While the demand of natural astaxanthin produced by *Haematococcus pluvialis* is increasing dramatically, state-of-the-art cultivation is suspension is limited by low quantum efficiency and biomass to volume ratios, increasing energy requirements and production costs. Immobilized cultivation using porous substrate bioreactors (PSBRs) depicts an innovative approach eliminating limitations of classical suspension cultures that has recently successfully been applied for continuous co-production of *H. pluvialis* biomass and astaxanthin at high light intensities. Although many efforts have been put toward elucidating the effect of different stressors on biomass and astaxanthin productivity, less attention has been drawn on investigating the underlying processes that are facilitating and limiting high productivities. To fill this gap, in the present study in-depth microsensor measurements of light, dissolved oxygen and photosynthesis were conducted in artificial *H. pluvialis* biofilms exposed to light intensities ranging from 50 to 1,000 µmol photons m^{-2} s^{-1} with or without depletion of the macronutrients nitrogen and phosphorus. During cultivation periods of ten days, maximum biomass productivities of 12 g m^{-2} d^{-1} with final standing crops of up to 127 g m^{-2} were achieved when biofilms were subjected to 650 µmol photons m^{-2} s^{-1}. Maximum astaxanthin productivities and dry-weight concentrations of 401 mg m^{-2} d^{-1} and 2.7%, equivalent to an amount of 2.2 g m^{-2}, were reached when 800 µmol photons m^{-2} s^{-1} was combined with nutrient depletion although reducing cellular chlorophyll contents. Microsensor measurements revealed with increasing light intensities of up to 650 µmol photons m^{-2} s^{-1} a contemporaneous increase of oxygen production and photosynthetic activities. In accordance with biomass productivities, higher light intensities and nutrient depletion diminished oxygen emission, but did not affect photosynthetic activities, indicating an influence of photo-respiratory factors on net photosynthetic productivities. Cross sectioning of biofilms and in-depth analysis of biomass and cell-size distributions revealed further differences in cell-interstices and pigment-contents among depth gradients. Accordingly, light measurements revealed savage alterations on light spectra by depth, which could be attributed to the formation of pigment gradients by depth and biofilm structure. Here it is shown, that cells-sizes alongside cellular pigment contents are also governing light transport into *H. pluvialis* biofilms. Using a statistical correlation approach, it could be further evidenced, that the formation of distinct cellular layers of equal radii arises in a response to the incident light intensity and nutrition. The acquired results were used to describe factors influencing biofilm productivities and, with regard to further optimization, discuss how the findings can be implemented in an industrial large-scale application.