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# Quantifying the Economic Advantages and Productivity Gains from Multitasking Machine operated by GNSS based Auto-Steering Tractor

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**ABSTRACT**

To address challenges related to crop input management and enhance field efficiency, a multitasking machine (MTM) was developed with the capability to switch between mechanical and pneumatic sowing methods for row crops. This machine is designed to perform multiple field operations simultaneously, significantly reducing operational time, costs, and labor while improving overall work efficiency. Additionally, to enhance the performance of existing tractors in Pakistan, a Global Navigation Satellite System (GNSS)-based auto-steering system was integrated by modifying the tractor's mounting equipment, enabling precise operations along a predefined path. The MTM, coupled with the modified tractor, was tested under various planned path scenarios and for different crops to assess its performance. Validation of the system was conducted using a Response Surface Methodology (RSM) model. Field tests on maize demonstrated minimal missing and multiple seeding indexes, achieving a high precision rate of 95.34%. The machine's ability to perform multiple functions in a single pass enhances its practical applicability. Additionally, the GNSS-based auto-steering system, when using an optimized path with two-row skips at headlands, saved 14.71% in distance and 25.49% in time compared to the best-performing alternate method. These findings highlight the efficiency and practical benefits of the multitasking machine and auto-steering system for field operations.

**Keywords:**

*Multitasking machine (MTM),GNSS auto-steering, Mechanical and pneumatic sowing,Field efficiency, Operational cost reduction, Precision agriculture, Tractor modification*

**1. INTRODUCTION:**

The rapid growth in population, scarcity of resources, and increaseddemandfor food demand precision andthe adoption of new mechanization and agronomic techniques in agriculture to increase on-field crop yield(Hemathilake & Gunathilake, 2022). Mechanization plays a major role in performing different tasks in the crop's life from beginning to end product, such as land preparation, sowing, weeding, threshing and milling, etc(Nag, Gite, Nag, & Gite, 2020). These tasks are related to practices that requireexpensive inputs or can lead to huge losses of money in terms of inputs if not performed efficiently(Kaplan & Cooper, 1998). It has been noticed that traditional manual sowing methodsshowed 20–25% higher seed waste and 30–40% fertilizer losses compared to precision seed drills(Atwal & Jaswal, 2024).Toovercome the issues and to perform different tasks, a multitasking machine was developed for row crops(Kumar, Mohan, & Skitova, 2023).The developed machine is capable of performing multiple operations simultaneously(i.e., bed formations, drip laying, fertigation, plastic mulchinstallation, and multiple crops seed sowing) during fieldwork. Performing all thementioned operations in one go of the tractor reduces the operational time, cost, andlabour requirements as well as improves the overall efficiency of the work. Other than operational efficiencies current situation of the available water for agriculture demands precision application of irrigation water(Bwambale, Abagale, & Anornu, 2022). To achieve this, various water-saving techniques are employed to conserve water, and the availability of suitable water for plants also enhances crop production. While conventional irrigation methods increase the rate of emergence of weeds, which results in a reduction of yield and to overcome the situation more weedicides are applied, which increases the cost of the product as well as environmental hazards. Drip Irrigation and plastic mulching are being used in agriculture for their multiple benefits like yield improvement, water saving, moisture conservation, Temperature and weeds management(Farooq, Flower, Jabran, Wahid, & Siddique, 2011). studied the impact of plastic mulching film on soil moisture and temperature for wheat crop, The study indicated that plastic mulching film improved the soil temperature and available soil water by controlling evaporation(Wu, Huang, Jia, Ren, & Cai, 2017).Furthermore, to increase the operational efficiency and working capability of the exciting tractors in Pakistan, Global Navigation Satellite (GNS) System-based auto steering system was installed on the tractor by modifying the tractor mounting equipment to perform operations according to planned path(Qu, Zhang, Qin, Guo, & Li, 2024). The developed multitasking machine along with modified tractor was tested in the field counting different agronomic practicesto estimate the benefits and cost cuts off as finds Precision agriculture technologies, including automated seeding and fertilization systems, reduce input wastage by 10–15% compared to conventional manual methods, primarily through optimized spatial distribution and reduced overlap(Getahun, Kefale, & Gelaye, 2024). Other benefits of using upgraded machinery for these processes include cost savings in operating time, labour, and energy(Galitsky, 2008).

Keeping the above-mentioned circumstances present study is carried out to develop a multitasking machine (MTM) that can perform multiple operations in one go to minimize the operational cost and labor requirements(Solano, Llinás, & Montoya-Torres, 2022). The machine is helpful to put fertilizer, sow seed, place drip tape and lay plastic mulch in one run of tractor. Performing all the mentioned tasks in one go helps to reduce the operational cost as well as labour requirements(Gunasekaran, Forker, & Kobu, 2000).

## 2. MATERIALS AND METHODS:

The multitasking machine (MTM) system as whole is ideal for sowing of multiple row crops with additional functions like fertilization, spreading of plastic film, laying of drip tape in one go with maintaining row to row distance up to cm level accuracy using GNS based auto steering tractor.

This current study was carried out in three phases.

Phase 1: Development of multitasking machine
Phase 2: Indigenization of GNS based auto steering system
Phase 3: Performance evaluation of the system

### 2.1. Phase 1: Development of Multitasking Machine

The multitasking machine is comprised of different components viz. supporting frame, bed shaping assembly, fertilizing assembly, drip installing assembly, plastic mulching, seeder assembly for sowing seeds and other supporting components (Figure 2.1). The basic specifications are given in Table 2.1.

Table 2.1 Basic specifications of a multitasking machine

| **Items** | **Specifications** |
|---|---|
| Type | Tractor operated (Maize, Sunflower, Watermelon, Cotton) |
| Overall dimensions (L*W*H) | 1700*2140*1500 mm |
| Tractor power | 65 hp or above |
| Seeding mechanism | Pneumatic, PTO driven |
| Seed Placement mechanism | Ground wheel driven |
| Fertilizing mechanism | Ground wheel driven |
| No. of fertilizer box | 2 |

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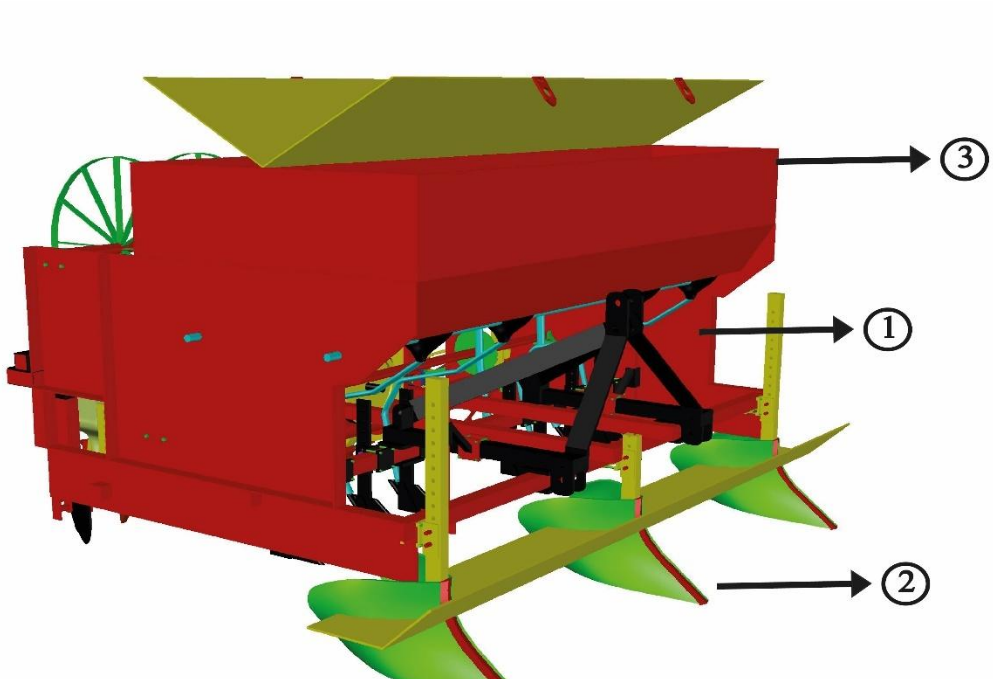
| | |
|---|---|
| No. of ridgers | Min: 2 Max: 3 (adjustable) |
| No. of seeder unit | Min: 2 Max: 4 (Adjustable) |
| No. of plastic mulch holder | 1 |
| No. of drip tape holder | Min: 1 Max: 2 (Adjustable) |




**(a)**

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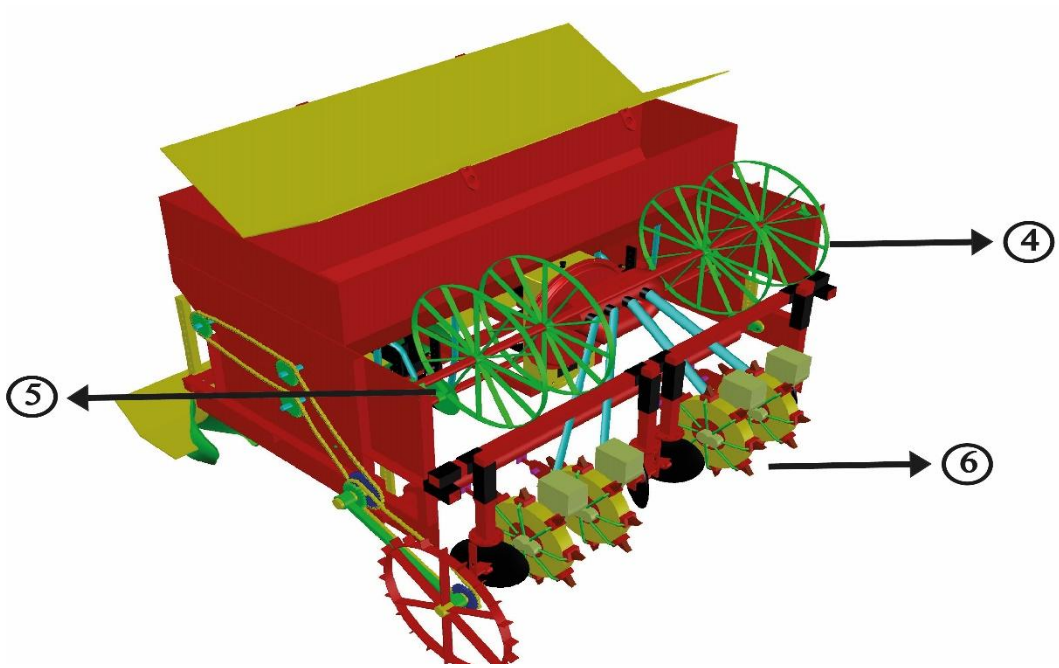


**(b)**

Figure 2.1 Isometric view of multitasking machine (1-supporting frame, 2-bed shaping assembly, 3-fertilizing assembly, 4-drip installing assembly, 5-plastic mulch assembly, 6-seeder assembly)

**2.2 Phase 2: Indigenization of GNS based auto steering system**

The GNS-basedauto steering system facilitatesperforming tractor-based operations with more accuracy and in efficient way. Automatic steering systems enable the operator to plan optimize the path for the work to improve row-to-row distance management for sowing and other field operations with no chances of overlapping, resulting in decreasing the total cost of the product. The system is modifiedaccording toMassey Ferguson's Tractor Model No. MF-385 to perform multiple agricultural operations like ditching, planting, fertilizing and harvesting with reliable and consistent accuracy of up to 2.5 cm throughout the farming seasons. The system is embedded with user-friendly software to quickly attain different settings according to different tractor and machines' dimensions (Figure 2.2).

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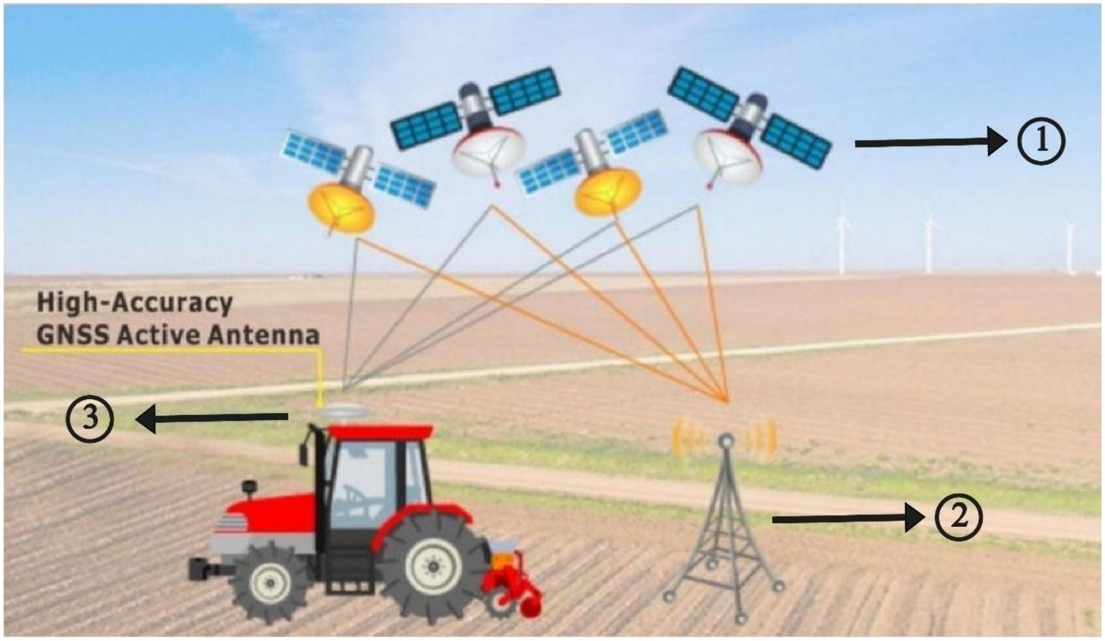


Figure 2.2 Seeder assembly (1-Satellite system , 2- Base station, 3- GNSS antenna)

**2.3 Phase 3: Performance Evaluation of the System**

Field performance evaluation registered economic and suitability of multitasking machine according to local requirements.

**2.3.1 Machine parameters:**

The factors that can influenced the economic benefits of the system were identified as

1. The factors which can increase the inputs cost or decrease the yield
2. The factors which can increase the working time of the operation

So multiple index, missing and quality feed index and precision were selected as evaluation parameters of the seeder performance, while during the field test the row spacing and plant to plant spacing for both the crops were set according to the requirement. The experimental area was divided into three blocks, each block (37.4 m × 50 m) was divided into 17-plots (each for one trial). Each plot was a (2.2 m × 50 m) area. In each plot the tractor was travel 50 m and each trial was repeated three times (3 blocks). The statistical tool RSM with 3D graphical representation was used to study the impact independent factors on response variables. In RSM, the optimization of independent variables consisted of seven steps. (1) choosing the response variables; (2) choosing the independent variables and giving them codes; (3) creating

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the experimental plan for response variables; (4) regression analysis; (5) development of a quadratic polynomial (response generation); (6) generating 3D surface of the observed response surface; (7) analysis of optimal conditions. The RSM along with Box-Behnken design (BBD) was carried out with 17-trials (5 sets of center tests and 12 sets of factorial tests) using Design-Expert v13.0 software (Stat-Ease, Inc. USA).A regression model including the considered parameters i.e., forward speed, pressure, and disk hole size was developed to estimate the response variable. The calculated equation should not be used to predict the relative impact of factors because all the coefficients are scaled to accommodate the units of all factors, and the intercept is not at the center of the designed space.

$$Missing\ Index = +12.15 - 3.91\,A - 1.59\,B - 0.28\,C + 0.0025\,AB + 0.0075\,AC + 0.015\,BC + 0.764\,A^2 + 0.168\,B^2 + 0.018\,C^2 \quad (1)$$

$$Multiple\ Index = +15.46325 - 4.272A + 0.339B - 0.642C + 0.045AB - 0.005\,AC + 0.04\,BC + 0.3565\,A^2 - 0.034\,B^2 + 0.091\,C^2 \quad (2)$$

$$Quality\ Feed\ Index = +72.404 + 8.182A + 1.248\,B + 0.921C - 0.0475AB - 0.003\,AC - 0.055\,BC - 1.12\,A^2 - 0.133\,B^2 - 0.108\,C^2 \quad (3)$$

$$Precision = +65.860 + 6.180\,A + 4.335\,B + 7.064\,C + 0.014\,AB + 0.094\,AC - 0.013\,BC - 0.903\,A^2 - 0.760\,B^2 - 1.090\,C^2 \quad (4)$$

Where:

A is the forward speed in km/h,
B is the pressure in kPa,
C is the disk hole size in the mm.

**2.3.2 Field Testing of the GNS Based Tractor:**

The installed SunNav automatic guidance system with parallel tracking capability is tested on different planned patterns of operations to analyze the distance and time saved during the process. Further, paths are tested in different available fields with adopting different maneuvers at headland of the fields. The total distance and time saving from optimum path is than compared to traditional paths by using equations 5 and 6 given below:

$$Distance\ Saving\ \% = \frac{(D_T - D_O)}{D_O} \times 100 \quad (5)$$

$$Time\ Saving\ \% = \frac{(T_T - T_O)}{T_O} \times 100 \quad (6)$$

Where;

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$D_T$Non-productive distance adopting traditional path
$D_O$ Non-productive distance adopting optimum path
$T_T$Non-productive time adopting traditional path
$T_O$ Non-productive time adopting optimum path

Different field patterns were adopted to perform field operations to evaluate the saved distance, time and ease with which the operation performed easily with the help of GNS based tractor. The system allows the user to adopt any pattern and perform operation in any row of the field which make this system more convenient to adopt planned route easily.

## 3. RESULTS AND DISCUSSION

In this chapter, the field data are presented and discussed. The results are discussed in four parts:

### 3.1. Machine Performance Parameters:

The Performance criteriawhich effects the input cost of the operation both theoretically and practically was recorded under appropriate level of the combinations based on the following values (Table 3.1) (Vincent & Hu, 2010).

Table 3.1. Selection criteria for a combination

| Quality of feed (%) | Multiple (%) | Missing Index (%) | Classification |
|---|---|---|---|
| >98.6 | <0.7 | <0.7 | Very good |
| >90.4 – ≤98.6 | ≥0.7 – <4.8 | ≥0.7 – <4.8 | Good |
| ≥82.3 – ≤90.4 | ≥4.8 – ≤7.7 | ≥4.8 – ≤10 | Moderate |
| <82.3 | >7.7 | >10 | Insufficient |

### 3.2 Field Testing of the GNS-Based Tractor:

Different field patterns were adopted to perform field operations to evaluate the saved distance, time saved during the turning of tractor at the headland area of the field assuming a constant distance and time in the rows. The pattern adopted with 2 rows skip is found to be the best among other traditional patterns being adopted in the field and these results are in good agreement with the study conducted by(Zhang, Zuo, & Yue, 2012). The percentage of the time and distance saved compared to best traditional pattern is calculated as:

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$$Time\ Saving\ \% = \frac{(D_T - D_O)}{D_O} \times 100$$

$$Time\ Saving\ \% = \frac{(21.33 - 17.00)}{17.00} \times 100$$

$$Time\ Saving\ \% = 25.49\ \%$$

Similarly;

$$Distance\ Saving\ \% = \frac{(T_T - T_O)}{T_O} \times 100$$

$$Distance\ Saving\ \% = \frac{(21.45 - 18.70)}{18.70} \times 100$$

$$Distance\ Saving\ \% = 14.71\ \%$$

**3.3 Cost Analysis of Multitasking Machine:**

Cost analysis was carried out to find out the machine viability. The purchase price of tractor and machine was PRs. 2400,000/- and PRs. 450,000/- respectively. The tractor and machine working life was assumed to be 15 year @ 400 hour/year and 10 year @ 90 hour/year respectively. The salvage value of tractor and machine, according to ASABE was 25% and 40% of the purchase price respectively. The cost calculations are given in Table 3.2.

Table 3.2. Cost analysis of the multitasking machine

| **Ownership cost** | | | |
|---|---|---|---|
| **Items** | **Formula** | **Tractor (PRs.)** | **Machine (PRs.)** |
| Depreciation (D) | $\frac{(P - S)}{L}$ | 300/hr | 300/hr |
| Interest @ 12% (I) | $\frac{(P + S)}{2} \times i$ | 450/hr | 420/hr |
| Insurance and housing (IH) | $\frac{(P + S)}{2} \times 0.01$ | 38/hr | 35/hr |
| Total ownership cost | D + I + IH | 788/hr | 755/hr |
| **Operating cost** | | | |
| Repair & maintenance (RC) | $\frac{\text{accumulated repair cost}}{\text{Useful hours}}$ | 100/hr | 130/hr |
| Fuel cost (FC) | 0.044 × Hp × Price/gallon | 1996/hr | 00/hr |
| Lubrication cost (LC) | 15% of Fuel cost | 300/hr | 00/hr |

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| | | | |
|---|---|---|---|
| Labor (L) | 1200/day (8 hr/day) | 150/hr | 150/hr |
| Total operating cost | RC + FC + LC + L | 2546/hr | 280/hr |
| **Total cost** | **Ownership + Operating** | **3334/hr** | **1035/hr** |
| **Tractor + Machine** | **3334+1035** | **4369/hr** | |
| **Sowing cost** | **1.77 Acre/hr** | **1768.8 Rs/Acre** | |

The sowing of maize using manual labour (known as choka method) was Rs. 2500 to Rs.3000 per hectare in Pakistan, while a multitasking machine is capable of doing multiple tasks at the same time which increases its operational benefits(Yousuf, 2017).

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