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Study of the Light Absorption and Utilization in Monoculture and Intercropping of Three Medicinal Plants of Black Cumin (*Nigella sativa* L.), Marigold (*Calendula officinalis* L.) and Borage (*Borago officinalis* L.)

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Introduction: One of the components of sustainable agriculture is multiple cropping (such as intercropping). Intercropping means the use of a farm to produce two or more crops through a year. Diversity in agricultural systems is a reason for sustainability and widespread and better production, and better use of natural resources and environment, such as water, light and nutrients has priority to monoculture. Intercropping is one of agronomical strategies to increasing the absorption and efficiency of radiation absorption and use.

In proper agronomical conditions that there is no limitation for crop growth, there is a linear relationship between dry matter and absorbed radiation and the slope of regression trend line between these two indices during growing season is radiation use efficiency (RUE).

Radiation use efficiency (RUE) relates biomass production to the photosynthetically active radiation (PAR) intercepted by a plant or crop. Radiation use efficiency is dependent on light, temperature, vapor pressure deficit and factors inherent to plant species. Linear relationship between biomass and accumulated intercepted radiation has been demonstrated for several herbaceous plants (e.g., beans, soybean and lettuce) and for a few tree species (e.g., willow, mesquite and juniper). The production of dry matter in conditions without any environmental stresses is a function of light absorption and efficiency of plant to production of dry matter from absorbed radiation.

Materials and Methods: In order to study RUE in intercropping pattern of three medicinal plants including marigold (*Calendula officinalis*), borage (*Borago officinalis*) and black cumin (*Nigella sativa*) in two and three species compared with their monoculture, an experiment was conducted based on a randomized complete block design with three replications at the Agricultural Research Station, Ferdowsi University of Mashhad in the growing season of 2013-2014. Treatments included 1:1 ratio of black cumin-marigold, black cumin-borage and marigold-borage and 1:1:1 ratio of black cumin-marigold-borage and monoculture of each of three species. LAI of plants during the growth season, K and RUE of every plant in related treatments were determined and calculated. To fit functions and drawing the figures Slide Write program and MS Excel was used.

Results and Discussions: The results showed that RUE was enhanced in intercropping of all three medicinal plants. Dry matter production by three medicinal plant species was linearly related to the amount of PAR intercepted. Since Intercropping is useful when mixed species have phonological and morphological differences for intercepting of light and up taking of elements and water, so improvement in yield of intercropping can be due to increasing in light interception, increasing of RUE or both of them. The value of RUE changed over time, partially as a consequence of changes in canopy photosynthetic rates. The highest RUE was observed in triple intercropping among the experiment treatments. RUE of triple intercropping for black cumin, marigold and borage were 1.34, 1.08 and 1.34 g MJ^{-1}, respectively and also lowest RUE was recorded in theirs monoculture and RUE values of treatments of double intercropping were between the other treatments. There are vacancies in monoculture leads to a large amount of light loss and thus reduced productivity of agricultural ecosystems.

It seems that RUE in all three studied plants from the beginning of the flowering stage to flowering stage was higher than that RUE after this stage. This result may be due to effects of reducing in photosynthesis and plant growth due to factors such as remobilization of the elements from leaves and partitioning of more photosynthetic substances to reproductive parts of plant like flowers or seeds. However, the response of canopy photosynthesis to radiation is complex and depends on incident radiation flux density and individual leaf photosynthetic response. Radiation use efficiency may be affected by change these variables as PAR increases.

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Conclusions: Light is one of the most important sources of growth and development of plants. The results of this study clearly showed the effect of intercropping on improving the light use efficiency of black cumin, marigold and borage. RUE changed partially as a consequence of changes in canopy photosynthetic rates. According to the results, intercropping of three medicinal plants of black cumin, marigold and borage can be beneficial in term of ecological management.

Keywords: PAR, Radiation absorption, Replacement intercropping series, Resource use efficiency