

Integrated Drought Management

Programme in Central and Eastern Europe



Activity 5.5. Policy oriented study on remote sensing agricultural drought monitoring methods

Output 3: Integration of RS and GIS tools and intervention levels into drought monitoring

(04/03/2015)

1. Basic information

Name of the milestone report	Integration of RS and GIS tools and intervention levels into drought monitoring
Activity leader	Prof. Dr. János Tamás
Participating partners	University of Debrecen, Hungary Institute of Hydrology of the Slovak Academy of Sciences, Slovakia University of Oradea, Romania
Duration	01/07/2014 – 31/01/2015
Chairman of the CWP	Dr. József Gayer

*Milestone report is information about the progress made within this activity from previous milestone report for GWP CEE Regional Secretariat, Programme Manager, Peer Review Group and partners involved into IDMP CEE. It is not intended for further distribution.

2. Activity Report

2.1. Short summary of the milestone report (max 2500 characters); *What have been done after the previous milestone report(s)?*

The Activity 5.5. "Policy oriented study on remote sensing agricultural drought monitoring methods" case study focuses on identification of agricultural drought characteristics and elaborates a monitoring method (with application of remote sensing data), which could result in appropriate early warning of droughts before irreversible yield loss and/or quality degradation occur. The spatial decision supporting system was developed to help the farmers in reducing drought risk of the different regions by plant specific calibrated drought indexes. In the frame of this innovation such a data link and integration, missing from decision process of IDMP, were established, which can facilitate the rapid spatial and temporal monitoring of meteorological, agricultural drought phenomena and its economic relations, increasing the time factor effectiveness of decision support system. This methodology could be extendable for other Central European countries if country specific data are available and entered into the system.

In this phase of the activity the impact of drought on wheat and maize price, concrete programming of a user friendly drought monitoring and yield loss mapping process and possible integration practices of drought monitoring and yield loss forecasting method were assessed and developed. The remote sensing based Agricultural Drought Monitoring and Yield Loss Forecasting Method can effectively indicate anomaly of droughts and yield losses and can identify the possible intervention areas. The methodology is also appropriate for early warning of droughts, since yield loss can be predicted 2 months before the irreversible yield loss and/or quality degradation realized. By plant specific calibrated yield loss maps the developed spatial decision supporting system gives precise information for farmers on drought risk of the different region. This milestone report

- facilitates the Agricultural Drought Monitoring and Yield Loss Forecasting Method to be part of a drought management system in CEE
- is taking into account the economic relations and indicators of drought,
- focusing on decision making, emphasizing the main points of integration of this method to a drought management system.

2.2. Describe the progress to the objectives of your activity

In the first part, the economic effect of drought were evaluated through the analysis of yield data and yield price data. Concerning yield price the role of other factors were also assessed.

The importance of remotely sensed yield monitoring was also emphasized. The user friendly drought monitoring and yield loss mapping process model contains several steps from masking of the region of interest, through reclassification to risk mapping and calculating the area effected by drought at five drought risk levels and not affected sites (Figure 8). There are three main steps:

- I. Input data identification (masking of Region of Interest)

- II. Reclassification (Using the NDVI threshold levels, calculated in Milestone 2.)
 - III. Drought risk and yield loss decision support map.
- The result of the process is the exact area calculation of the drought affected site in hectares. This is also important for regional scale, especially for decision makers in order to know how large are the different yield loss affected sites in a region, or watershed, or in a country.

2.3. The expected final output (s). At what stage you are now in the process of producing the final output(s)?

Final output: Integration of RS and GIS tools and intervention levels into drought monitoring system

The case study has three important steps, milestones, which correspond and relate to each other in hierarchical way. First, the green and brown water resources should be analysed on the examined watershed(s) in order to gather information on water utilization of a site. These data are necessary for the second step, the calibration and validation of remote sensing data. Our activity is in the end of the second phase, so green and brown water were identified, and the calibration of remote sensing data was done. The third milestone, which is the implementation of the signalling levels of drought is based on the results of the integrated data of step 1 and step 2 in order to develop drought indicators and integrate them into a drought monitoring system.

In the frame of Milestone 1 databases, which were homogenous from meteorological, soil physical, plant production, GIS and RS point of view were produced for the Tisza river basin for the recent years. In Milestone 2 using GIS geoprocessing and time series analysis, drought maps were generated based on the established drought risk levels.

In Milestone 2 a specific data integration process were managed to set with which other conventional drought indices can be specified and refined by actual yield loss data, based on the calibration of remote sensing based maps. Toolbox was elaborated for concrete identification of remote sensing and GIS data tools was also added for Agricultural Drought Monitoring and Yield Loss Forecasting Method, which eventually provides information on physical implementation of drought risk levels. As a result, five drought risk levels were developed to identify the effect of drought on yields, such as: Watch, Early Warning, Warning, Alert and Catastrophe.

In the final stage a user-friendly Agricultural Drought Monitoring and Yield Loss Forecasting Method was generated in order to make it possible for yield forecasting of other users in ArcGIS environment. Thus decision makers can easily use it to estimate yield loss in a certain field. Such models were generated, which can be used by other users for other drought risk affected areas. This digital IDMP geoprocessing framework process makes it possible to access and share the knowledge tool of drought monitoring and yield loss forecasting for users and stakeholders.

With help from Agricultural Drought Monitoring and Yield Loss Forecasting Method, the effect of drought on crops can be detected 4-6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest, which is the most vital need for global food security and trade. This information can reduce impacts if delivered to decision makers in a timely and appropriate format and if mitigation measures and preparedness plans are in place.

2.4. Have you introduced any change in the original plan as outlined in the Activity List?

No changes have been done.

2.5. Identify links with other IDMP CEE activities

Activity 2.1: Guideline for Drought Management Plan - Our MODIS NDVI based agricultural drought mapping method can be one of the support guideline in preparation of Drought maps.

Activity 5.1: Experimental field research on increasing of soil-water holding capacity in agriculture and

Activity 5.6: Upgrading agricultural drought monitoring and forecasting: the case of Ukraine and Moldova - Soil water capacity mapping, described in this Output can support the identification of soil water holding capacity in regional scale.

Activity 5.4: Drought Risk Management Scheme: a decision support system - Yield calibrated drought risk levels can decrease the risk of uncertainty and increase the feasibility of other recently available decision support systems by the visualization and communication of the probability of occurrence of different phases of droughts.

Activity 6.2: Capacity building trainings - Participation on capacity building trainings with interpreting how to implement NDVI based yield-calibrated imagery in drought mapping and yield loss forecast.

Activity 7.1: Development of the Compendium of Good Practices - Review of remote sensing in Agricultural Drought Monitoring and Yield Loss Forecasting Method for decision support system.

2.6. Other issues (problems during the implementation, how they were solved, etc.)

There were no critical problems to be solved

2.7. List if National Reports have been used, and if so, provide details on the National Reports (title, authors, publication data and location)

National reports were not used, instead statistical data of several parameters obtained from Hungarian Central Statistics Office (www.ksh.hu) Research Institute of Agricultural Economy (www.aki.gov.hu).

3. Attachments

Integration of RS and GIS tools and intervention levels into drought monitoring system

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1. Introduction

Drought differs from the other natural disasters in several aspects. It occurs slowly and its formation often needs several months in Hungary. Neither its precise beginning and end, nor its spatial extent are hard to solely determine. Spatial extent of agricultural drought usually takes longer than the other major disasters. Its effect occurs in all areas of life. (Wilhite and Svoboda, 2000).

In the case of most watercourses, network of runoff measuring instrument has already been operated so hydrologic drought is forecastable. While on watershed areas just a few data available in the case of soil moisture content and water supply for plants. Though the largest natural reservoir potential in CEE is the soil, this capacity is only at low utilization level at present and continuous measurements for getting information on actual soil water stock are only carried out by 2-5% of farmers. Better and a more complete use of this capacity can reduce efficiently and effectively the drought sensitivity and the direct effects of the drought as well as it was described in Activity 5.1. (Várallyay 2012).

Crop growth and yield are determined by a number of factors such as genetic potential of crop cultivar, soil, weather, cultivation practices (date of sowing, amount of irrigation and fertilizer) and biotic stresses. However, generally for a given area, year-to-year yield variability has been mostly modelled through weather as a predictor using either empirical or crop simulation approach. With the launch and continuous availability of multi-spectral (visible, near-infrared) sensors on polar orbiting earth observation satellites (Landsat, SPOT, IRS, etc) remote sensing (RS) data has become an important tool for yield modelling. RS data provide timely, accurate, synoptic and objective estimation of crop growing conditions or crop growth and allow issuing yield forecasts at a range of spatial scales. RS data have certain advantage over meteorological observations for yield modelling, such as dense observational coverage, direct viewing of the crop and ability to capture effect of non-meteorological factors. Recent developments in GIS technology allow capture, storage, retrieval, visualization, and modelling of geographically linked data. An integration of the crop yield data, RS data and GIS can provide an excellent solution to monitoring and modelling of crop yield loss at a range of spatial scales.

Presently there is minimal technological barrier of the wide range technical applications of remote sensing (RS), though the cumulated knowledge on RS can slowly be implemented into practice. Thus due to the lack of knowledge or some kind of misunderstanding, decision makers talks about this technology as research task, but it is a practice oriented development. There is a possible way to continuously gather spectral physical data on plant water content, though the direct interpretation of these data is not feasible for decision makers and farmers. However, on one hand, farmers have no experience with practical application of this spectral anomaly information, and the other hand they do not know how to correlate with different species, and growing vegetation phases. But using field reference data (data of green and brown water content) as a calibration for remote sensing data, real plant water demand quickly and effectively can be mapped in spatial and in time on the surface. Therefore determination of yield loss is a possible solution in the detection and identification of the extent of agricultural drought.

In order to the farmers realize the efficiency of the expenditure for drought risk reduction investments and to invest in food industry and in rural development, it is necessary to calculate not only the cost but the virtual benefit of them which can occur in a case of a severe drought event. The direct economic and political benefit has to be taken into consideration as well, which benefit is coming from the increase of food safety and security resulted by a more reliable drought monitoring and forecasting system. These results support growing economic stability and thus decrease political risks in the drought affected regions.

The Activity 5.5. “Policy oriented study on remote sensing agricultural drought monitoring methods” case study focused on identification of agricultural drought characteristics and elaborated a monitoring

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method (with application of remote sensing data), which could result in appropriate early warning of droughts before irreversible yield loss and/or quality degradation occur. The developed spatial decision supporting system could help the farmers in reducing drought risk of the different regions by plant specific calibrated drought indexes. This methodology can be extendable for other Central European countries when country specific data are available and entered into the system.

Output 3 focuses on the impact of drought on wheat and maize prices, concrete programming of a user-friendly drought monitoring and yield loss mapping process, as well recommend possible integration practices of drought monitoring and yield loss forecasting method. based on remote sensing and GIS data tools examined in Output 2 which provides information on physical implementation of drought risk levels. This activity integrated Agricultural Drought Monitoring and Yield Loss Forecasting Method focuses on the impact of the spatial and temporal yield loss based on drought mapping and forecasting, taking into account the economic relations and indicators of drought, eventually on decision making emphasizing the main points of integration of this method to a drought management. Within the deliverables of this output 3 the purpose of the report is to:

- facilitate the Agricultural Drought Monitoring and Yield Loss Forecasting Method to be a part of drought management system in CEE
- taking into account the economic relations and indicators of drought,
- eventually focusing on decision making, emphasizing the main points of integration of this method to a drought management system.

2. Effect of agricultural droughts (yield loss) and their economic costs

The considerable regulatory and structural changes have taken places on the grain market in recent decades which have greatly influenced the strategies and pricing of the grain market operators. The structure formation is connected with the historical and political background of the past 15 years furthermore nowadays with the EU grain market regulations (Horváth, 2007). In the first year of the EU membership of Hungary in 2004, outstanding production and profitability indicators of the agricultural sector was due to the weather, while the excessive precipitation had deteriorated the quality in 2005. Compared to 2004, the grain supply was slightly lower, which deduction was difficult to relate to one reason owing to high transportation costs, shrinking livestock and rearrangement of export markets. The supply deduced from the export, was cut back by the high intervention price as well. The supply reduction and increase in demand for cereals caused significant price increase on the EU grain market as well as in the Eastern European region in 2006. The grain production was almost decreased by 10% in Hungary. Little grain was offered for intervention on the expenditure side, although, exports have increased. The 2007 domestic adverse market developments (production decline, the growth rate of foreign foods) were caused by the clash of interests among the product chain operators that correlates the weak vertical integration as well. Despite the extreme weather condition, the gross value of agricultural production increased within 5%. The sharp decline in domestic production and the unusually high price levels were typical. In 2008, the volume of output of agricultural products rose by 27%, the production of crop products increased by 47%. The increase in grain yield can be highlighted among them. The increasing agricultural and decreasing food production follow that the rate of lower processed agricultural products continued to increase within exports. Declines in demand, due to the economic crisis, resp. expansion of supply resulted in reduction in the prices of the source material and the finished products by 2009. Reduction in the supply of agricultural and food products were also influenced by borrowing difficulties and liquidity problems of the producers and the processors (Majóczki-Katona, 2014).

Besides the falling supply due to the effect of extreme weather, the increase of world market and export prices and the increasing foreign demand triggered increase in the price of crop production in 2010. The effects of the 2010 weather was further aggravated by the wheat and maize growing regions of China dominated by prolonged drought, therefore were loss of crops which were responsible for increasing cereal prices on world markets. Considering the "tipped" grain market equilibrium in the United States and Europe, the China's drought has affected on the world situation of the grain. 12 millimetres of precipitation fell to the region of Yangtze River from September 2010 to April 2011, which was not enough for the vegetation to survive on 40% of the grain-growing areas. The traditionally developed irrigation was not possible in the Yangtze region because the average water level was six feet lower than in the same period of the previous year. The quantity of precipitation was for the last time in 1954 as low as had been measured since autumn of 2010. The Chinese economic plan was to reach the 181.5 million tons of corn harvest for replacement of shortages with the increased sown area but the produce of this amount was not succeeded for the adverse weather conditions. The price of corn reached a record in March, which, due to low reserves, significantly raised food prices. However, the world cereal production took a turn for the better in 2011 than in 2010. The commodity markets have been felt in the previous shortage reduction since the beginning of 2011, record level prices declined steadily in the second half of the year, but it have still been stabilized at a relatively high level of crop prices. In Hungary, the price of wheat increased by 29% while the fodder maize increased by 30% in 2011 compared to the previous year (Figure 1 and Figure 2) (AKI, 2012).

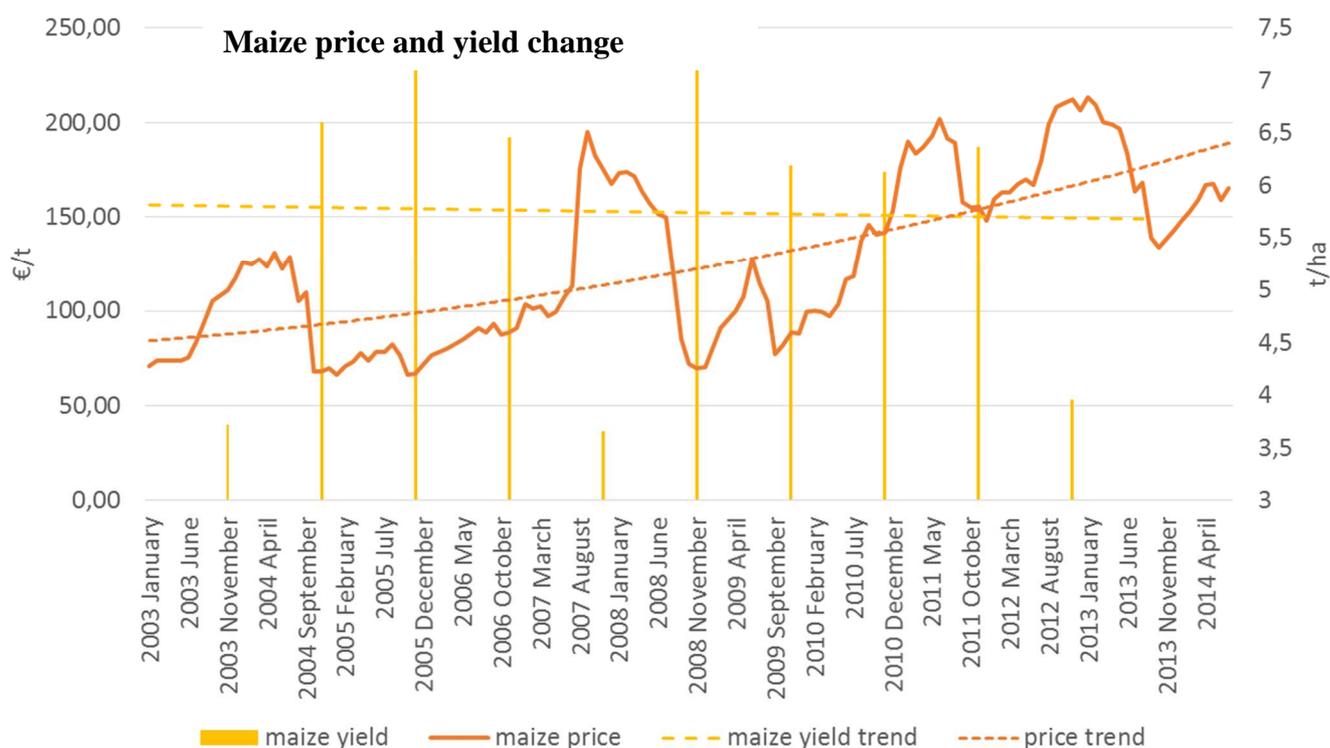


Figure 1. Changes of maize prices and yield (based on KSH and AKI data)

In 2012, the hottest and driest summer of the century caused yield losses and price shock on the world grain market. The forward price of more crops reached a historical peak on the commodity markets but the global economic crisis and the lack of trade restriction prevented from the emergence of an even higher price levels. In Hungary, the producer price of bread wheat increased by 17%, the fodder wheat by 28% and the fodder maize also increased by 16% compared to the year 2011 (Research Institute of Agricultural

Economics AKI, 2012). The yield of grain was 10.3 million tons. The yield due to the extremely dry weather dropped by 24% compared to the previous year. The biggest loss derived from corn harvest. The 4.7 million tons harvest was only 59% of the previous year. Wheat was grown by 8% larger area (1.1 million hectares) in 2012 than the previous year. Despite the increased sown area, the wheat harvest was only 4 million tons which was by 3% less than in 2011 (Hungarian Central Statistical Office - HCSO, 2013).

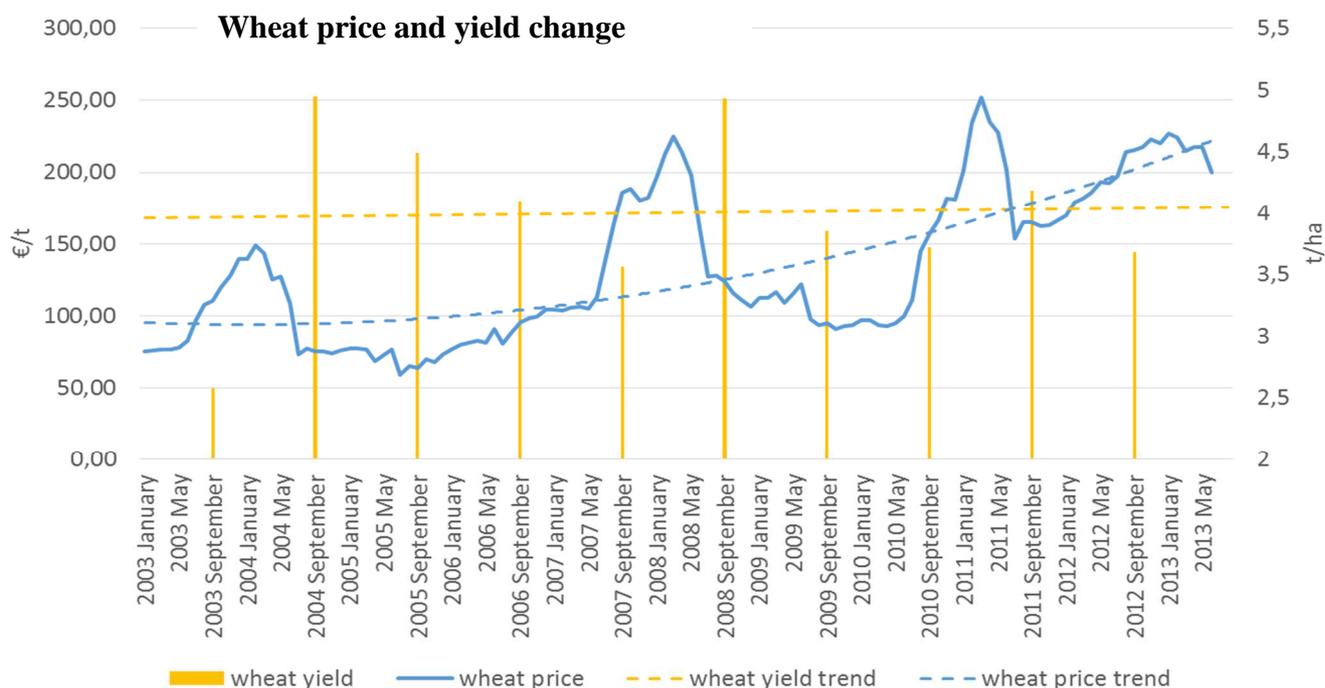


Figure 2. Changes of wheat prices and yield (based on KSH and AKI data)

In 2012, the hottest and driest summer of the century caused yield losses and price shock on the world grain market. The forward price of more crops reached a historical peak on the commodity markets but the global economic crisis and the lack of trade restriction prevented from the emergence of an even higher price levels. In Hungary, the producer price of bread wheat increased by 17%, the fodder wheat by 28% and the fodder maize also increased by 16% compared to the year 2011 (Research Institute of Agricultural Economics AKI, 2012). The yield of grain was 10.3 million tons. The yield due to the extremely dry weather dropped by 24% compared to the previous year. The biggest loss derived from corn harvest. The 4.7 million tons harvest was only 59% of the previous year. Wheat was grown by 8% larger area (1.1 million hectares) in 2012 than the previous year. Despite the increased sown area, the wheat harvest was only 4 million tons which was by 3% less than in 2011 (Hungarian Central Statistical Office - HCSO, 2013).

In summary, the price of cereals reached a low point in 2005. By 2006, the prices exceeded the intervention price level. A year later, owing to the drought resulted to domestic crop failure, to lower demand and the global market trends, the prices doubled after the harvest. A strong fall in prices took place on the grain market in 2008. Despite the drop in production, the prices fell a year after. A marked increase in prices occurred on the grain market in 2010. At the beginning of 2011, the record price levels decreased steadily in the second half of the year, but even so, the prices have stabilized at relatively high levels, and the forward prices of more crops reached a historical high peak on the commodity markets in 2012. 2013 year was characterized by a decrease in grain prices (Majóczyki-Katona, 2014).

The changes in wheat and maize price is similar. This can be considered by the high correlation ($r^2=0.878$ $p=0.001$) between wheat and maize price (Figure 3). This similarity and high correlation seems to be a bit controversy, because wheat is less drought sensitive in CEE region than maize. The standard deviation of wheat yield is 17%, while in the case of maize it is 25%. However, wheat price has the same changing character than maize, because of two reasons.

1. If the wheat is drought affected, the quality of it would also decrease, thus smaller amount could be used in human nutrition, and larger amount will be for animal forage. In contrary, maize is produced generally for animal forage. Therefore the decrease of wheat with good gluten and other parameters will enhance the yield loss effect of the drought.
2. Wheat and maize are complementary to each other in animal nutrition. Therefore even if there is less yield loss in wheat (17%) or drought has the effect on drought causing quality decrease and larger rate of wheat yield for animal forage, large maize yield loss (25%) will increase wheat price.

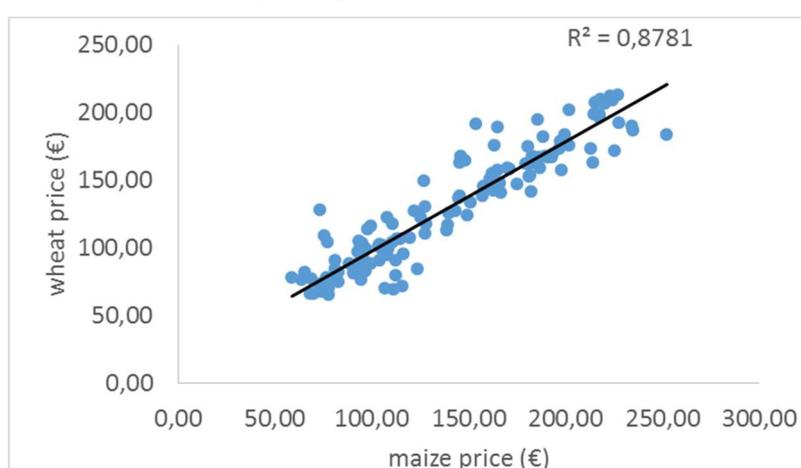


Figure 3. Correlation between wheat and maize price (based on AKI data)

Though there are many factors, wheat and maize yield (t/ha) has significant effect on prices. The effect is started generally after harvesting until the first quarter of the following year. This suggests that until harvest, there are no widespread reliable methods for yield prediction, or there is not enough awareness on existing drought monitoring systems or yield forecast methods that can be used as a useful tool in yield loss prediction, which can facilitate decision makers on the market. Our remote sensing based drought monitoring and yield loss forecast tool, (presented in Output 2 report) can be a good solution, since it predicts yield loss 1-3 months before harvesting. The results of correlation also show, that in the case of maize the effect of yield on price is much higher (above $r^2=0.7$) than in the case of wheat, (around $r^2=0.5$), which suggests that the maize yield can have significant effect on wheat prices as well (Figure 4). Therefore the correlation analysis was made between wheat prices and maize yield, and stronger correlation was found than in the case of relationship between wheat price and yield. This statement suggests that maize yield (which can be more affected by drought) is a dominant factor in wheat price as well, and supports that similar changes can be observed in wheat and maize price.

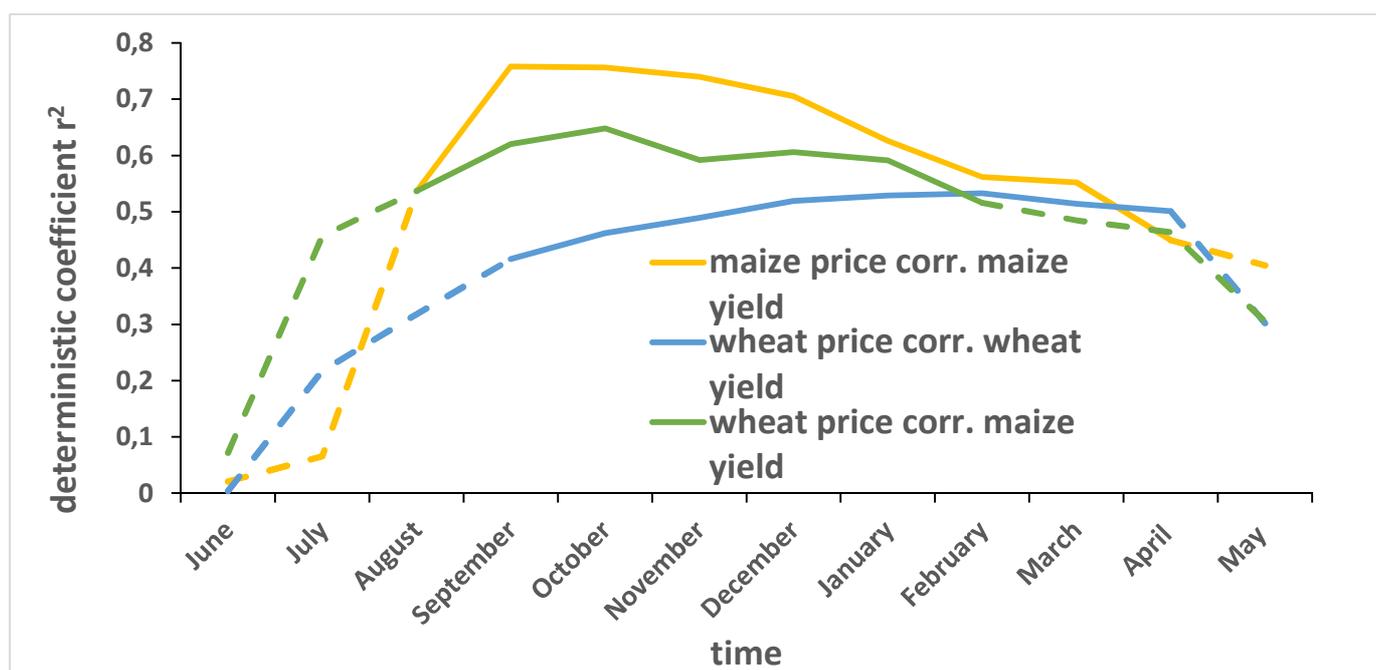


Figure 4. The effect of wheat and maize yield (t/ha) on prices in different months (continuous line – significant, dashed line – not significant correlation, corr. – in correlation with)

It can be traced well from the change of the prices and average yields that both wheat and corn prices have been going through a continuous rise in the past ten years. However, when examining the average yield of 10-year data series no similar trend was observed. The grain yield was virtually average 4.16 t/ha for wheat and about 5.75 t/ha for maize (Figure 1). Certainly, the grain price increased clearly in years affected by drought, although it has stabilized at a higher price level from especially 2010. This is because of the harvest prices, besides the drought, are also influenced by other factors affecting particularly the prices.

- Growing population –growing demand: Across the Arab world, grain production is stagnating, yet grain demand is growing rapidly as population expands. Since 1960, the region’s population has nearly quadrupled to 360 million. By 2050 the region is projected to add another 260 million people, dramatically increasing pressure on already stressed land and water resources (Rasmussen, 2012). Access to land is a prime source of social tension. Expanding world population has cut the grain land per person in half since 1950 to a mere quarter-acre (Brown, 2009).
- Stock: Stocks played two roles in the price spike. Stocks were falling in large part since growth of demand was faster than that of supply and signalled those changes. Once reduced to critical thresholds, there were no longer sufficient to prevent the short-term triggers driving prices up strongly and thereby prompting the panic reactions that accelerated the price rises (Wiggins and Keats, 2009). In 2014, due to the global oversupply on the export markets, the wheat price followed decreasing trends in January (AKI, 2014).
- Strength of national economy: The increase of the crop price were limited by the competitive Russian wheat prices owing to the weakening of the rouble in 2014 (AKI 2014).
- Export markets: Export has a significant role in grain market. The bulk grain supply chain in the CEE region is the farm, country storage, port terminal, generally in the Black Sea region's ports and exporting to Arabic country and to the Middle East (Figure 5). If there is a problem in this chain, the

price of grain will change. If there is a severe drought in CEE and in costumer countries, domestic destination would be more emphasized, and the demand of grain in costumer countries will be high, which results sharp increase in prices.

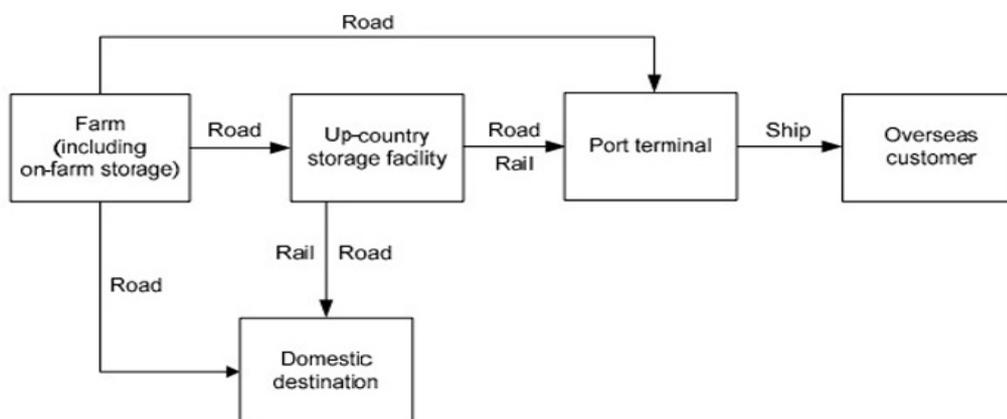


Figure 5. Bulk grain supply chain (Source: www.abc.net.au/news/2013-11-19/bulk-supply-chain-graphic/5095590)

The trade can be hindered by logistical problems because of the extreme weather condition, as it was happened in the USA in 2014. Competitiveness of the grain is also important; the worsening competitiveness of CEE the region resulted increasing demand for wheat from other EU countries (AKI 2014).

- Virtual water transport: Hoekstra (2003) have defined the virtual-water content of a product (a commodity, good or service) as "the volume of fresh water used to produce the product, measured at the place where the product was actually produced". It refers to the sum of the water use in the various steps of the production chain. It takes 1,600 cubic meters of water on average to produce one metric ton of wheat. The precise volume can be more or less depending on climatic conditions and agricultural practice (Figure 6). The figure confirms that wheat and maize plants are the key plants in the CEE region and how much is dependent on water/drought and also the Arab world and Middle East how strongly depend upon grain import coming from the CEE region.

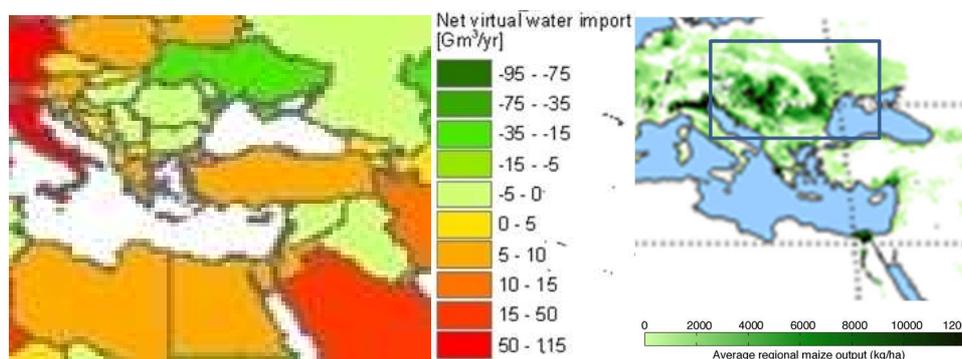


Figure 6. Virtual water balance per country related to trade in agricultural and industrial products over the period 1996-2005. Net exporters are shown in green and net importers in red (Mekkonen and Hoekstra, 2011) and average regional maize output (based on FAOSTAT 2011 data, <http://en.wikipedia.org/wiki/Maize>)

- Bio-ethanol production: From 1990 to 2005, world grain consumption, driven largely by population growth and rising consumption of grain-based animal products, climbed by an average of 21 million tons per year. Then came the explosion in grain used in U.S. ethanol distilleries, which jumped from 54 million tons in 2006 to 95 million tons in 2008 (Figure 5). This 41-million-ton jump doubled the annual growth in world demand for grain almost overnight, helping to triple world prices for wheat, rice, corn, and soybeans from mid-2006 to mid-2008 (Brown, 2009). A World Bank analyst attributes 70 percent of the food price rise is due to bio-ethanol production and other factors including reduced stocks (World Bank 2008).
- International conflicts: Ukraine has become an important crop exporter. It was the fourth biggest seller of corn in 2013. As one of the world's biggest exporters of both crops, wheat and corn prices rose sharply in response to the crisis in Ukraine in May, 2014 (<http://www.theguardian.com/business/2014/mar/03/ukraine-crisis-crimea-hits-price-wheat-corn>).

In addition, the yield was not only affected by the drought:

Extreme weather conditions decrease the wheat quality and result fungal diseases which increase toxins (e.g. DON toxin) in seeds. Low temperature causes longer vegetation period and delays in seeding time. When mean daily temperatures are below 20°C, e.g. in the case of cold springs, there is an extension in days to maturity of 10 to 20 days (http://www.fao.org/nr/water/cropinfo_maize.html). For germination the lowest mean daily temperature is about 10°C, with 18 to 20°C being optimum (Csajbók, 2012). The problem is especially in case of maize if the sowing cannot be started in time for the cold spring, or extreme wet weather. A few weeks delay would result that the maize has not reached the early grain filling stage to the dry period (mid-July) yet, but still was before flowering. The corn is well known that it is the most drought sensitive at the time of flowering.

The frequency of the arid, droughty periods increased in the last few years, and the intensity of nutrient supply decreased, therefore the previously used higher plant density needs reducing. Of course, there are also big differences between maize hybrids in density capability. There are wide and narrow optimum plant density hybrids and there are hybrids sensitive to higher plant density (Pepó and Sárvári, 2011).

In the CEE FAO No. 200-599 hybrid are important. The crop of super early group (FAO 100-199) is small, grown in the north of Hungary. The FAO 500 group is long-term breeding hybrids and it does not ripe in Hungary and in the CEE. There are positive correlation between fertility and breeding time of the hybrids. The long-term breeding hybrids can yield more. The early and mid-season hybrids (FAO 300-400) are predominant in Hungary as well as in CEE. Due to the frequency of drought years thus the production risk of mid-season hybrids increases, since the crucial period of water supply for the CEE FAO 400 hybrids is very likely to coincide with the possible drought period. Therefore in recent years, the proportion of very early group (FAO 200) increases, while the mid-season ones reduced. (Csajbók, 2012).

In summary, attributing significance to one factor or another in the price spike is not easy, given the complex way that the various cases contribute. Take away one or other of several of these factors and there would have been no price spike, but that does not mean that each of these was the cause of the event. Indeed, Abbott et al. (2008) comment: “There is no doubt that the causes of the current agricultural commodity price increases are complex. We make no attempt to derive percentages attributable to the many disparate causes, and, indeed, think it impossible to do so.”

3. The importance and the development of MODIS NDVI based Agricultural Drought Monitoring and Yield Loss Forecasting Method

Nowadays in water management, remote sensing is one of most important solution for measuring agricultural droughts and its effects. However, traditional drought indices highly usable for drought monitoring and forecast may also be suitable for the estimation of yield loss with appropriate calibration. A good example is the SPI (Figure 7). Between the average yield of maize (*Zea mays* L.) and the SPI-3 was strong, linear correlation ($r=0.75$) can be found. This suggests that, after suitable calibration, SPI is also possible to estimate the yield loss. However, this does not provide specific spatial data for yield loss, characterizes by only the mean conditions of the region. From the agricultural point of view and because of being one of the input data of several drought monitoring of soil water content is also important, and there is moderate, but significant correlation ($r^2=0.59$ $p=0.012$) was found between soil water anomaly (European Drought Observatory (EDO) data) (http://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_soilmoisture.pdf) and yield. But these point data have also spatial uncertainty, and cannot represent properly a site, or larger, heterogeneous area.

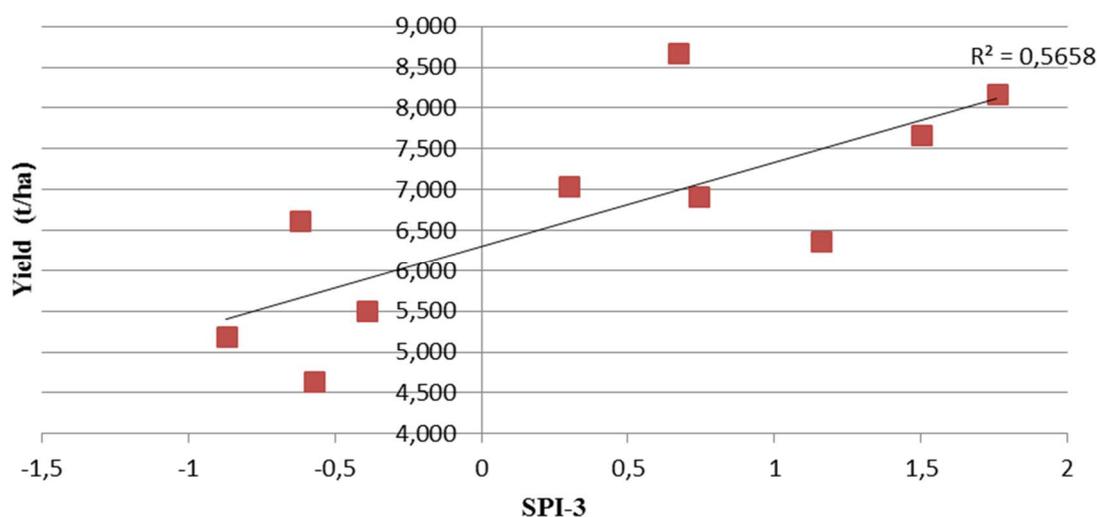


Figure 7. Comparison of maize (*Zea mays* L.) yields and the SPI-3 between 2003-2013 (based on AKI and EDO data)

The disadvantages of traditional drought indices in site-specific yield prediction are generally based on the input data characteristics. Input data are point scale, and these data are interpolated to as a continuous surface, which smoothers the real heterogeneity. This heterogeneity is well characterized by the differences of local data of field meteorological station, and the data of official stations. For example, there were large differences between precipitation data between EDO data for Debrecen and one of field meteorological stations near to Debrecen (Table 1).

Table 1: The differences in the amount of precipitation (mm) for Debrecen (grey: dry years) (based on local and AKI data)

	Local meteorological station data on a field in Debrecen	Data from EDO for Debrecen	Differences between precipitation values (Local-EDO)
2003	422	489	-67
2004	630	683	-52
2005	638	649	-11
2006	576	531	44
2007	401	595	-195
2008	690	681	8
2009	362	492	-131
2010	868	946	-79
2011	620	538	82
2012	427	479	-53

In contrast with the conventional agricultural drought indexing methods, which mainly uses point source meteorological data, Agricultural Drought Monitoring and Yield Loss Forecasting Method can estimate the expected yield loss based on remote sensing data with 250*250 m spatial resolution. Our case study was based on multi-spectral remote sensing data (MODIS NDVI) and spectral based models, soil maps, and yield data and drought indices, concrete practical agricultural drought monitoring method and intervention levels were formulated with calibrating of the important crops (wheat, corn) which are representative in the study area. In this way drought monitoring and yield loss forecast support to fill the gap of knowledge between remote sensing data and decision-making, in order to develop agricultural drought related decision parameters and application in practice from raw spectral datasets.

Our developed Agricultural Drought Monitoring and Yield Loss Forecasting Method is based on NDVI, (MODIS NDVI). NDVI is the most studied index on the field of vegetation analysis, but other spectrally based indexes (e.g. fAPAR selected by the JRC EDO) are also known to be strongly related to water stress. Important aspect is the data availability: both NDVI and FAPAR are available worldwide for free at <http://earthexplorer.usgs.gov/> and at <http://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Browse;Root=512260;Time=NORMAL,NORMAL,-1,,,-1,,>. The reason for choosing NDVI is complex.

- MODIS NDVI datasets have 250 m spatial resolution, which means 1 pixel represents 6.25 ha, while fAPAR has 1 km spatial resolution, which corresponds to 100 ha pixel size. In Europe, an average farm size is about 19-20 ha, while in CEE it is less. Therefore the monitoring of drought through the possible yield loss of a specified crop is not appropriate with datasets, such as fAPAR, having low spatial resolution, because one pixel of fAPAR exceeds the possible farm size, and crop field sizes.
- In correlation with the pixel size, local pixel error has also significant role in the case of satellites. Satellites survey the same areas from time to time, but at pixel scale, 10-30% error can occur when covering the same pixel. The smaller a pixel, the larger the opportunity to have neighbouring sites with similar characteristics. Therefore both temporally and spatially better spatial resolution provides smaller data oscillation and more homogenous changes of NDVI in pixel scale, than in case of larger resolution. MODIS NDVI also has oscillation; therefore we used smoothed, 16-day NDVI images for our study.

- It is also important, that the CORINE dataset (used as arable land input data in data processing) maps objects with at least 25 ha size. Therefore it is much reliable to use dataset with spatial resolution less than (or equal to) 25 ha.
- Other satellite data (e.g. LANDSAT) can also be used as input NDVI images. LANDSAT has 30 m resolution, but the data acquisition is more complicated. LANDSAT channels are possible to download, but after downloading NDVI datasets the usable datasets should be generated from channel 3 and 4, while in case of MODIS, NDVI images can directly be downloaded making the monitoring easier and faster and more user friendly. Another problem is, that LANDSAT has 16 days revisit time, thus the frequency of the datasets is lower in one year than MODIS. Furthermore, many images cannot be used because of abundant cloud cover.

Based on the results and as a direct continuation of Chapter 5 of Output 2 a user friendly modelling of Agricultural Drought Monitoring and Yield Loss Forecasting Method (Figure 8) were generated in order to make it possible for yield forecasting of other users in ArcGIS environment.

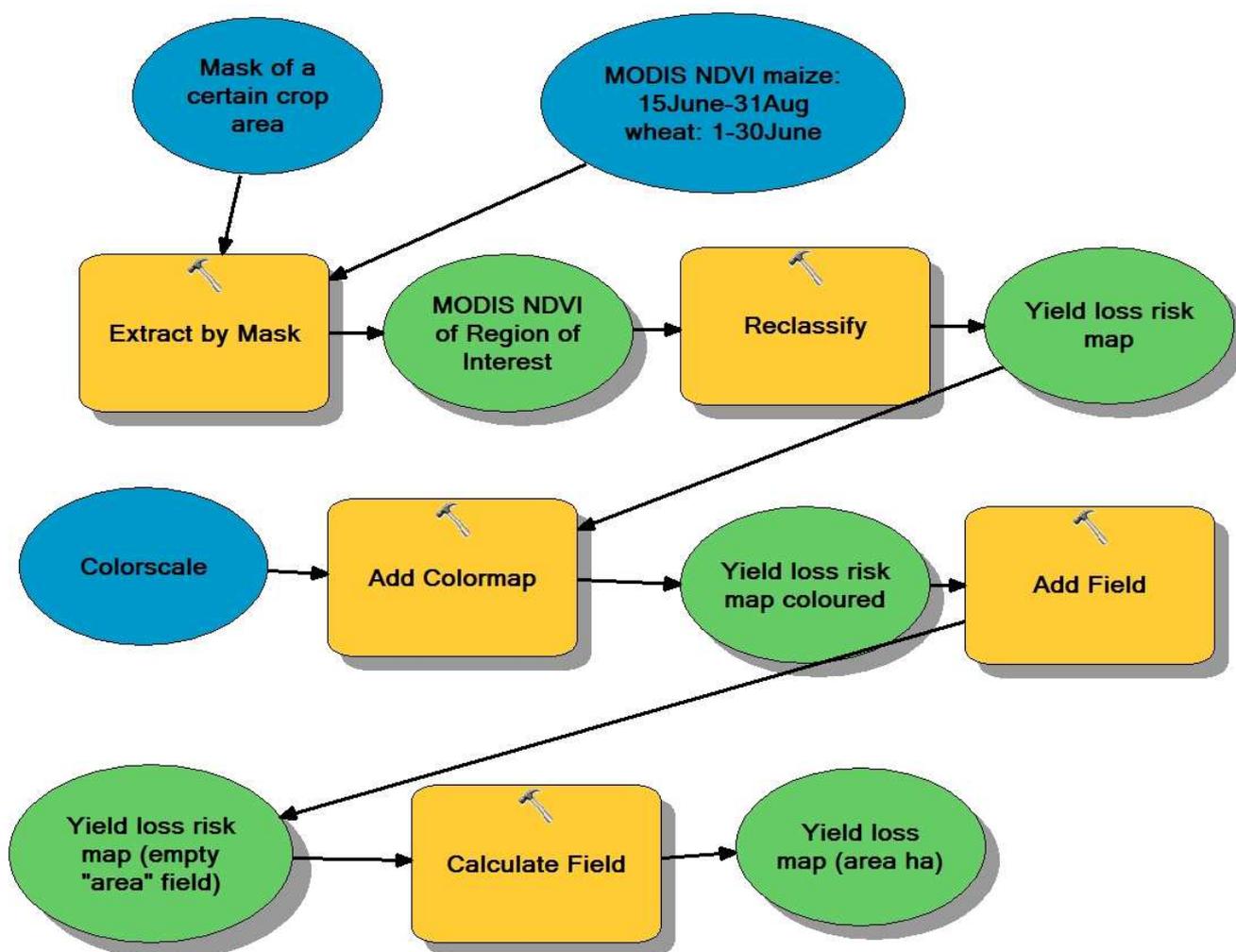


Figure 8. The final model of Agricultural Drought Monitoring and Yield Loss Forecasting Method

The model (which refers to the contains several steps from masking of the region interest, through reclassification to risk mapping and calculating the area effected by drought at five drought risk levels and not affected sites. There are three main steps:

- I. Input data identification (masking of Region of Interest)
- II. Reclassification (Using the NDVI threshold levels, calculated in Output 2.)
- III. Mapping of drought risk and yield loss, calculating area of the different stages of yield loss.

The input data of the model are MODIS NDVI image with 16 days compositing period, a mask image and these must have the same georeference system (UTM). Based on the result discussed in Milestone 2 report, MODIS NDVI images representing data of 15th June to 31st August period can be used for maize yield loss forecast. For wheat, yield loss forecast MODIS NDVI images can only be used from the period of June. Mask of a certain crop area is a Boolean file or a vector, which represents the spatial distribution of the growing site of a certain crop (possible mask building process is given in details in Figure 2 of Output 2 report). After running the masking process, MODIS NDVI image is produced for the croplands of maize or wheat (a region of interest).

Using the NDVI threshold levels (Table 2) reclassification can be made in order to map the drought affected yield loss risk. NDVI threshold levels were calculated based on the results of calibration process, interpreted in details in Output 2. In Chapter 5 of Output 2 the identification of those available and most appropriate remote sensing data and GIS transformation, calibration tools were carried out, with which remote sensing based agricultural drought monitoring and yield loss forecast can be implemented. These tools are synthetized into one huge toolbox including landuse, soil physical, meteorological and satellite data integrating them into a model, which can be a feasible tool for plant specific drought risk evaluation. This model contains several steps from data acquisition, through processing and calibration to risk mapping and evaluation. As a result, five drought risk levels were developed to identify the effect of drought on yields: Watch, Early Warning, Warning, Alert and Catastrophe.

Table 2. Reclassification NDVI thresholds for maize and wheat in the significant period

	<i>No yield loss</i>	<i>Watch</i>	<i>Early Warning</i>	<i>Warning</i>	<i>Alert</i>	<i>Catastrophe</i>	
Yield loss %	0%	<10%	10-20%	20-30%	30-40%	>40%	
Map category	6	5	4	3	2	1	
maize							
Yield loss (t/ha)	0	<0.7	0.7-1.4	1.4-2.1	2.1-2.8	>2.8	
Reclassification NDVI thresholds	<i>25-Jun</i>	0.75-1	0.72-0.75	0.69-0.72	0.66-0.69	0.64-0.66	0-0.64
	<i>11-Jul</i>	0.74-1	0.71-0.74	0.68-0.71	0.65-0.68	0.64-0.65	0-0.64
	<i>27-Jul</i>	0.74-1	0.71-0.74	0.67-0.71	0.64-0.67	0.62-0.64	0-0.62
	<i>12-Aug</i>	0.71-1	0.67-0.71	0.63-0.67	0.58-0.63	0.56-0.58	0-0.56
	<i>28-Aug</i>	0.66-1	0.61-0.66	0.56-0.61	0.51-0.56	0.49-0.51	0-0.49
wheat							
Yield loss (t/ha)	0	<0.4	0.4-0.8	0.8-1.2	1.2-1.6	>1.6	
Reclassification NDVI thresholds	<i>9-Jun</i>	0.67-1	0.64-0.67	0.61-0.64	0.59-0.61	0.56-0.59	0-0.56
	<i>25-Jun</i>	0.62-1	0.59-0.62	0.55-0.59	0.52-0.55	0.49-0.52	0-0.49

The threshold levels were determined based on the linear regression between the yield and NDVI values. Then the regression model was used to determine NDVI threshold, based on the threshold of the yield loss. For example, average wheat yield was set to 3.9 t/ha (Csajbók, 2012). Above this we do not have yield loss. This yield was then put into the regression model, and the NDVI threshold was calculated. Therefore the threshold between no yield loss and “Watch” is 0.67. (for June).

These five drought risk levels as thresholds, depending on maize or wheat, and the date of origin of MODIS NDVI image, can be applied in the reclassification as model parameter. These reclassification thresholds are threshold pairs, representing the “from” and “to just less than” characteristics of a certain class. The threshold pairs should be adjusted in reclassification process.

After creating the risk map, it is possible to standardize the colour, which is provided by a colour file in “Add Colormap” additional and optional step. The result of the process is the exact area calculation of the drought-affected site in hectares. This step is also important for regional scale, especially for decision makers in order to know how large are the different yield loss affected sites in a region, or watershed, or in a country.

The main strengths of Agricultural Drought Monitoring and Yield Loss Forecasting Method are the following::

- Yield loss maps give systematic and spatially continuous picture of the vegetation water stress at a high spatial resolution (250 m) for the entire CEE region.
- There is a low disturbance of cloud cover due to the 1 day revisit time and 16 day smoothing of the MODIS NDVI images.
- Yield loss can be calculated 1.5-2 months before harvesting.

Although Drought and water stress are not the only factors that can cause a decrease of yield. This is the weakness of this method, since it cannot take the difference between NDVI changes caused by drought or other factors. Change in land covers or pests and diseases can also be responsible for such variation of the yield loss. Therefore this method must be used jointly with other data giving information on the deficit of rainfall /soil moisture in order to determine if the variation in the vegetation response (signal) is linked with a drought event or not.

4. Implementation of Agricultural Drought Monitoring and Yield Loss Forecasting Method to CEE and its integration possibilities to drought management plans

The remote sensing based Agricultural Drought Monitoring and Yield Loss Forecasting Method can effectively indicate anomaly of droughts and yield losses and can identify the possible intervention areas. The methodology is also appropriate for early warning of droughts, since yield loss can be predicted 2 months before the irreversible yield loss and/or quality degradation realized. By plant specific calibrated yield loss maps the developed spatial decision supporting system gives precise information for farmers on drought risk of the different region. The magnitude of the potential yield losses is connected to the five drought risk levels, which are applicable to other IDMP CEE countries. In case of average weather circumstance the optimal amount of corn and wheat yields (t/ ha) have little difference in the CEE region. Therefore 40% yield loss is catastrophic in every CEE country. Certainly, there could be small differences in the intensity of crop production, wheat species and especially in corn hybrids between countries, which differences could influence the amount of yield to some extent. (In case of maize, the larger FAO number means larger energy demand of corn, longer vegetation period and higher possible yield.)

The other reason, that this methodology is also extendable for other IDMP CEE countries is the utilization of NDVI, which is a normalized data and the calibration of it is also based on normalized yield data sources. NDVI data and yield loss data from the whole CEE countries can be easily compared. Since NDVI is strongly correlates to biomass, and biomass with yield; thus low NDVI means low biomass and low yield in CEE countries.

The results of Agricultural Drought Monitoring and Yield Loss Forecasting Method are also appropriate for establishing of further complex studies on water use, water management and water scarcity in IDMP CEE region:

- The extent of the drought can be transformed to exact amount of water, that is missing for an average yield (t/ha) from an area and should be utilized in a certain farm or a watershed. Both wheat and maize has it characteristic water demand unit for producing 1 ton of yield. Within the growing yield amount, the partial water utilization for production of 1 tonne of yield is decreasing. Based on this statement and a hyperbolic algorithm, the partial water usage of maize, wheat can be calculated (described in details in Output 1). If the partial water usage is known, the absolute water usage and the ‘missing’ water amount can be easily calculated.
- Using Agricultural Drought Monitoring and Yield Loss Forecasting Method for the time series analysis those site can also be identified, where irrigation is often required. Combining these results and soil maps and the drought related soil moisture regime map (developed in Chapter 6. of Output 2.) those sites can be identified, where drought has regular effect, and possesses good soil characteristics, with large available water content capacity. It is important to irrigate primarily good soils, because the marginal utility of irrigation water is the highest in good circumstances. If the sites are identified, DDM, LandSat, and hydrological maps can be used to plan the water governance.
- Drought can have socio economic relations as well. The remote sensing based Agricultural Drought Monitoring and Yield Loss Forecasting Method can be used borderless, therefore the effect of a widespread drought phenomenon on yield loss can be assessed for a whole region. This information also facilitates the decision of which rural areas and its population suffers the most from the effect of yield loss. Since yield loss has negative effect not only on farmers but also on the whole agricultural sector, which can be influence the economy of regions and definitely the prices of wheat and maize based food, including animal nutrients, thus livestock prices).
- The results can also a basis of international joint control of stocks. Since stocks highly influence prices, mapping of yield losses of CEE region can support to create joint export market strategy of the region and can give information in future stock problems.

The results of Agricultural Drought Monitoring and Yield Loss Forecasting Method provide a complete observation of drought and spatially dense observation of crop growth. This complements the information on daily weather parameters that influence crop growth. agricultural drought monitoring signalling and intervention levels is a convenient vehicle to capture our understanding of yield loss and weather with GIS providing a framework to process the diverse geographically linked data. Currently agricultural drought monitoring, signalling and intervention levels can regularly provide information on regional crop distribution, and yield loss. This can be coupled to crop simulation models in a number of ways. These include, (a) direct use of MODIS NDVI as forcing variable, (b) re-initializing or re-calibrating MODIS NDVI by yield data, and (c) using yield calibrated NDVI to estimate thresholds for drought (yield loss) categories and final using MODIS NDVI and thresholds in mapping of yield loss forecast.

In practical terms, after the Agricultural Drought Monitoring and Yield Loss Forecasting Method foundation for its structure and operation can take place on the following points.

- Need to be ensured soil, yield, land use and MODIS NDVI data for the occurrence of drought forecasting. Ensure yield, land use and MODIS NDVI data. The supply of data shall be easily accessible to all.
- The regular monitoring of drought need to be carried out testing simultaneously with several parameters. Several indices should be used simultaneously for extent and effects of drought, and its versatility assessment which can be accessible on the online page of the EDO and effectively usable in the CEE regions (CDI, fAPAR).
- The intensity of drought and the of the damages and economic losses, which occur during the cultivation of crops on a specific time and field, shall be assessed with the comparatives analyses of the climatic and hydrological factors and the farmer attitude and adaptation
- These results are the basis of state aid, and any possible determination of compensation.

In the case of agricultural drought monitoring signalling and intervention levels for yield loss forecasting the skill level of the users have highlighted role. Understanding of Agricultural Drought Monitoring and Yield Loss Forecasting Method needs to be achieved in a higher level. There are a number of ways of strengthening this link.

- Primarily, the Agricultural Drought Monitoring and Yield Loss Forecasting Method must make its information accessible and easy to interpret, and they must deliver a clear, consistent message to decision makers so that they can act on this information. Although this seems obvious, it can be hard to achieve in practice.
- Agricultural drought monitoring signalling and intervention levels information is most likely to be used if it is calibrated.
- To counteract the decision makers' tendency to delay a response until there is hard evidence of a crisis, ignoring genuine Agricultural Drought Monitoring and Yield Loss Forecasting Method.

Beside the mentioned fight against drought, and the results of Agricultural Drought Monitoring and Yield Loss Forecasting Method is one of the most important, perhaps the single most important factor is to maintain relationship between the farmer and the technical advice, and to develop a technical advice network. Technical advice must be made interactive.

Public participation is not only in the interest of decision-makers, but a number of legal obligations also require it. The effective social inclusions have many essential elements, of which the most important are the identification of stakeholders; defining the concern; the wording of the messages; inclusion and dialogue opinions; feedback and participation in the implementation. Effective communication, planning and implementation complement each other, neither indispensable part of the process. The open design and implementation must ensure the proper amount of resources. The active tools of the social involvement are the professional forums, interactive web sites, direct negotiations (workshop with representatives of interest groups, with farmers, representatives of large farms). Passive devices are the specialized training for people (e.g. water management to farmers, about the practical significance of drought mitigation management and interpretation for agricultural drought monitoring and the yield loss forecast.); advertising (print and electronic media) campaign; thematic programs; Placing messages in non-thematic programs and the launch of vocational subjects in the educational curriculum (higher education).

In addition, information and communication programs are necessary between the governmental, professional, the cooperatives for the sales of produce, and the farmers. The government and professional

organizations encourage the stakeholders who will demand the regular media activities on agricultural drought and yield loss forecast monitoring.

Drought early warning and monitoring are crucial components of drought preparedness and mitigation plans (Wilhite and Svoboda, 2000). The Agricultural Drought Monitoring and Yield Loss Forecasting Method is designed to identify signalling and intervention levels to detect the emergence or probability of occurrence and the likely severity of drought. Recent advances in operational space technology have improved our ability to address many issues of early drought warning and efficient monitoring. With help from Agricultural Drought Monitoring and Yield Loss Forecasting Method, the effect of drought on crops can be detected 4-6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest, which is the most vital need for global food security and trade. This information can reduce impacts if delivered to decision makers in a timely and appropriate format and if mitigation measures and preparedness plans are in place. Understanding the underlying causes of vulnerability is also an essential component of drought management because the ultimate goal is to reduce risk for a particular location and for a specific group of people or agricultural or economic sector.

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