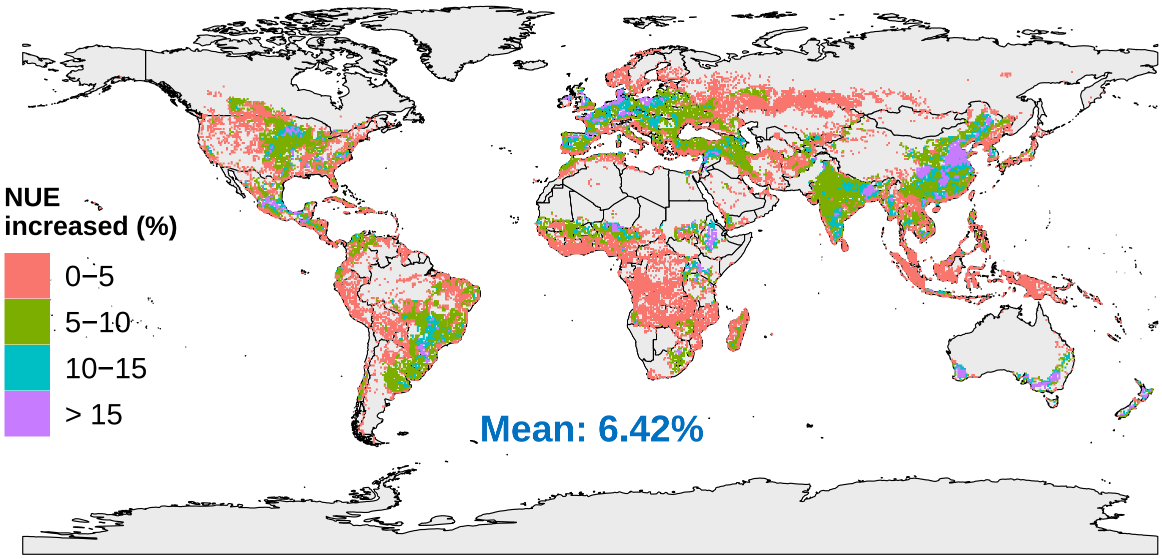

```
############################################ scenario_SI5 (RFT) ################################

# set theme
theme_set(theme_bw())

# get the raster to plot
r15 <- terra::rast('D:/date/homework/tif/scenario_SI5.tif')

# convert to data.frame
r15.p <- as.data.frame(r15,xy=TRUE)
# Exclude outliers greater than 70%
r15.p <- r15.p[r15.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p15 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
```

```r
    geom_tile(data = r15.p,aes(x=x,y=y, name ='none',
                               fill = cut(improvement,breaks= c(-10,0,5,10,15,1000),
                                          labels = c('< 0','0-5','5-10','10-15','> 15') ))) +
    theme_void() +
    theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
          legend.background = element_rect(fill = NA,color = NA),
          panel.border = element_blank()) +
    labs(fill = 'NUE\nincreased (%)') +
    theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
          legend.text = element_text(color = "black", size = 11))+
    #theme(legend.position = "none")+
    xlab("Longitude") + ylab("Latitude") +
    ggtitle("Right fertilizer timing (RFT)") +
    #ggtitle("World map", subtitle = "Mean change for scenario 4") +
    annotate("text",x=0.5,y=-50,label="Mean: 6.42%",size=5, colour="#0070C0",fontface = "bold")+
    coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r15.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
  p15
```

Right fertilizer timing (RFT)

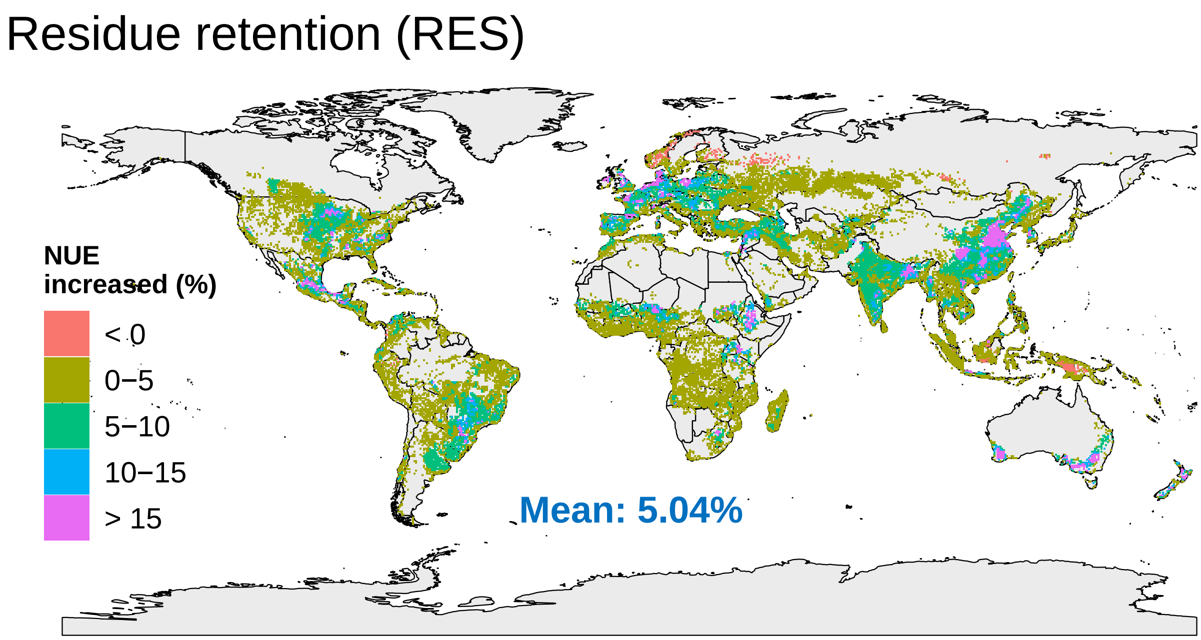



```
############################################# scenario_SI7 (RES) ################################

# set theme
theme_set(theme_bw())

# get the raster to plot
r17 <- terra::rast('D:/date/homework/tif/scenario_SI7.tif')

# convert to data.frame
r17.p <- as.data.frame(r17,xy=TRUE)
# Exclude outliers greater than 70%
r17.p <- r17.p[r17.p$improvement <70,]


# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p17 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
```

```r
    geom_tile(data = r17.p,aes(x=x,y=y, name ='none',
                               fill = cut(improvement,breaks= c(-10,0,5,10,15,1000),
                                          labels = c('< 0','0-5','5-10','10-15','> 15') ))) +
    theme_void() +
    theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
          legend.background = element_rect(fill = NA,color = NA),
          panel.border = element_blank()) +
    labs(fill = 'NUE\nincreased (%)') +
    theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
          legend.text = element_text(color = "black", size = 11))+
    # theme(legend.position = c(0.5, 0.1),
    #       legend.direction = "horizontal")+
    xlab("Longitude") + ylab("Latitude") +
    ggtitle("Residue retention (RES)") +
    #ggtitle("World map", subtitle = "Mean change for scenario 4") +
    annotate("text",x=0.5,y=-50,label="Mean: 5.04%",size=5, colour="#0070C0",fontface = "bold")+
    coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r17.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
  p17
```



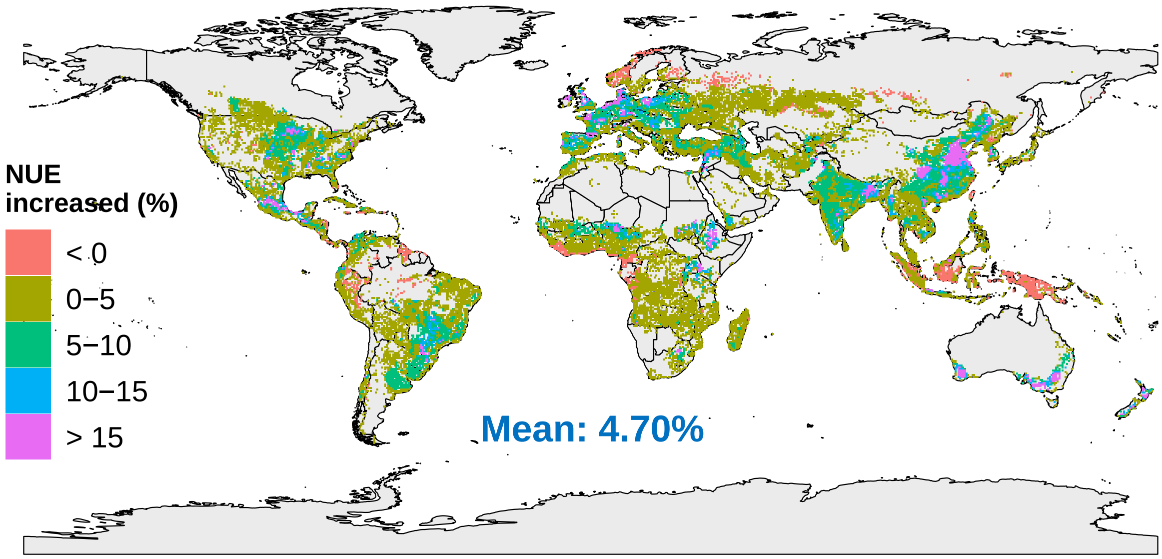

```
############################################ scenario_SI8 (CC/ROT) ############################

# set theme
theme_set(theme_bw())

# get the raster to plot
r18 <- terra::rast('D:/date/homework/tif/scenario_SI8.tif')

# convert to data.frame
r18.p <- as.data.frame(r18,xy=TRUE)
# Exclude outliers greater than 70%
r18.p <- r18.p[r18.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p18 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
```

```r
      geom_tile(data = r18.p,aes(x=x,y=y, name ='none',
                                 fill = cut(improvement,breaks= c(-10,0,5,10,15,1000),
                                            labels = c('< 0','0-5','5-10','10-15','> 15') ))) +
      theme_void() +
      theme(legend.position = c(0.1,0.45), text = element_text(size = 15),
            legend.background = element_rect(fill = NA,color = NA),
            panel.border = element_blank()) +
      labs(fill = 'NUE\nincreased (%)') +
      theme(legend.title = element_text(color = "black", size = 10, face = "bold"),
            legend.text = element_text(color = "black", size = 11))+
      #theme(legend.position = "none")+
      xlab("Longitude") + ylab("Latitude") +
      ggtitle("Cover cropping or Crop rotation (CC/ROT)") +
      #ggtitle("World map", subtitle = "Mean change for scenario 4") +
      annotate("text",x=0.5,y=-50,label="Mean: 4.70%",size=5, colour="#0070C0",fontface = "bold")+
      coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r18.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
    p18
```

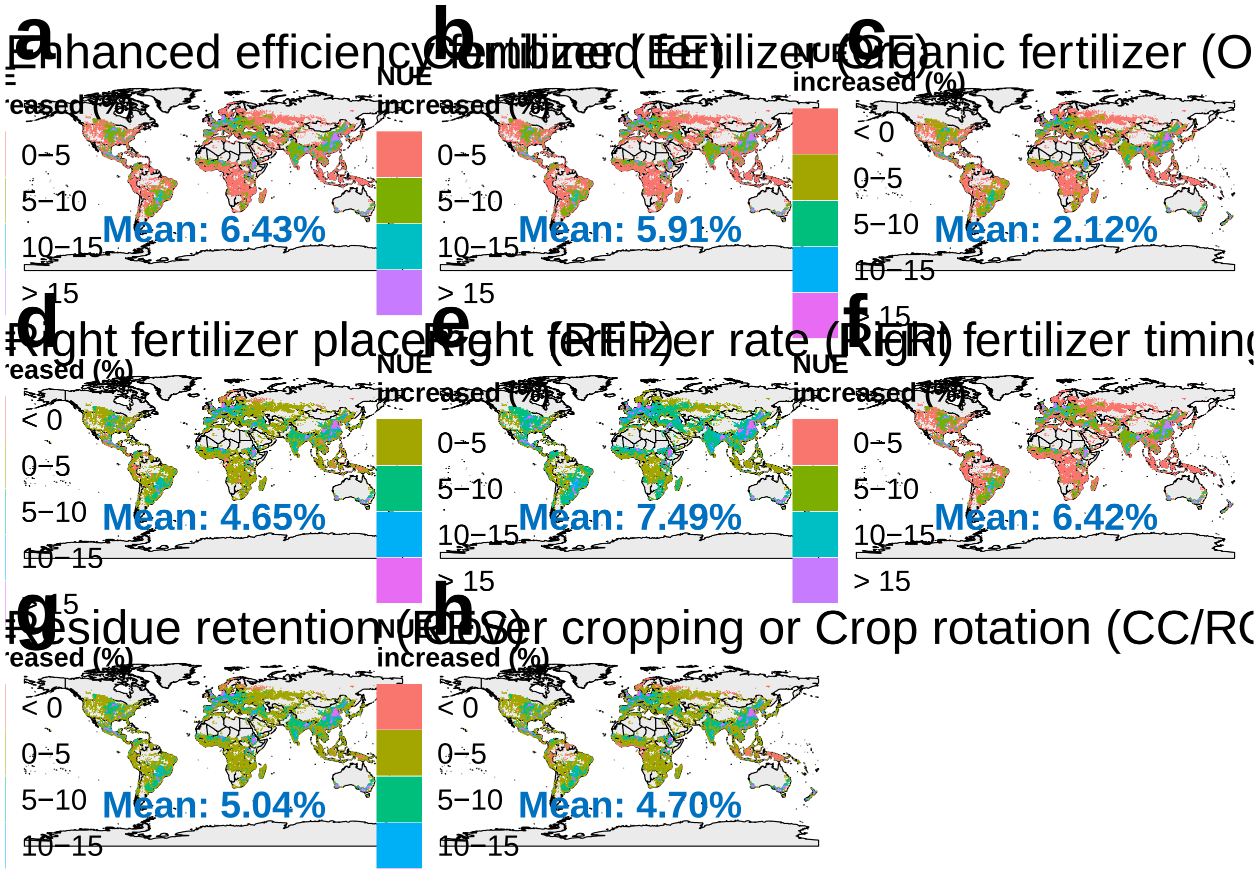
Cover cropping or Crop rotation (CC/ROT)




```r
#2*2
library(ggpubr)
```

```
##
## 载入程序包: 'ggpubr'

## The following object is masked from 'package:cowplot':
##
##     get_legend

## The following object is masked from 'package:terra':
##
##     rotate
```

```r
p_S5<-ggarrange(p10,p11, p12, p13, p14,p15,p17,p18, heights = c(4, 4, 4, 4), ncol = 3, nrow =
                labels = c("a", "b","c","d","e","f","g","h"), font.label=list(size=28),hjust =
p_S5
```



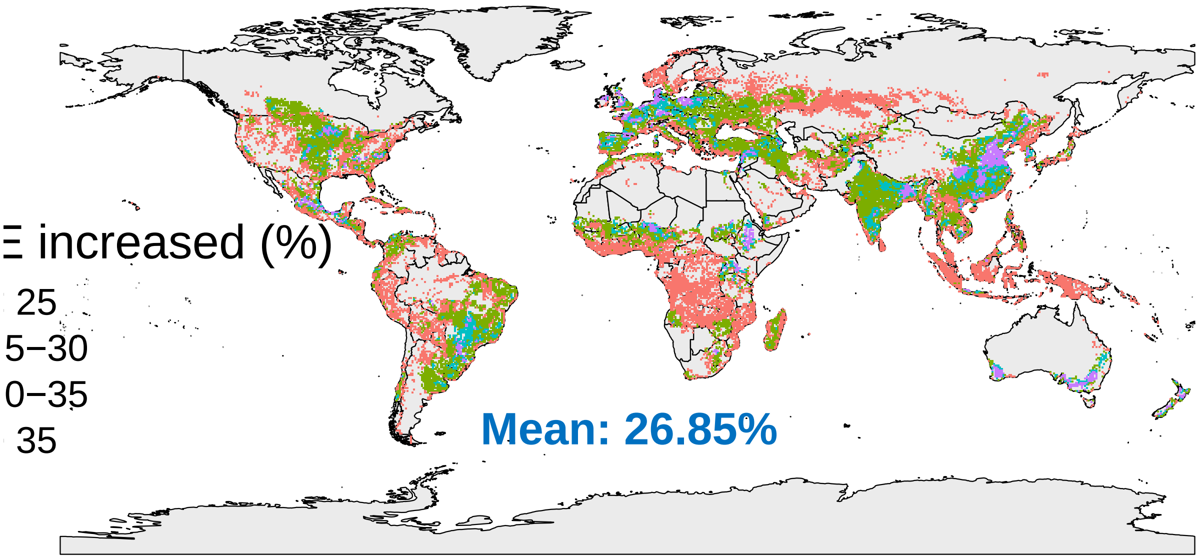

```
ggsave(p_S5, file = "D:/date/homework/picture/Figure_S5.png",width = 410,height = 197, units =

############################################ scenario_1 (optimal nutrient management) ###########
# set theme
theme_set(theme_bw())

# get the raster to plot
r1 <- terra::rast('D:/date/homework/tif/scenario_1.tif')

# convert to data.frame
r1.p <- as.data.frame(r1,xy=TRUE)
# Exclude outliers greater than 70%
r1.p <- r1.p[r1.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

#plot a basic world map plot
```

```r
p1 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
  geom_tile(data = r1.p,aes(x=x,y=y, name ='none',
                            fill = cut(improvement,breaks= c(15,25,30,35,800),
                                       labels = c('< 25','25-30','30-35','> 35') ))) +

  # scale_fill_gradientn(colours = rainbow(3)) +
  #scale_fill_viridis_c()+
  theme_void() +
  theme(legend.position = c(0.1,0.4), text = element_text(size = 18),
        legend.background = element_rect(fill = NA,color = NA),
        panel.border = element_blank()) +
  labs(fill = 'NUE increased (%)') +
  #theme(NULL)+
  xlab("Longitude") + ylab("Latitude") +
  ggtitle("Optimal nutrient management") +
  # ggtitle("World map", subtitle = "Mean change for scenario 1") +
  annotate("text",x=0.5,y=-50,label="Mean: 26.85%",size=6, colour="#0070C0",fontface = "bold")
  coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r1.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
p1
```

Optimal nutrient management

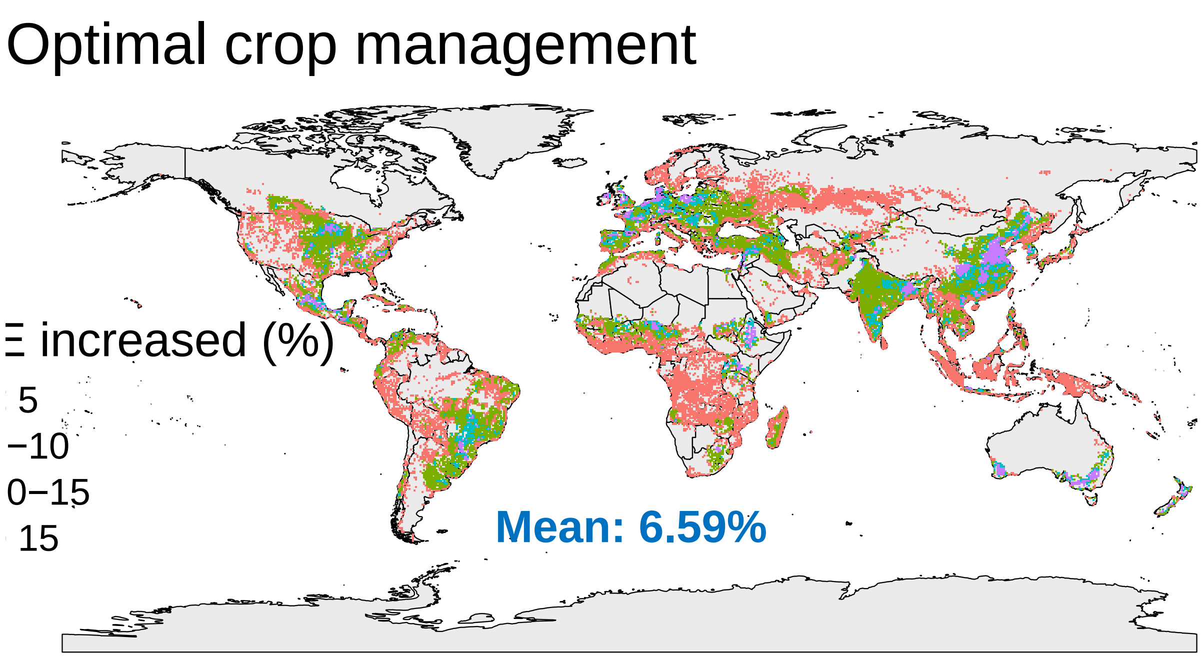



```
############################################ scenario_2 (optimal crop management) #############

# set theme
theme_set(theme_bw())

# get the raster to plot
r2 <- terra::rast('D:/date/homework/tif/scenario_2.tif')

# convert to data.frame
r2.p <- as.data.frame(r2,xy=TRUE)
# Exclude outliers greater than 70%
r2.p <- r2.p[r2.p$improvement <70,]



# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p2 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
```

```r
    geom_tile(data = r2.p,aes(x=x,y=y, name ='none',
                              fill = cut(improvement,breaks= c(0,5,10,15,800),
                                         labels = c('< 5','5-10','10-15','> 15') ))) +
    theme_void() +
    theme(legend.position = c(0.1,0.4), text = element_text(size = 18),
          legend.background = element_rect(fill = NA,color = NA),
          panel.border = element_blank()) +
    labs(fill = 'NUE increased (%)') +
    xlab("Longitude") + ylab("Latitude") +
    ggtitle("Optimal crop management") +
    #ggtitle("World map", subtitle = "Mean change for scenario 3") +
    annotate("text",x=0.5,y=-50,label="Mean: 6.59%",size=6, colour="#0070C0",fontface = "bold")+
    coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r2.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

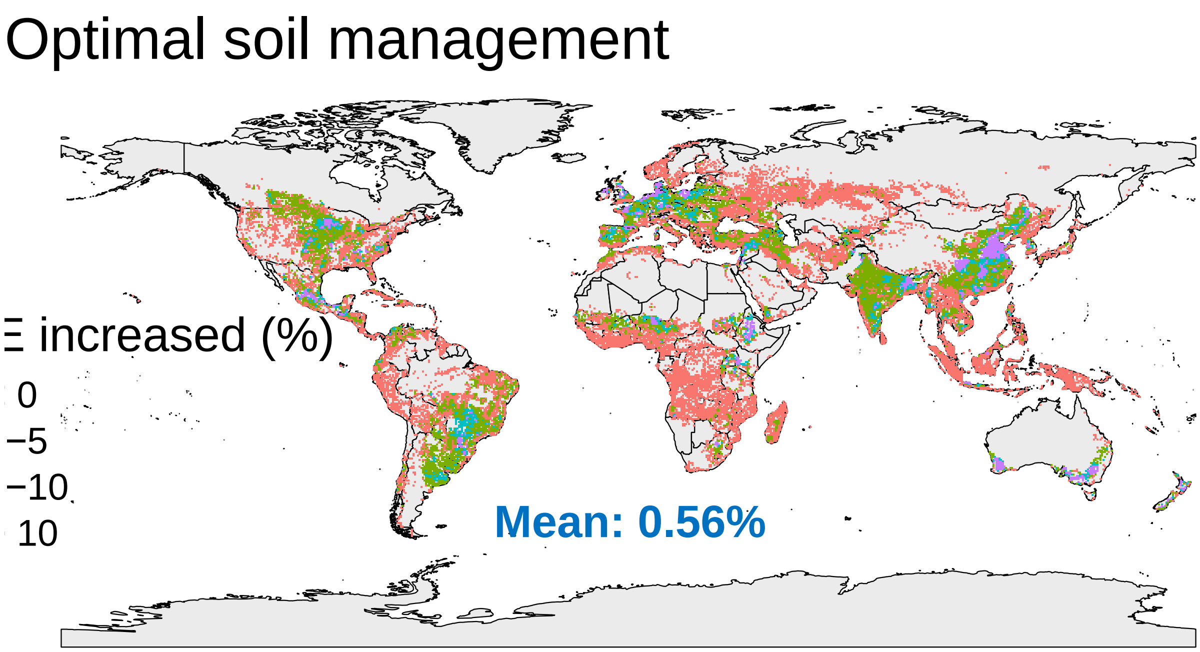
```r
p2
```



```r
########################################## scenario_3 (optimal soil management) ###########

# set theme
theme_set(theme_bw())

# get the raster to plot
r3 <- terra::rast('D:/date/homework/tif/scenario_3.tif')

# convert to data.frame
r3.p <- as.data.frame(r3,xy=TRUE)
# Exclude outliers greater than 70%
r3.p <- r3.p[r3.p$improvement <70,]


# write.csv(r3.p, file="E:/phD/Papers/paper2/You_et_al_2022/NC/tillage.csv")

# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")

# plot a basic world map plot
p3 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
  geom_tile(data = r3.p,aes(x=x,y=y, name ='none',
                            fill = cut(improvement,breaks= c(-7,0,5,10,800),
                                       labels = c('< 0','0-5','5-10','> 10') ))) +
  theme_void() +
  theme(legend.position = c(0.1,0.4), text = element_text(size = 18),
        legend.background = element_rect(fill = NA,color = NA),
        panel.border = element_blank()) +
  labs(fill = 'NUE increased (%)') +
  xlab("Longitude") + ylab("Latitude") +
  ggtitle("Optimal soil management") +
  #ggtitle("World map", subtitle = "Mean change for scenario 4") +
  annotate("text",x=0.5,y=-50,label="Mean: 0.56%",size=6, colour="#0070C0",fontface = "bold")+
  coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r3.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```
p3
```

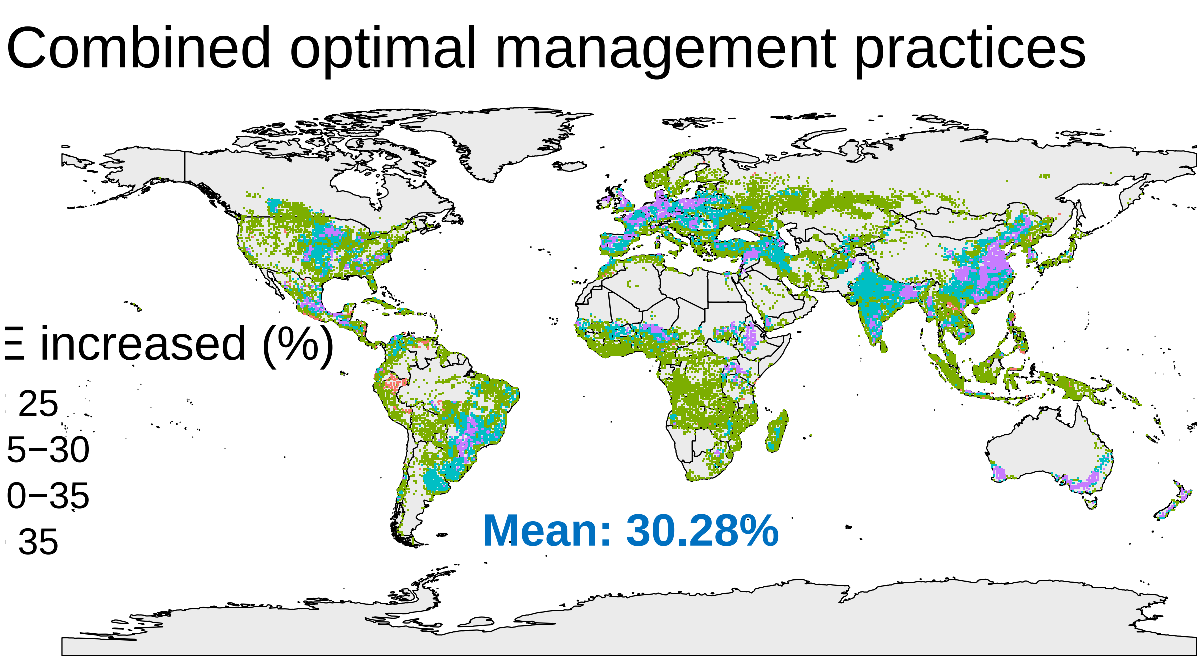



```
############################################ scenario_4 (combined optimal management practices)

# set theme
theme_set(theme_bw())

# get the raster to plot
r4 <- terra::rast('D:/date/homework/tif/scenario_4.tif')

# convert to data.frame
r4.p <- as.data.frame(r4,xy=TRUE)
# Exclude outliers greater than 70%
r4.p <- r4.p[r4.p$improvement <70,]


# get base world map
world <- ne_countries(scale = "medium", returnclass = "sf")
```

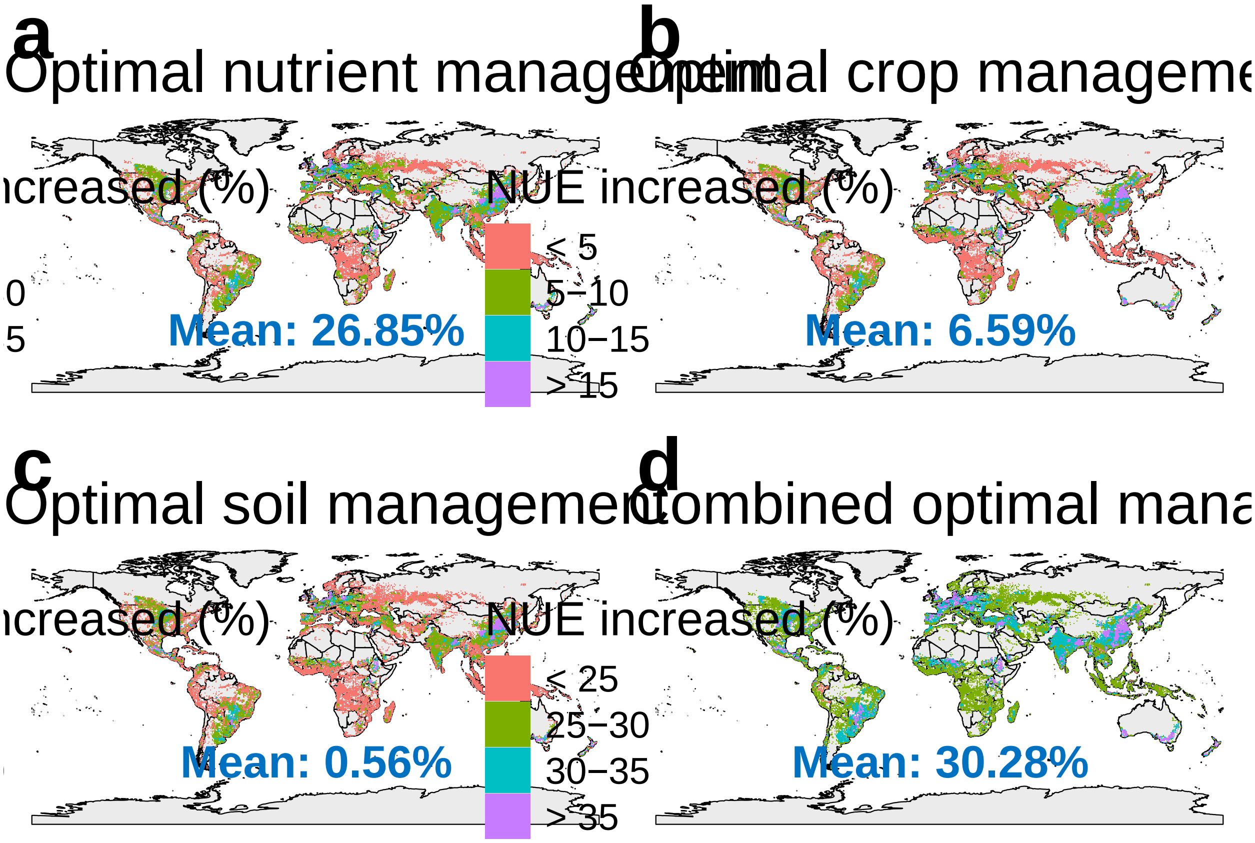
```r
# plot a basic world map plot
p4 <- ggplot(data = world) + geom_sf(color = "black", fill = "gray92") +
  geom_tile(data = r4.p,aes(x=x,y=y, name ='none',
                            fill = cut(improvement,breaks= c(20,25,30,35,800),
                                       labels = c('< 25','25-30','30-35','> 35') ))) +
  theme_void() +
  theme(legend.position = c(0.1,0.4), text = element_text(size = 18),
        legend.background = element_rect(fill = NA,color = NA),
        panel.border = element_blank()) +
  labs(fill = 'NUE increased (%)') +
  xlab("Longitude") + ylab("Latitude") +
  ggtitle("Combined optimal management practices") +
  #ggtitle("World map", subtitle = "Mean change for scenario 4") +
  annotate("text",x=0.5,y=-50,label="Mean: 30.28%",size=6, colour="#0070C0",fontface = "bold")
  coord_sf(crs = 4326)
```

```
## Warning in geom_tile(data = r4.p, aes(x = x, y = y, name = "none", fill =
## cut(improvement, : Ignoring unknown aesthetics: name
```

```r
p4
```



```r
#2*2
library(ggpubr)
p<-ggarrange(p1, p2, p3, p4, heights = c(4, 4, 4, 4), ncol = 2, nrow = 2, #common.legend = TRU
             labels = c("a", "b","c","d"), font.label=list(size=28),hjust = -0.2, vjust = 1)
p
```




```r
ggsave(p, file = "D:/date/homework/picture/Figure_4.png",width = 410,height = 197, units = "mm
```

R Markdown

This is an R Markdown document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see http://rmarkdown.rstudio.com.

When you click the **Knit** button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document. You can embed an R code chunk like this:

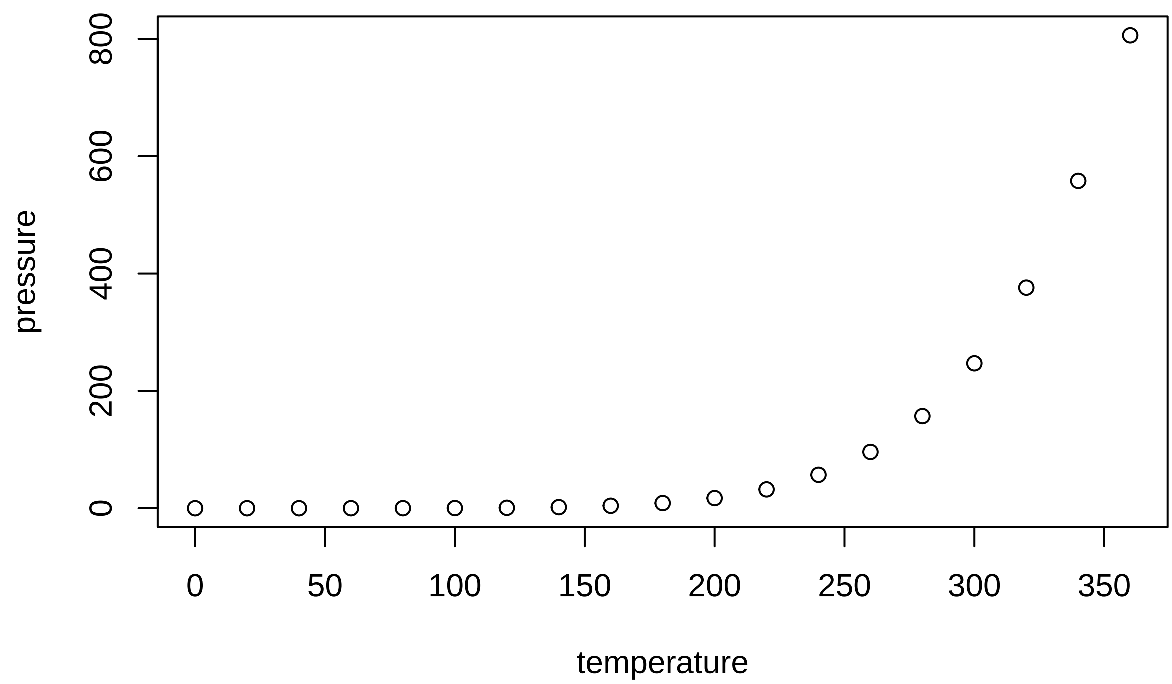
```r
summary(cars)
```

```
##      speed           dist
##  Min.   : 4.0   Min.   :  2.00
```

```
##  1st Qu.:12.0   1st Qu.: 26.00
##  Median :15.0   Median : 36.00
##  Mean   :15.4   Mean   : 42.98
##  3rd Qu.:19.0   3rd Qu.: 56.00
##  Max.   :25.0   Max.   :120.00
```

Including Plots

You can also embed plots, for example:



Note that the `echo = FALSE` parameter was added to the code chunk to prevent printing of the R code that generated the plot.