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Assessment of Soil Nutrients along hree Catenae for Crop Suitability in Kachia Local Government Area, Kaduna State, Nigeria

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Abstract

The study assessed soil nutrients status along three catenae in Kachia Local Government of Kaduna State, Nigeria. In line with the FAO requirement for soil nutrient quality and crop growth, the study revealed poor Nutrient concentration across the soil horizon in the respective Catenae. Samples of soil were collected using the stratified random sampling Technique representing three slopes. Based on catenae differentiation (Crest ≥ 700m, Middle slope 401m – 699m and Base slope ≤ 400). A total of 144 soil samples were obtained from the three slopes based on randomised blocks along soil depth of 0 - 20cm and 20 – 50cm. The three samples were analysed for available soil macronutriets (P, N, K, Na, Ca, Mg) and micronutrients (Zn, Fe, Cu, SOM, pH, SOC, CEC, BS).The result was analysed descriptively using mean and standard deviation compared with the FAO limits. The soil nutrients across the catenea revealed among others that nitrogen showed a high level of deficiency across the catenea irrespective of soil depth. The value of sodium (1.1 ±0.04 cmol/kg) and magnesium (2.84 mg/kg) in the subsoil horizon of the based slope catenae are deficient compared to the FAO limit (1.5 and 5 cmol/kh). The values (F = 1.651; = DF = 2; P = 0.199>0.05), (F = 1.044; DF = 2; P = 0.357>0.05), K^+ (F = 2.386; DF = 2; P = 0.100>0.05) and Mg^{2+} (F = 2.024; DF = 2; P = 0.140>0.05) across the three catenae in the top horizon are not statistically significant. In general, the middle slope and base slope catenae are considered the most suitable zones in for crop cultivation considering the availability of soil macronutriets and micronutrients at the topsoil horizon. Conclusively, the study area lacks adequate nitrogen and potassium nutrients critical for plant growth. It was recommended that the application of organic fertilizer to boost the soil nutrients is a prerequisite for improving the soil and achieving Food security. Application of fertilizer with different ratio of macronutriets (N:P:K) and micronutrients (Zn and Fe), as well as organic manures should be done for different portions of the landscape regarding their rate of difficiency.

Keywords: Soil Nutrients, Catenae, Crest, Middle slope, Base slope, Crop Suitability.

Introduction

In most developed nations such as United States of America (USA), improvement in agricultural land is responsible for crop production per unit of land. However, in developing nations, higher yields are achievable through the expansion of cultivated land (Madojemu, et, al.,2017). This practice is the leading cause of soil nutrient mining which in the past years was ameliorated through fallow practices. Nevertheless, population pressure now forces farmers to grow crop after crop, “mining” or depleting the soil nutrients without remediation (Arthur and Okae-Antu, 2022).

With little access to fertilizers, farmers are forced to bring less fertile soils on marginal land into production (International Fund for Agricultural Development). The consequences are that about 85% of African farmland (185 million hectares) is subjected to nutrient mining rates of more than 30 kg/ha of nutrients yearly, and 40% have rates greater than 60 kg/ha yearly (Awwal and Maniyunda, 2023). The escalating rates of soil nutrient mining make nutrient losses highly variable in agricultural areas in the sub-humid and humid savannah of West and East Africa, and in the forest areas of Central Africa (Sadiq, et.al.,2022). Depletion rates range from 30 to 40kg of nitrogen, phosphorus, and potassium (NPK)/ha yearly in the humid forests and wetlands of southern Central Africa and Sudan to more than 60kg NPK/ha in the sub-humid savannah of West Africa and the highlands and sub-humid areas of East Africa (Thomas, *et. al.,2016*).

Despite the expanse of agricultural land in Sub-Sahara Africa (SSA) estimated at over 50% of the world's potential land for cultivation, only a fraction satisfies conditions for cultivable agricultural land (Conforti, *et. al.*, 2020). Current crop yields in Sub-Sahara Africa are low, often falling well short of water-limited yield potentials due to deficiencies in soil nutrient, soil physical constraints, pests and diseases and sub-optimal management (Hengl, *et. al.*, 2017). According to Jimoh *et. al.*, (2022), the status of soil nutrients in Nigeria differs spatially and is relatively associated with the differences in crop production from the North to the South. In Nigeria rain-fed and irrigated croplands, nutrient replenishment through fertilizers and manures remains far below the crop removal, thus causing mining of native soil nutrient reserves over the years (Ferrier, *et. al.*, 2020, Awwal, et.al.,2023). In Imo State, Nigeria, increasing rate of low yield has been attributed to accelerated rate of nutrient mining associated with continuous cultivation amidst low farm inputs (Usman, et.al., 2016).

The global call on food security is to ensure that the world records zero hunger by 2030. Specifically, the global agenda of SDG Goal 2 is to end hunger, achieve food security and improve nutrition and sustainable agriculture. Feeding the world population, which is projected to reach 9.5 billion by 2050, requires an increase in agricultural production (Hengl, et.al., 2017). Accordingly, the global production of major food calories (maize, rice, wheat, and soybean) is reportedly increasing at 1.6%, 1.0%, 0.9%, and 1.3% per year. However, non-compounding rates, show that the production of these major food crops is less than the 2.4% rate required per annum to meet the global food demand by 2030 and beyond (Patrick, *et. al.*, 2024). **To be** specific, the objective of the study is to assess the soil macronutriets and micronutrients for crop growth base on Food and Agriculture Organization specifications.

Study Area

Kachia Local Government Area is located in the Southern part of Kaduna State in the Middle Belt of Nigeria. The Local Government Area covers a fairly large area, which lies between latitudes 07° 3 to 10° 1 North of the Equator and longitudes 07° 1to 08°East of the Greenwich Meridian (Bahago,et.al.,2018). Kachia Local Government Area shares boundaries with Zangon Kataf Local Government Area to the east, Kajuru Local Government Area to the northeast, Kagarko Local Government Area to the south, Jaba Local Government Area to the southeast, Chikun Local Government Area to the northwest and Niger State to the west. According to Kunda,et.al.,2016), Kachia Local Government Area consist of Godan Tagwai, Sabon Sarki, Kurmin Musa, Kwaturu, Awon, Katari and Bishini. Kachia Local Government Area covers a total landmassof4,570km.^{2}

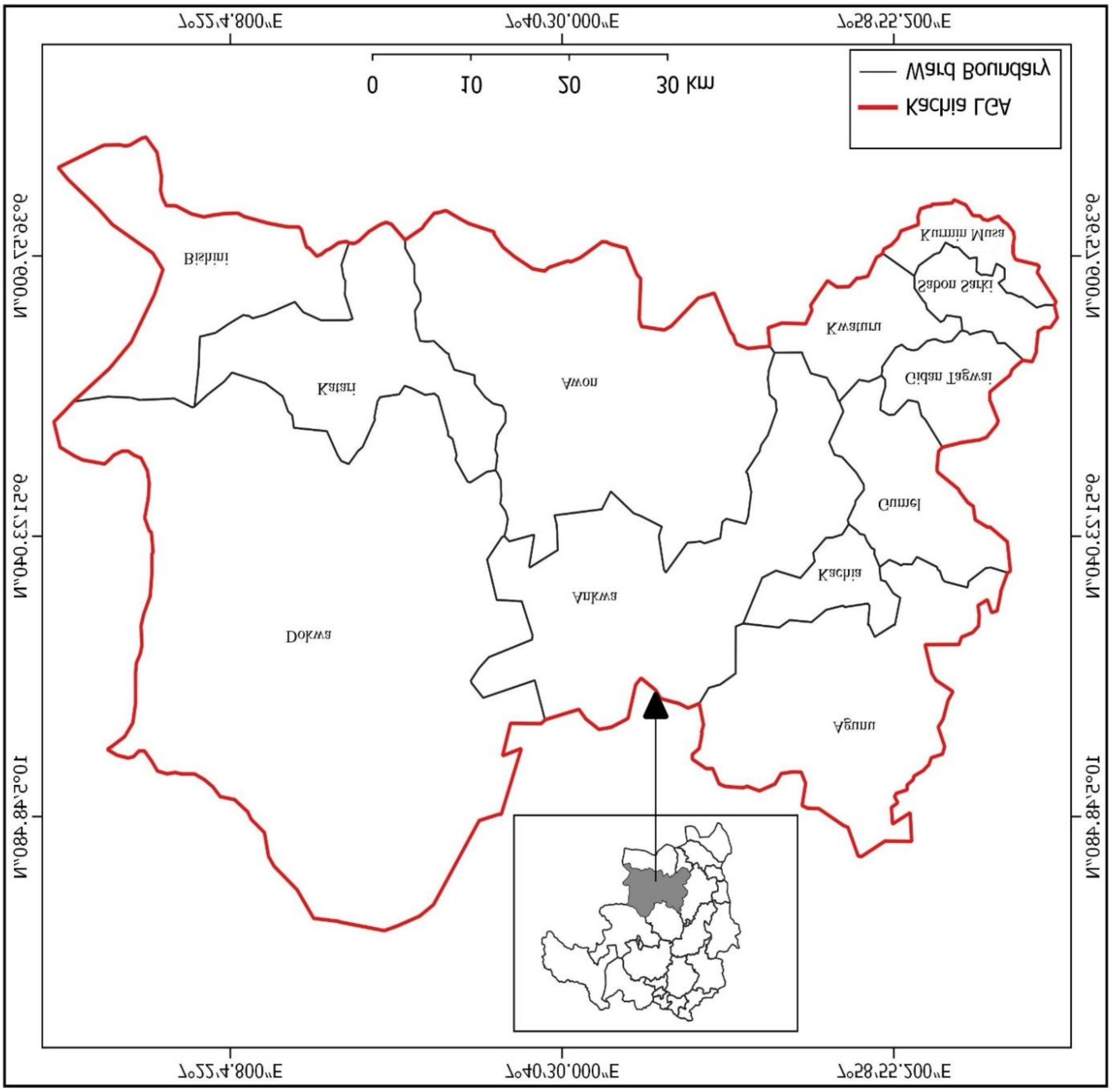

Fig.1: Location of wards in Kachia Local Government Area

Source: Adapted from Administrative Map of Kaduna State (2026)

Methodology

The study methodology was designed on the premise of experimental research design. This approach was adopted on the basis that it provides a platform for testing objective theories among variables and drawing inferences without bias.

In order to determine the spatial point for the collection of soil samples, a preliminary survey was conducted in the study area. Basic information such as point coordinates were determined to rectify deviations and defined the spatial corrections (ground truthing) of the study area.

This study was relied solely on the variables of soil macronutrients (P, N, K, Na, Ca, Mg) and micronutrients (Zn, Fe, Cu,) as well as other significant

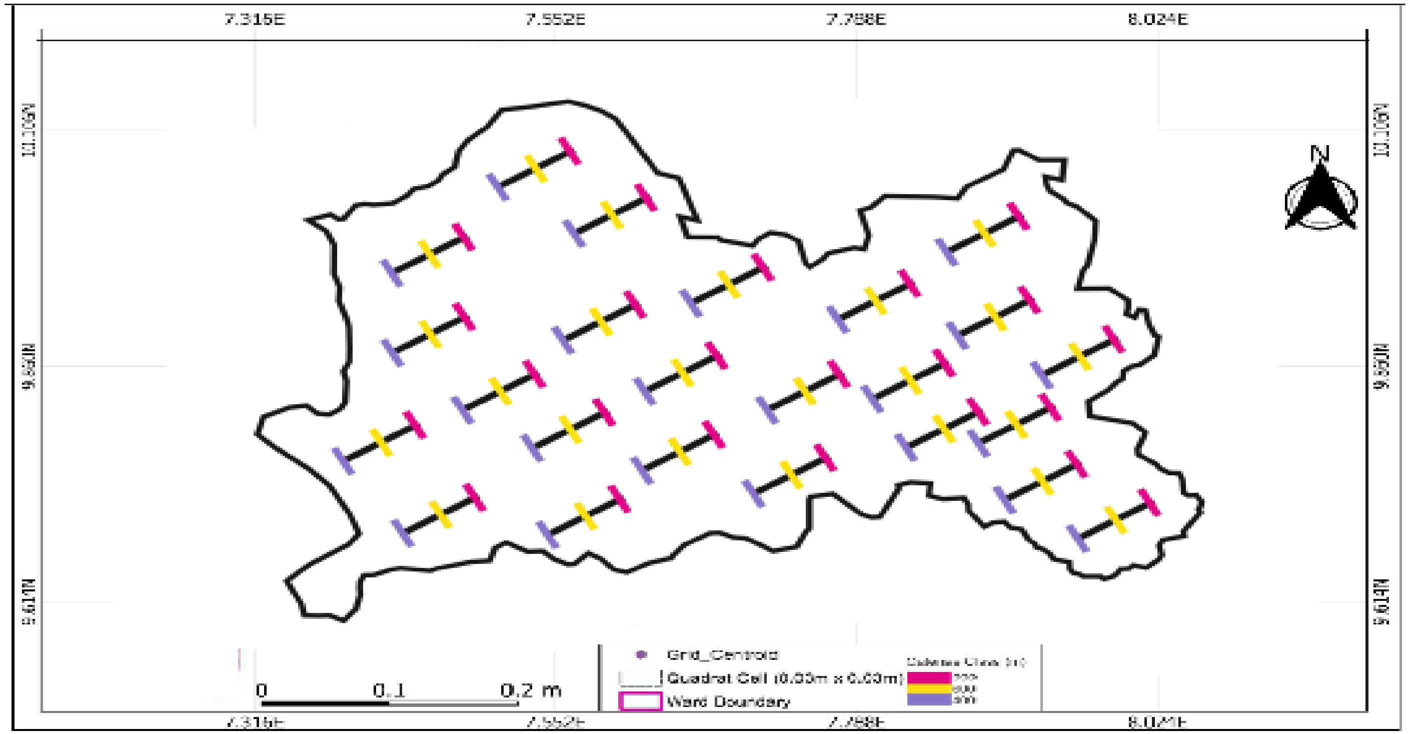

Fig.2: Soil Catenae Classification of the Study Area
Source: Ahmadu (2026)

physiochemical properties of the soil (SOM, SOC, pH, CEC and BS).

In order to determine the spatial point for the collection of soil samples, a preliminary survey was conducted in Kachia Local Government Area. The survey involved one month of intensive field visit and investigation during which the nature of the entire research area assessed. Basic information such as point coordinates were determined to rectify deviations and defined the spatial corrections (ground truthing) of the study area. This was used to provide a control check in defining the study area map as well as fixing the point for soil samples collection with the use of soil auger. The obtained soil samples were analysed in the laboratory.

The spatial extent of Kachia LGA is approximately 4,570 km^2. Since the study does not deal with human population, but rather soil nutrient, the entire Kachia Local Government Area was purposefully considered for the study. Samples of soil were collected across catenae (crest, middle slope, and base slope) in the study area. Soil samples were collected using systematic sample random technique across catena (crest, Middle slope and base slope), from 24 sample point at two depths for topsoil and subsoil (0-20 cm and 20-50cm) resulting in a total of 144 samples.The soil samples were analysed based on standard methods. Soil samples were air-dried for 4 days, sieved with a 4.75 mm (gravel), 2 mm (medium particles), 0.42 mm (sand and silt) and 0.075 mm(clay and fine silt) size mesh for particles size differentiation. This explained the distribution of nutrients and why certain crops are suitable at specific locations.

Result and Discussion

In line with the study objective, the average concentration of soil macronutrients and micronutrients obtained from the analysed soil samples were rated according to soil nutrient level specified by FAO (Table 1). The study hypothesis was tested at 0.05% level of confidence, from which inferences was deduced. The result was analysed descriptively using mean and standard deviation compared with the FAO limits.

Accordingly, the result showed that the availability of some critical soil macronutrient level was low and below the requirement for optimum plant growth. These include the concentration of nitrogen in the topsoil (0.37 ±0.0%, 0.4 ±0.0% and 0.4 ±0.01%) and subsoil (0.25 ±0.0%, 0.3 ±0.0% and 0.2 ±0.01%) horizon across the crest, middle slope and base slope. These values were far below the FAO limit of 20%, indicating a poor nitrogen content in the study area. This implied that the application of chemical fertilizer to boost the soil nitrogen nutrient is a prerequisite to improving the soil and achieving food security. Similarly, the concentration of potassium nutrients in the topsoil (1.69 ±0.0cmol/kg, 1.8 ± 0.3cmol/kg and 1.7 ±0.03cmol/kg) and subsoil (1.37 ±0.0cmol/kg, 1.7 ±0.3cmol/kg and 1.6 ±0.03cmol/kg) horizons, as well as the concentration of magnesium content in the topsoil (3.47 ±0.2cmol/kg, 3.5 ±0.2cmol/kg and 3.4 ±0.03cmol/kg) and subsoil (1.41 ±0.4cmol/kg, 2.8 ±0.2cmol/kg and2.4 ±0.03cmol/kg) horizons were far below the level of 12 cmol/kg and 5 cmol/kg recommended by FAO. Both nitrogen and potassium are critical nutrient requirements for soil health.

Table 1: Rating of Soil Macronutrients and Micronutrients to FAO Requirement

Parameters	Topsoil Crest Mean/SD	Topsoil Middle Slope Mean/SD	Topsoil Base Slope Mean/SD	Subsoil Crest Mean/SD	Subsoil Middle Slope Mean/SD	Subsoil Base Slope Mean/SD
Macronutrient						
Nitrogen (%)	0.37 ±0.0	0.4 ±0.0	0.4 ±0.01	0.25 ±0.0	0.3 ±0.0	0.2 ±0.01
A. Phosphorus (mg/kg)	26.51 ±0.9	28.2 ±0.7	28.9 ±0.6	23.23 ±0.9	26.3 ±0.7	27.5 ±0.6
Potassium (cmol/kg)	1.69 ±0.0	1.8 ±0.3	1.7 ±0.03	1.37 ±0.0	1.7 ±0.3	1.6 ±0.03
Sodium (cmol/kg)	3.21 ±2.3	1.8 ±0.0	1.8 ±0.04	2.54 ±1.9	1.6 ±0.0	1.1 ±0.04
Calcium (cmol/kg)	4.67 ±0.1	4.4 ±0.4	4.2 ±0.18	2.40 ±0.2	3.4 ±0.4	3.6 ±0.18
Magnesium (cmol/kg)	3.47 ±0.2	3.5 ±0.2	3.4 ±0.03	1.41 ±0.4	2.8 ±0.2	2.4 ±0.03
Micronutrients						
Zinc (mg/kg)	3.65 ±0.4	3.6 ±0.3	4.0 ±0.01	3.5 ±0.01	3.3 ±0.3	2.84 ±0.6
Copper (mg/kg)	0.43 ±0.0	0.4 ±0.0	0.4 ±0.01	0.23 ±0.0	0.4 ±0.0	0.3 ±0.01
Iron (mg/kg)	5.65 ±0.3	5.65 ±0.3	5.8 ±0.2	3.72 ±0.3	3.9 ±0.2	4.7 ±0.2
SOM (%)	3.01 ±0.6	3.2 ±0.5	0.4 ±0.01	2.09 ±0.6	3.0 ±0.5	2.9 ±0.6
SOC (%)	0.32 ±0.0	0.3 ±0.0	0.3 ±0.01	0.30 ±0.0	0.3 ±0.0	0.2 ±0.01
pH (H_20)	6.8 ±0.1	6.8 ±0.1	6.8 ±0.1	6.6 ±0.2	6.6 ±0.1	6.5 ±0.1
CEC (cmol/kg)	11.90 ±0.5	11.5 ±0.1	11.0 ±0.3	7.5±0.7	10.4±0.1	10.5 ±0.3
Base Saturation (%)	92.08 ±0.9	92.6 ±0.5	9.16 ±0.9	80.5 ±5.3	91.6 ±0.5	90.6 ±0.9

KEY

Low	Medium	Hig

Source: Researchers Field Work (2026)

Thus, the deficiency of these nutrients in the study area may affect crop production with a multiplying effect on food security. This implication has been reported in previous studies within the middle belt region of Nigeria (Patrick, *et.al.*, 2024).

On the contrary, available phosphorus was reportedly high in the topsoil (26.51 ±0.9mg/kg, 28.2 ±0.7mg/kg and 28.9 ±0.6mg/kg) and subsoil (23.23 ±0.9mg/kg, 26.3 ±0.7mg/kg and 27.5 ±0.6mg/kg) horizons in the crest, middle slope and base slope region respectively. Similarly, sodium and calcium nutrients in the topsoil (3.21 ±2.3cmol/kg, 1.8 ±0.0cmol/kg and 1.8 ±0.04cmol/kg; 4.67 ±0.1cmol/kg, 4.4 ±0.4cmol/kg and 4.2 ±0.18cmol/kg) and subsoil (2.54 ±1.9cmol/kg, 1.6 ±0.0cmol/kg and 1.1 ±0.04cmol/kg; 2.40 ±0.2cmol/kg, 3.4 ±0.4cmol/kg and 3.6 ±0.18cmol/kg) horizons showed high level of concentration above the FAO limit of 1.5cmol/kg and 1.3cmol/kg.

The result presented in Table 1 shows that the concentration of soil micronutrients across the soil catenae in both the topsoil and subsoil horizons is rated as medium to high in line with the FAO requirement for soil health and crop nutrient requirements. On the contrary, the subsoil values of zinc in the base slope (2.84 ±0.6mg/kg) as well as CEC (7.5 ±0.7cmol/kg) in the middle slope are low compared to the FAO limit (3 mg/kg and 10 cmol/kg).

CONCLUSION

This study assessed soil nutrients along three catenae in the Kachia Local Government Area of Kaduna, Northwest Nigeria. Samples of soils were collected using the stratified random sampling technique representing three strata based on catenae differentiation (crest ≥ 700 m, middle slope 401m – 699m and base slope ≤ 400). A total of 144 soil samples were obtained from each stratum based on randomised blocks across soil depth (0-20cm and 20–50cm) representing the topsoil and subsoil horizons. The samples were analysed for available soil macronutrients and micronutrients.

The result was analysed descriptively using mean and standard deviation compared and categorized in line with FAO limit for the soil nutrient requirement of crops on the Area irrespective of soil depth, indicating decreasing concentration of phosphorus nutrient with an increase in the slope gradient along the catenae. Thus, among the critical soil nutrient requirement (NPK) for plant growth, Nitrogen showed a high rate of deficiency across the catenae irrespective of soil depth.

Recommendations

The application of fertilizer with different ratios of macronutrient (N:P:K) and micronutrient (Zn and Fe), as well as organic manures should be done for different portions of the landscape regarding their rate of deficiency. Thus, farmers in the study area are advised to understand the soil nutrient requirements of their field before the application of fertilizer to ensure the appropriate fertilizer and ratio needed for optimum soil enrichment are not exceeded.

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Appendix : Coordinates of the grid-cell blocks for soil sampling

id	left	Top	right	Bottom	id	Left	top	right	bottom	id	left	top	right	bottom
	Stratum 1 (Base Slope)					Stratum 2 (Middle Slope)					Stratum 3 (Crest)			
1	7.2399	9.5646	7.2749	9.5296	25	7.5899	10.0196	7.6249	9.9846	49	7.7999	10.0196	7.8349	9.9846
2	7.2749	9.7396	7.3099	9.7046	26	7.5899	9.9146	7.6249	9.8796	50	7.8349	10.0546	7.8699	10.0196
3	7.2749	9.5996	7.3099	9.5646	27	7.5899	9.8796	7.6249	9.8446	51	7.8349	9.9846	7.8699	9.9496
4	7.3099	9.7046	7.3449	9.6696	28	7.5899	9.8096	7.6249	9.7746	52	7.8349	9.9496	7.8699	9.9146
5	7.3099	9.6346	7.3449	9.5996	29	7.5899	9.7396	7.6249	9.7046	53	7.8699	10.0196	7.9049	9.9846
6	7.3449	9.7396	7.3799	9.7046	30	7.6249	9.9846	7.6599	9.9496	54	7.8699	9.9146	7.9049	9.8796
7	7.3449	9.6696	7.3799	9.6346	31	7.6249	9.8796	7.6599	9.8446	55	7.9049	10.0546	7.9399	10.0196
8	7.3799	9.7046	7.4149	9.6696	32	7.6249	9.8446	7.6599	9.8096	56	7.9049	9.9846	7.9399	9.9496
9	7.3799	9.6346	7.4149	9.5996	33	7.7649	9.7396	7.7999	9.7046	57	7.9049	9.9496	7.9399	9.9146
10	7.4149	9.7396	7.4499	9.7046	34	7.7999	9.7396	7.8349	9.7046	58	7.9399	10.1246	7.9749	10.0896
11	7.4499	9.6346	7.4849	9.5996	35	7.5549	9.8796	7.5899	9.8446	59	7.9399	10.0896	7.9749	10.0546
12	7.2399	9.7746	7.2749	9.7396	36	7.6949	9.6696	7.7299	9.6346	60	7.9399	10.0196	7.9749	9.9846
13	7.2749	9.7746	7.3099	9.7396	37	7.7299	9.7046	7.7649	9.6696	61	7.9749	10.0546	8.0099	10.0196
14	7.3099	9.8446	7.3449	9.8096	38	7.3099	9.9846	7.3449	9.9496	62	7.9749	9.9846	8.0099	9.9496
15	7.3099	9.8096	7.3449	9.7746	39	7.4849	10.0546	7.5199	10.0196	63	8.0449	9.9146	8.0799	9.8796
16	7.3449	10.0546	7.3799	10.0196	40	7.4849	9.9846	7.5199	9.9496	64	7.6949	9.8446	7.7299	9.8096
17	7.3449	9.7746	7.3799	9.7396	41	7.5199	10.1246	7.5549	10.0896	65	7.6949	9.8096	7.7299	9.7746
18	7.3799	10.0896	7.4149	10.0546	42	7.5199	10.0896	7.5549	10.0546	66	7.8699	9.8796	7.9049	9.8446
19	7.3799	10.0196	7.4149	9.9846	43	7.5199	10.0196	7.5549	9.9846	67	7.8699	9.8446	7.9049	9.8096
20	7.3799	9.8446	7.4149	9.8096	44	7.5549	10.0546	7.5899	10.0196	68	8.0449	9.7746	8.0799	9.7396
21	7.3799	9.8096	7.4149	9.7746	45	7.5549	9.9846	7.5899	9.9496	69	8.0099	9.8796	8.0449	9.8446
22	7.4149	10.1596	7.4499	10.1246	46	7.5549	9.9496	7.5899	9.9146	70	8.0099	9.6696	8.0449	9.6346
23	7.4149	9.7746	7.4499	9.7396	47	7.5549	9.9146	7.5899	9.8796	71	8.0449	9.6346	8.0799	9.5996
24	7.3449	9.8796	7.3799	9.8446	48	7.5899	10.0896	7.6249	10.0546	72	8.0799	9.6696	8.1149	9.6346