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# Bio-energy, water-use efficiency and economics of maize-wheat-mungbean system under precision-conservation agriculture in semi-arid agro-ecosystem

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The maize-wheat-mungbean (MWMb) cropping system is being advocated as an alternative to the traditional rice-based cropping systems of north-western Indo-Gangetic Plains (IGP) to address the issues of energy and nutritional scarcity, residue burning, decline in biomass productivity and water tables. In semi-arid regions, the climate-change-induced variability in rainfall and temperature may have an impact on phenological responses of cereals and pulses which in turn would affect biomass production, economic yield and energy and water-use efficiency (WUE) of the crops. Henceforth, quantification of bioequivalent yields, energy requirement, economics and WUE of MWMb system is essentially required owing to have better understanding of this cropping system. Following a 4-year study was conducted under different tillage and nutrient management. ZT and PB plots had significantly higher pooled average (17.2–20.3%) biomass productivity, (34.4–39.8%) net returns and (49.8–66.2%) biomass water-use efficiency with lesser (8.5–16.1%) water-use than the CT plots. Significantly higher pooled bioenergetic yields (21.7–35.2%), net returns (31.4–37.8%) and biomass water-use efficiency (30.1–35.2%) was observed in SSNM/Ad-hoc plots compared with FFP plots. The total pooled energy input in ZT/PB and SSNM/Ad-hoc plots was significant ($P < 0.05$) higher than CT and FFP plots, respectively, with greater net energy output, energy productivity and energy efficiency. The interactions between tillage and nutrient management practices on pooled input energy and energy productivity of MWMb system was significant ($P < 0.05$). Thus, adoption of conservation tillage (ZT/PB) practices with improved nutrient management (SSNM/Ad-hoc) could be a viable option for achieving higher biomass productivity, water and energy-use efficiency and profitability in MWMb system.



## 1. Introduction

In any cropping system biomass production is a key indicator for its sustainability and soil health [1]. Under limited water environments rapidly falling water tables [2], deteriorating soil health [3], leading to lower system biomass productivity and energy efficiencies [4], the challenge is far most to sustain the biomass productivity levels through optimized tillage and nutrient management practices. The rice [*Oryza sativa* L.] - wheat [*Triticum aestivum* L.] (RW) system of north-west India is characterized by high fertilizer use [5], high levels of irrigation [6] and intensive

*Abbreviations:* Ad-hoc, recommended dose of fertilizer; CA, conservation agriculture; CT, conventional tillage; FFP, farmers' fertilizer practice; GEY, glucose equivalent yield; ICAR, Indian Council of Agricultural Research; MWMb, maize (*Zea mays* L.) - wheat (*Triticum aestivum*)- mungbean (*Vigna radiata* L.) Wilczek); NE, Nutrient Expert®; PB, permanent beds; PEY, protein equivalent yield; PEYA, protein equivalent yield for adults; SSNM, site specific nutrient management; ZT, zero tillage.

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tillage and energy use [7]. However, the declining biomass factor productivity and reduced resource and energy-use efficiency [8] in RW system has questioned the sustainability of the RW system as a viable option for future food and energy security. Consequently, the possibilities of an alternative crop rotation, which may help improve biomass productivity, water and energy use efficiency and farm profitability [9] under future extreme climatic conditions [10] in this region is being explored.

Maize (*Zea mays* L.), an important crop for food and nutritional security in India, is grown in diverse ecologies and seasons on an area of 8.67 million hectare [11]. Globally, it provides approximately 30% of the food calories to more than 4.5 billion peoples in 94 developing countries, and the demand of maize is expected to double worldwide by 2050 [12]. To meet the rising demand, a quantum jump in maize biomass production is required. In the previous decade (2003–2004 to 2012–2013), the maize area in India expanded by 1.8% and production increased by 4.9% with a productivity growth at 2.6% for each year [13]. Earlier evaluations of maize as an alternate crop to rice with in the RW system failed due to lower biomass yield and market price of maize. However, recent introduction of single cross high biomass yielding, water and energy-use efficient hybrids of maize are provided genotypic options for crop diversification in the RW systems. The Indo-Gangetic Plain (IGP) of India, covering about 44 Mha, is dominated by cereals based cropping sequences. The maize–wheat (MW) system is the third most important (1.86 Mha) cropping system after rice–wheat and cotton–wheat systems [14] in the IGP. The integration of a short-duration mungbean [*Vigna radiata* (L.) Wilczek] crop in the MW system provides an option to improve bio-energy and biomass production, soil health, increase farmer's profits with several other co-benefits [15–18].

Recent published information from different studies conducted in south Asia and elsewhere have shown that the adoption of zero tillage (ZT) and PB, where drilling or planting is done directly through the residue of the previous crop, and balanced fertilization leads to alterations in soil physical properties [19] and it could maintain and improve plant water availability [20]. These reports also indicate that adoption of conservation agriculture based practices requires the least energy in farm operation and enhances biomass productivity with lower production cost and natural resources use compared to other systems [21]. CA based PB/ZT permits uniform permanent maintenance of soil cover for higher moisture/water capture and conservation [22–24]. The reduction in soil disturbance (tillage) and optimum crop nutrition can stimulate the crop growth and development due to improved plant metabolic activities, which may result in higher biomass water-use efficiency [25]. Inappropriate use of inorganic fertilizer [26] affects the biomass yield and water and energy-use efficiency. The enhanced biomass yield and water-use efficiency under balanced fertilizer application have been observed in maize and wheat [27,28]. Energy use, soil conditions and nutrient dynamics change under reduced tillage and hence the nutrient management practices need to be different as compared to conventional tillage systems. More energy has been consumed in fertilizer treatments for MWMb sequence compared to control and increasing the levels of nutrients decreased the energy use efficiency and productivity [29].

Energy plays a vital role for development of a nation as it is required in industries, infrastructure development, agriculture including processing and packaging, transportation, power generation and irrigation projects, education and health services, domestic and other services use. Because of that the developed nations realized energy crisis due to adoption of conventional mechanized agricultural practices earlier than the developing countries [30]. For example in Romania during energy shortage scenario, the tee vegetable oils also have potential for electricity production and heating systems, instead of the current situation of using as biodiesel for improving renewable energetic resources [31–33]. A scientific evaluation is needed to use a holistic approach of principles and procedures known to reduce input energy in land preparation, use of fertilizers and agro-chemicals and irrigation application to enhance energy use efficiency of these operations with precision conservation agriculture. In earlier published literature from various studies the crop residue biomass which either incorporated in soil under conventional tillage or retained on the soil surface by conservation agriculture based practices (ZT/PB), was deliberately not taken into consideration for energy analysis. Despite the fact that during production quantum proportion of energy is retained in the residue contributed from various energy resources as well as residue recycling improves the soil and environment quality. In developing nations like India crop biomass/residues are being used for feeding cattle, thatching house and as domestic fuel. We hypothesized that crop residues of high productive cereal/maize based cropping sequences should be considered as input energy where, preceding crop residue is left intentionally and utilised as input to succeeding crop. This is our contribution to energy journal in existing literature on the energy relation analysis under changing scenario farming practices and climate which also includes crop residues as input energy.

Moreover, no precise information is available on biomass productivity, bio-energy yield, WUE, energy consumption and profitability of intensified maize-wheat-mungbean cropping system in this region as affected by CA based crop establishment and improved nutrient management. Therefore, the present study was set out with following objectives (i) to evaluate the biomass and bio-energy production, and its profitability and water-use efficiency under precision conservation practices, (ii) to find out the most energy use efficient CA based tillage practices (ZT and PB) and Nutrient Expert®-based, site specific nutrient management (SSNM), in intensified maize (rainy)-wheat (winter)-mungbean (summer) crop rotation.

## 2. Materials and methods

### 2.1. Experimental site and soil

An experiment under maize-wheat-mungbean (MWMb) system was conducted during four consecutive years (2012–2016) at a fixed site at the research farm of ICAR-Indian Institute of Maize Research, New Delhi, India (28°38′N, 77°11′E and 228.6 m above mean sea level). The soil (0–30 cm) of the experimental site was sampled on 15 June 2012 after the uniformity trial. The soil was sandy loam (TypicHaplustept) in texture with 64.1% sand, 16.9% silt and 19.0% clay, pH 7.9, bulk density 1.63 Mg $m^{-3}$, hydraulic conductivity (saturated) 0.835 cm $h^{-1}$, organic carbon 4.89 g $kg^{-1}$ soil, EC 0.32 dS $m^{-1}$, Alkaline $KMnO_4$-N (152.0 kg $ha^{-1}$) [34], 0.5 M $NaHCO_3$ extractable P (13.8 kg $ha^{-1}$) [35], and $NH_4OAc$-K (152.3 kg $ha^{-1}$) [36]. The moisture content at saturation was 0.38 $m^3$ $m^{-3}$, which varied from 22 to 27% at 0.033 MPa (Field capacity) and 8–12% at 1.5 MPa (Permanent Wilting Point) in different soil layers of 0–30 cm depth.

### 2.2. Experimental details and crop sowing and agro-techniques

The experiment was laid out in a split-plot design with crop establishment/tillage practices [zero tillage with residue biomass retention (ZT); permanent bed with residue biomass retention (PB); and conventional tillage with residue biomass incorporation (CT)] as main plot and nutrient management [Control (unfertilized); Farmers' Fertilizer Practice (FFP); Recommended dose of fertilizers (Ad-hoc); and Nutrient Expert® decision support tool-