# Potato yield empowerment by photosynthesis, carbon assimilation and evapotranspiration

Eleni Neofytou[a,c], Stelios P. Neophytides[a,c], Ilias Tsoumas[b,e], Andria Tsalakou[d], Michalakis Christoforou[d], Marinos Eliades[a,c], Christiana Papoutsa[a,c], Charalampos Kontoes[b], Diofantos G. Hadjimitsis[a,c]

[a]ERATOSTHENES Centre of Excellence, Limassol, Cyprus

[b]National Observatory of Athens, Athens, Greece

[c]Department of Civil Engineering and Geomatics, Cyprus University of Technology, Limassol, Cyprus

[d]Department of Agricultural Science, Biotechnology and Food Science, Cyprus University of Technology, Limassol, Cyprus

[e]Wagenigen University & Research

## ABSTRACT

By the end of the twenty-first century, atmospheric $CO_2$ is expected to have increased from its current level of approximately 400 μmol $CO_2$ $mol^{-1}$ to approximately 700 μmol $CO_2$ $mol^{-1}$. A significant rise in atmospheric $CO_2$ concentration could have a global impact on crop output, photosynthetic efficiency, and plant development. The majority of C3 plant species will be benefited by the predicted rise of the atmospheric $CO_2$ concentration, especially through increased rates of photosynthesis and water use efficiency (WUE), which could ultimately improve plant biomass and yield. Potatoes are considered the world's most popular non-cereal food in terms of global food security. Water stress has a significant impact on photosynthesis. Water deficit can prevent $CO_2$ absorbance from leaves and/or interfere with mesophyll cells' capacity to carboxylate $CO_2$, negatively affecting photosynthesis. Water shortage can lead to partial or whole leave stomata closure reducing the transpiration rates leading to low photosynthetic rate. Since potatoes are cultivated in a variety of climates, it's critical to comprehend how photosynthetic rate, gross primary productivity as a proxy of soil organic carbon, and actual evapotranspiration are correlated with yield productivity. In this study, satellite products of NASA's MODIS are derived to gather the needed observations and a regression analysis is performed to identify the relations between yield and natural processes.

**Keywords:** yield, irrigation, natural processes, earth observation, correlation analysis

## 1. INTRODUCTION

Potatoes are the most widely used non-grain food crop worldwide [1]. It is valued for its high yield, and high nutritional content, all of which make it a precious contributor to global food security. Along with corn, rice, and wheat, potatoes are the fourth most consumed food crop in the world. The International Year of the Potato was proclaimed by the UN in 2008, further highlighting the potato's ranking position as the world's most popular non-cereal food in terms of global food security. Due to their high yield and nutritional value, potatoes are widely grown and thus guarantee a steady supply of food and financial income for developing countries. In countries like Philippines and the Republic of India, potatoes are viewed as a high-value crop because they are increasingly used for processing which in turn increases the oncome of small-scale food producers [2]. During the Food Agriculture Organization's (FAO) International Year of Potato (IYP), the crop's significance in reducing poverty and hunger was also emphasized [3]. Even though potatoes are grown once a year, in

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countries like Cyprus, Egypt and Israel, they are cultivated all year round. The northern countries grow potatoes as long as they have sufficient rainfall where the southern countries are irrigating using ground / dam water.

Higher atmospheric CO2 levels have been observed to have a favorable effect on potato yield. Increase in production rates observed due to CO2 elevation by experimental performance performed over the years on cotton, grasses, wheat and vines. However, such results may occur in some places of the world, and it must be mentioned that other climatic issues might compensate for such an effect [4]. Nearly all C3 species with adequate nutrient supplies have higher photosynthetic rates in their leaves when CO2 is elevated. However, other elements like transport capacity and the existence of small or large assimilation sinks can affect a plant's ability to use the extra carbon fixed by elevated CO2 to fuel structural growth or long-term storage [4]. Potatoes are drought-sensitive, and even mild water stress might result in production losses. It has been demonstrated that higher atmospheric CO2 concentrations enhance C3 species' water use efficiency (WUE), net photosynthetic rate, and above-and/or below-ground biomass [5]. Therefore, estimated rises in global CO2 could minimize the negative effects of drought on potato yields.

Furthermore, a key factor in regulating potato production is moisture dynamics. Certain models mimic the processes of crop development and yield generation by using the soil's or crop's transpiration or evapotranspiration (ET) as a driver. The development of sensible irrigation techniques for the effective use of scarce water resources can be aided by these water-driven models [6]. Growing potatoes can be difficult, particularly when there is moisture stress. Events of extreme water stress lower crop yields and occasionally eliminate carbon sinks[7]. In certain mid-latitudes and subtropical regions, rising global mean temperatures and falling precipitation are leading to a shortage of water and a rise in the frequency of heat stress events [8]. When predicting a crop's irrigation needs based on weather conditions, ET measurement is critical [9]. Early potato crops are often fertilized and irrigated throughout vegetative growth and tuber bulking in order to achieve the quality requirements demanded by the fresh vegetable market and to encourage earliness along with high yields. Specifically, irrigation is essential because premature potatoes are particularly susceptible to water stressors throughout the tuber initiation and bulking stages, which negatively impact yields as well as earliness [10]. Due to its shallow root structure, potatoes are known to be a crop that is vulnerable to drought. Water stress can have a significant effect on both the yield and quality of the tuber. As a result, any restrictions on its production endanger the world's food supply, which affects over a billion people [7].

In Cyprus, potatoes are the most important crop, yielding 106 000 tons overall in 2018. Because of the benefits of the climate, farmers may harvest potatoes early in the spring, increasing their income and making them one of the most exported agricultural products (around 40%) [2], [11]. The potato crop is a major economic driver in Cyprus, accounting for about half of the country's agricultural export earnings, around €48 million, which are mostly ascribed to shipments to other countries in the EU in addition to fulfilling domestic demand [12]. Because of the unique red clay soil, potatoes are mostly grown in the southeast of Cyprus, in an area known as "Kokkinochoria" (red villages). The primary feature of Cyprus potatoes, which set them apart in the international market, is the clayey texture of the red soil, which causes it to adhere to the tubers. Additionally, red soils have high potassium levels, which is crucial for the delicate flavor of potatoes. Potatoes can be grown almost all year round in this semi-arid region because of its modest, wet winters and long, dry summers. There are four distinct growing seasons: winter (August to November), spring (November to March), intermediate (October to February), and summer (only in the mountains). (April–June). The two most common growing seasons are spring and winter, with spring crop being the most significant for export [2].

Remote sensing methodologies used for Earth observation (EO) can be used to generate information on the physical, chemical, and biological processes of our planet. This kind of data is essential in areas like the Eastern Mediterranean, Middle East, and North Africa (EMMENA) region that are vulnerable to a variety of disasters such as climate change, droughts, floods, earthquakes, and landslides and where there is a lack of ground data [13].

Remote Sensing (RS) and land surface models have been extensively used for carbon and water fluxes estimations either on regional or global scales. These models have shown that they have high capacity in regard to water and carbon fluxes quantification. Land surface model in order to extract accurate outputs it requires high amounts of data in order to simulate the needed outcome. Such data can be climatic data, soil data, land cover information etc. [14]. However, because of the missing model processes, incorrect model parameters, and ambiguous input data, these models could result in significant mistakes. On the other hand, RS models that are primarily based on satellite observations, are presented to be the most effective approach. Based on straightforward techniques, these models can efficiently estimate GPP and ET over a wide range with a minimal number of model input data and model parameters. The most widely applied satellite measurements are from the Moderate Resolution Imaging Spectroradiometer (MODIS), which describes the carbon and water cycle processes in many terrestrial ecosystems using modeling techniques based on fundamentally simplistic assumptions [14]. Therefore, it is preferable to use methods for measuring crop diversity effects that take into account relevant climatic factors like temperature and soil moisture [15].

This study aims to determine (i) how photosynthesis, carbon assimilation, and ET relate to potato yield in the growing season of 2023 and (ii) study the environmental differences of the plot sites. Pearson and Spearman correlation analysis between the three natural processes data, independently, with yield was employed. The rest of the paper is structured as follows: methodology section that describes the approach used for the current study along with the study area, the results section which describes the results obtain along with the analysis and the conclusion section with the general outcomes.

## 2. METHODOLOGY

### 2.1 Data acquisition

MODIS is a key instrument of the Terra and Aqua satellites. Those satellites are covering the entire planet in a temporal resolution of 1-2 days and deliver insightful satellite products for environmental monitoring. In this study, 2 different MODIS products are derived for a correlation assessment:

- MOD17A2H.061: Terra Gross Primary Productivity 8-Day Global 500m
- MOD16A2GF.061: Terra Net Evapotranspiration Gap-Filled 8-Day Global 500m

Those satellite products were used to collect data for: Gross Primary Productivity (GPP), Net Photosynthesis (PsnNet) and Actual Evapotranspiration (ETa). Furthermore, historical potato yield data of the Spunta variety for the period 2022-2023 have been collected.

### 2.2 Correlation analysis

In this investigation, the correlation coefficients between the factors and potato yield were determined using Pearson (Eq. 1) and Spearman (Eq. 2). A correlation coefficient used in statistics to assess the linear correlation between two sets of data is the Pearson correlation coefficient (PCC). It is effectively a normalized measurement of covariance, with a value that is always between −1 and 1. It is defined as the ratio between the covariance of two variables and the product of their standard deviations. Pearson correlation coefficient formula is determined as follow:

$$r = \frac{\Sigma\,(x_i - \overline{x})\,(y_i - \overline{y}\,)}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (1),$$

where r is the Pearson correlation coefficient, $x_i$ are the values of x-variable in a sample, $\bar{x}$ are the mean values of x-variable, $y_i$ is the is the value of y-variable in the sample and $\bar{y}$ is the mean value of the y-variable.

The Spearman rank correlation coefficient is defined as a nonparametric measure of rank correlation which means that it is a statistical dependence between the ranking of two variables. The formula is determined as follow:

$$\rho = 1 - \frac{6\sum d_i^2}{n\,(n^2 - 1)} \quad (2)$$

Where ρ is the Spearman's rank correlation coefficient, the $d_i$ is the observation differences between the two ranks and the n is the observation numbers.

Pearson correlation measures the linear relationships of the variables. A strong positive linear relationship is indicated when the value is close to +1 while a strong negative linear relationship is indicated when the value number is close to -1. A little to no linear relationship is indicated when the value is 0. However, Spearman correlation measures the monotonic relationships of the variables. As a statistical methodology it does not care if there is a constant (linear) increase or decrease as long as there is a consistent general trend. A positive monotonic trend is indicated when the value number is close to +1 while negative monotonic trend is indicated when the number is close to -1. A little to no monotonic relationship is suggested when the value number is near 0. Pearson correlation was used due to its capability to measure the linearity of the relationship between yield and the satellite variables (i.e., GPP, PnsNet and ETa). At the same time Spearman correlation was used due to the reason that can measure the non-linearity relationship between the selected variables used for this research and it is a robust outlier for the current data used.

### 2.3 Study Area

The island of Cyprus is situated in the eastern Mediterranean Sea (35°N, 33°W). Cyprus belongs in the area of the Eastern Mediterranean, Middle East and North Africa (EMENA) region [13]. Cyprus characterized as a semi-arid region with regular drought event. The total area covering the island is 9254 $km^2$.

Cyprus often experiences dry summers and humid winters, which are traits common to the Mediterranean region. According to reports from the Climate Change Knowledge Portal for 2021 [1], the average mean land surface temperature in Cyprus from 1991 to 2020 was 11.2 °C for the winter, 16.82 °C for the spring, 26.69 °C for the summer, and 21.03 °C for the autumn. Precipitation records were 281.06 mm in the winter, 90.9 mm in the spring, 10.3 mm in the summer, and 87.81 mm in the autumn.

The data concerns the growing potatoes period of 2022-2023 in the Cyprus island. In total, historic yield data for 150 agricultural parcels were collected from farmers for this study. The data was categorized as whole data that indicates all the plots is the island of Cyprus, the interior areas that includes the Orounta and Peristerona villages and the seaside areas that includes the regions of Xylofagou, Frenaros, Sotira, Liopetri, and Mandria. Figure 1 below illustrates the interior and seaside research areas used for the current case study with the black polygons showing the agricultural lands that the data obtained.


Figure 1.Study areas of Cyprus used for the current research

[1] Home | Climate Change Knowledge Portal (worldbank.org)

## 3. RESULTS

The results obtained from the all areas of Cyprus data indicates that GPP-YIELD, PsnNet-YIELD and ET-YIELD have statistically significant positive correlation (Table 1). Higher Spearman correlation coefficients observed in relation to Pearson correlation coefficient indicating the monotonic trend of each relationship. The results obtained show that the relationship of natural processes proxies and yield have strong correlation to one another.

In all areas of Cyprus, Spearman correlation coefficient between the GPP-YIELD and PsnNet-YIELD is 0.465 and 0.470 respectively. This result suggests that the proxies have a positive monotonic relationship. The p-value of either coefficient is low, indicating that there is a statistical significance in the correlation. The Spearman correlation coefficient of between the GGP-YIELD and ET-YIELD is 0.465 and 0.562 indicating the positive monotonic relationship. Also, a positive statistically significant correlation was observed for ET-YIELD with the p-value= $1.87^{-7}$.

Table 1. Pearson and Spearman correlation coefficient in all areas of Cyprus

| All areas of Cyprus | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GPP-YIELD | | | | PsnNet-YIELD | | | | ET-YIELD | | | |
| Pearson | p-value | Spearman | p-value | Pearson | p-value | Spearman | p-value | Pearson | p-value | Spearman | p-value |
| 0.413 | $1.59^{-7}$ | 0.465 | $8.23^{-7}$ | 0.413 | $1.57^{-5}$ | 0.470 | $5.88^{-7}$ | 0.461 | $3.49^{-5}$ | 0.562 | $1.82^{-7}$ |

The correlation analysis performed for the interior areas of Cyprus as described in Section 2 indicates higher Pearson correlation coefficient than Spearman indicating the linearity of each relationship. The p-value observed showed that the correlation coefficients of GPP-YIELD, PsnNet-YIELD and ET-YIELD have statistically significant positive correlation since the p-value is smaller than 0.05 (Table 2).

In the interior areas of Cyprus, it appears that Pearson correlation coefficient between the GPP-YIELD and PsnNet-YIELD have a moderate linear correlation coefficient with 0.481 and 0.484 respectively. However, ET-YIELD has stronger correlation coefficient than the GPP-YIELD and PsnNet-YIELD with 0.510. All three parameters according to these results have a positive statistical correlation with the result to be lower than 0.05. The Pearson and Spearman correlation coefficient values between GPP-YIELD and PsnNet-YILED obtained showed to have close values suggesting that the relationship might be monotonic but not necessarily linear. In comparison with the above-mentioned proxies, ET-YILED showed a clear strong linear relationship.

Table 2. Pearson and Spearman correlation coefficient in the interior areas of Cyprus

| Interior areas of Cyprus | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GPP-YIELD | | | | PsnNet-YIELD | | | | ET-YIELD | | | |
| Pearson | p-value | Spearman | p-value | Pearson | p-value | Spearman | p-value | Pearson | p-value | Spearman | p-value |
| 0.481 | 0.001 | 0.466 | 0.002 | 0.484 | 0.001 | 0.461 | 0.003 | 0.510 | 0.004 | 0.404 | 0.029 |

However, the correlation coefficient performed in the seaside areas of Cyprus indicates a monotonic trend of the outputs with higher values observed from Spearman that Pearson correlation. As shown in Table 3 strong positive monotonic trend observed for GPP-YIELD, PsnNet-YIELD and ET-YIELD. In addition, the results show that there is a statistically significant positive correlation between the proxies.

In the seaside section of Cyprus in comparison to Interior areas Spearman correlation coefficient was higher than Pearson indicating that stronger positive monotonic relationship of the values. The monotonic outcome derives from the values of GPP-YIELD that was 0.478 and PsnNet-YIELD with 0.485. A much stronger positive monotonic relationship was observed for ET-YIELD with 0.596 in comparison to the other two. All three proxies according to these results showed that all coefficients have low p-value illustrating the positive statistically significant correlation. A significant difference observed between the Pearson correlation coefficient and Spearman in ET-YIELD meaning that the data have a nonlinear monotonic relationship.

Table 3.Pearson and Spearman correlation coefficient in the seaside areas of Cyprus

| Seaside areas of Cyprus | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GPP-YIELD | | | | PsnNet-YIELD | | | | ET-YIELD | | | |
| Pearson | p-value | Spearman | p-value | Pearson | p-value | Spearman | p-value | Pearson | p-value | Spearman | p-value |
| 0.409 | 0.0008 | 0.478 | $7.30^{-5}$ | 0.416 | 0.0006 | 0.485 | $5.40^{-5}$ | 0.453 | 0.001 | 0.596 | $1.55^{-5}$ |

The statistical differences observed between the interior areas and seaside areas of Cyprus can be caused by several factors including environmental difference, human activities and spatial heterogeneity. It is possible to assume that in the interior as well as the seaside parts of Cyprus there is a different environmental condition such as climatic conditions, irrigation, vegetation and soil composition. Environmental variations can impact the water availability dynamics, vegetation growth and productivity as well as the interaction between the variables such as GPP-YIELD, ET-YIELD and PsnNet-YIELD. Human activities can also be considered as a parameter of the observed differences between the interior and seaside areas of Cyprus. Such activities can be considered urbanization, agriculture and tourism that can lead to differences in land management and land use patterns. Ecosystems' processes can be influenced from these human induced activities leading to the alteration of the relationships between the variables that are related to vegetation and water. Spatial heterogeneity is a naturally induced factor that occurs in every place on earth. This comes with the variability in environmental conditions and ecological processes across different geographic locations. Different relationships can occur due to the spatial heterogeneity of Cyprus.

No previous similar studies have been identified in literature. Most of the works targeted on environmental aspects. More specifically, numerous studies used Pearson and Spearman correlation coefficient to obtain the relationship of crops yield with environmental variables such as temperature, radiation etc. Other studies used RS indices such as NDVI, LAI, etc to obtain possible relationships with crop yield. Pearson and Spearman are common statistical methods used in that research. However other methods such as regression analysis and artificial intelligence methodologies are also used.

Normalized difference vegetation index (NDVI) and other vegetation indices have been used for the development to monitor crop yield and serving in the creation of predictive models at high spatial resolutions in comparison to agricultural statistical data. Environmental variables were also used in research studies. Vannoppen and Gobin [16] evaluated the performance of random forest (RF) using the NDVI along with environmental variables and root zone soil water reduction for beet and potato farm yields. The yield-affecting weather and soil water conditions were not sufficiently detected by the NDVI series of early and late potato crops. They discovered that a significant portion of the variability in late-season potato and sugar beet yields could be explained by conditions that were water-saturated early in the growing season and high temperatures later in the growing season. In this study authors used Pearson correlation coefficient between the yield data and environmental proxies with the outcome of strong correlation between the data [16].

Ojeda et al, [17] research was based in the identification and measurement of the primary factors influencing the variance in irrigated potato production, taking into account the effects of soil, climate, and crop management techniques. Temperature and solar radiation were used as variable along with three irrigation management practices plus the non-irrigation practice. They found that the planting date, soil type, and irrigation technique had a significant impact on the mean and coefficient of variation of the simulated crop yield [17]. In relation to environmental parameters, they obtain different responses. More specifically, a strong positive correlation was observed between the solar radiation and yield but in regard to rainfall a negative correlation was obtained. The maximum temperature on simulated yield showed a positive correlation [17].

Other study performed by Bala and Islam in 2007 [18] they used remote sensing indices including NDVI, Leaf Area Index (LAI) and photosynthetically active radiation (fPAR) for crop growth monitoring and yield estimation along with regression models. TERRA MODIS employed for the potato yield estimation. High correlation coefficient obtains for NDVI, LAI and fPAR with yield with $R^2$ 0.84, 0.72, and 0.80 respectively. During their research they suggest that Vegetation Indices (Vis) can be considered as an effective tool for early potato yield estimation [18].

## 4. CONCLUSION

In conclusion, differences observed in the interior areas and seaside areas of Cyprus that could be caused by environmental, human activities and spatial heterogeneity highlights their complex interactions to yield impact. Thus, understanding these differences is of high importance in order to develop more efficient land management practices, initiatives development for sustainability and conservation. The stronger correlation is observed between ET and potato yield for potatoes sowed at seaside areas of Cyprus. The weaker correlation was observed in the interior parts of Cyprus that might cause due to environmental difference in relation to seaside conditions.

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